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SOCIAL ANTHROPOLOGY | RESEARCH ARTICLE

Agroforestry: A second soil fertility paradigm? A case of soil fertility management in Western Kenya

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Abstract: This paper explores the claim whether agro-forestry is a second soil fertility paradigm. The answer to this question, however, is not unequivocal. Farmers in Western Kenya generally do not apply fertiliser and rather rely on many soil fertility replenishment (SFR) strategies. Scientists recognised that lowering the costs of restoring fertility is vital to the future of agriculture in the region and beyond. Agroforestry emerged as an alternative strategy to replenish soil fertility and has been introduced through various programmes and institutions in Western Kenya since the early 1990s. Detailed field and case studies show that people are indeed convinced that agro-forestry helps them to replenish soil fertility and that over the years yields indeed have increased. The paper also traces the emergence of localised practices (niches) of soil fertility management. These niches stand for local ways of reproducing soil fertility. These practices coexist with improved fallows, and mutually transform each other through various kinds of interactions at field and village level as well as with technology institutions. Together they reflect the diversified soil fertility options that resonate well with the multiple nature of nutrient and other soil constraints. Low-cost technologies for supplying nutrients to crops are needed on a scale wide enough to improve the livelihood of farmers. The aim of the paper is to



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Nelson Mango is a rural development sociologist specialised in agrarian transformation processes with an emphasis on small scale-farming, technology development and social change, endogenous development and rural livelihoods. Over the years, he has done substantive fieldwork on socio-technical dimensions of maize, zero-grazing dairy farming and soil fertility (re) production, in East Africa. He has also worked on livestock, livelihoods and poverty in southern Asia and, Sub-Saharan African countries using a wide range of methodologies drawn from both quantitative and qualitative research approaches. His other research activities have been on Conservation Agriculture and how to improve farmers' livelihoods through multi-stakeholder innovation platforms for linking smallholder farmers to research, extension and business development services in Southern Africa countries. Currently his research focus has shifted to Policy, Institutions, and Markets in East and Central Africa. Theoretically, he combines actor perspective with broader questions related to political economy.

PUBLIC INTEREST STATEMENT

This paper focuses on Agro-forestry, a soil fertility replenishment approach introduced in Western Kenya to enhance agricultural development in the mid 1990s. Agro-forestry is from both a theoretical and practical point of view an interesting approach as it emerged out of critiques of the Green Revolution. While Green Revolution based technologies were critiqued because of their negative social and spatial effects (e.g. increasing social and regional inequalities), agro-forestry technologies have been developed specifically to circumvent the high costs and market incorporation effects of Green Revolution technologies. Agroforestry is a central component of what scientists have labelled the second soil fertility paradigm. Developing low cost technologies is a specific rationale of many agro-forestry based strategies. Such a technology trajectory, it is believed, can make a difference to poverty alleviation in smallholder agriculture in Africa.

show whether and how externally induced improved fallow innovations resonate with farmer-produced niches in the domain of SFR in Luoland. The paper contributes in this way to a more appropriate understanding of socio-technical innovations.

Subjects: Area Studies; Behavioral Sciences; Development Studies; Development Studies, Environment, Social Work, Urban Studies; Social Sciences

Keywords: agroforestry; soil fertility improvement; improved fallows; biomass manure; Western Kenya

1. Introduction

This paper explores from a social science perspective whether the claim once made that agro-forestry is a second soil fertility paradigm. The claim was made by Pablo Sanchez in his capacity as the director of the World Agro-Forestry Centre (ICRAF) (Sanchez, 1999). A paradigm is here treated as an internally consistent set of concepts and approaches to understand and make sense of processes of development. Paradigms also pave the way for interventions to improve on the situation. Paradigms are not fixed or static but shift as a result of paradigmatic struggles after which a new paradigm emerges and become to dominate science. In contrast to this classic understanding of paradigm shifts (cf. Kuhn, 1970), we proceed here from the idea that there is not one paradigm but there are many coexisting and sometimes contrasting paradigms of development. The soil fertility paradigm that hinges on the application of chemical fertilizers to enrich soil fertility is predominant ever since the high days of the Green revolution. It is however seriously critiqued and today countered by a soil fertility enriching paradigm that hinges on the use of biological resources. Improved fallow is positioned as one of such new ways of enhancing soil fertility. Improved fallows are part of the agro-forestry family and consist of deliberately planted species—usually legumes but also trees—with the primary purpose of fixing N₂ as part of a crop-fallow rotation. They cover entire fields in a farm.

Sanchez (1999, p. 3) points out that improved fallows become of age after years of experimentation and implementation: “Many lessons have emerged from short-term improved fallows”. Improved fallows are used across a range of farm sizes, dry seasons that are unfavourable for crop production become productive periods; improved fallows combines the planting of woody and herbaceous leguminous fallows that have the potential to accumulate nitrogen (N) and potentially reducing both the use of chemical fertilizers and the importance of phosphate (P) (Basweti, Jama, Koech, & Okalebo, 2011; Jama, Eyasu, & Mogotsi, 2006; Jama, Swinkels, & Buresh, 1997; Jama et al., 2000). Improved fallows also provide a range of other key eco-systems services: fuel wood production, recycling of nutrients besides N, provision of a C supply to soil microorganisms, weed suppression, Striga control, and improved soil water storage (Jama, Mutegi, & Njui, 2008; Kiptot & Franzel, 2011; Noordn, Place, Franzel, & De Wolf, 2003). Natural fallows of non-legume shrubs may also provide lessons for the development of improved fallows. Genetic diversity in improved fallow systems is an overriding outcome. An important limiting factor in Africa however is the supply of germplasm of improved fallow species; this can be solved, Sanchez (1999) argues, by the development of large-scale seed orchards and nurseries. If these conditions are met, an “impact at the scale of millions of farmers can take place” (Sanchez, 1999, p. 3).

The analysis of the claim that agro-forestry is a second soil fertility paradigm assumes that agro-forestry is not contested in the field and in villages; it has indeed been evaluated by local people as useful and enhancing soil fertility (Place, Adato, Hebinck, & Omosa, 2003, 2007b). We do not question that improved fallows or agro-forestry more broadly is not a second soil fertility paradigm, but rather whether it indeed represents a shift or even a complete break with the predominant one. From a social science point of view one would expect a second soil fertility paradigm to be a “configuration that works” (cf. Rip & Kemp, 1998) which would include not just a new set of practices (e.g. improved fallows) or technologies but a new or perhaps a radically different set of social relations between farmers, villagers, the state and its bureaucracy, the market, researchers and implementers. This is one of the lessons learned from the broader field of technology studies which has become

a popular strand in social sciences during the last 20–30 years (Rip, 2009). Rip (2009) and Rip and Kemp (1998) warn against viewing technological change through technology, technologists or artefacts alone and propose to incorporate the social environment with its own dynamics that have already shaped opportunities and ideas about new technologies. Experiences with previous or still dominant thoughts about soil fertility continue to shape peoples practices, ideas, relations and expectations.

Technology has been studied from a variety of disciplines and perspectives ranging from technological determinism and the (neo-classical) economic conceptualisation of technology development to the social-constructivist school and actor network theory. We will not attempt to present a complete overview of the merits and critical issues of these perspectives in this paper. We argue that we need a perspective that is capable of handling, at the same time, the artefacts, the designers as well as the so-called “end users” of technology, as well as the social interactions amongst and between them. Inspired by an actor oriented approach to social and technological transformation (Long, 2001) this requires a notion of agency which can not only be attributed to the experts designing technologies, but also to policymakers and farmers who use but also design and redesign technologies and new practices. Nature as a non-human actor (e.g. soils, improved fallows, trees, shrubs) is also included and forms part of the network that produces technological change (Latour, 2005). Technology experts, techno-scientists, politicians, state institutions and farmers are network builders that shape, through processes of enrolment, the dynamics and directions of technological change. We thus argue that examining a new technology or new set of practices such as improved fallows is not simply the result of new scientific discoveries but involves complex social relationships between the social actors involved and the expectations that are raised in these interactions (Fressoli et al., 2014; Jansen & Vellema, 2011).

The context of this paper is the problem of soil fertility and its influence on agricultural development in Western Kenya. The gradual decline of soil fertility is a concurrent issue in the agricultural history of the region (Mango, 1999, 2002). It is now, as in the past, a priority for farmers, government bodies, research institutions and NGOs alike (Mango, 2002; Place et al., 2003). For farmers it represents a major threat to producing a significant return to their labour potentially rendering farming economically unattractive venture. The research community, and both government and non-governmental agencies associate soil fertility with environmental degradation, and above all with increasing rural poverty and malnutrition (Wanjiku, Ackello-Ogutu, Kimenye, & Place, 2003). Both crop and livestock production is seriously affected by the decline of soil fertility (Mango, 1999, 2002; Place et al., 2002, 2007b; Smaling, 1993). Many agencies, including the Ministry of Agriculture and Rural Development (MOARD), the Kenya Agricultural Research Institute (KARI) and several international research centres (including ICRAF and CIAT) have argued the need for a plan of action.

Solutions to soil fertility related problems have, till recently, predominantly followed the fertilizer technology trajectory. The fertilizer paradigm is expected to solve these problems and promises to solve the pertinent issue of loss of soil fertility, particular in Africa. It does so through expanding and intensifying market relationships. Agro-forestry, in its turn, is presented as an alternative trajectory for soil fertility problems (Sanchez, 1999). It is an approach implemented in Western Kenya since the mid-1990s to enhance agricultural development through soil fertility replenishment (SFR). The Soil Fertility Replenishment and Recapitalisation Project (SFRRP) was a collaborative design effort between the World Agro-forestry Centre (ICRAF), the Kenya Forestry Research Institute (KEFRI) and KARI, and implemented together with the Extension department of MOARD, Non-Governmental Organisations (NGOs) and private sector organisations.

SFRRP is from both a theoretical and practical point of view an interesting approach as it emerged out of critiques of the Green Revolution. While Green Revolution based technologies were critiqued because of their negative social and spatial effects (e.g. increasing social and regional inequalities), SFRRP technologies, such as agro-forestry technologies, have been developed specifically to circumvent the high costs and market incorporation effects of Green Revolution technologies. SFRRP is a

central component of what Sanchez (1999, p. 3) has labelled the second soil fertility paradigm. Developing low cost technologies is a specific rationale of many agro-forestry based strategies, notably for soil management (Young, 1997). Such a technology trajectory, it is believed, can make a difference to poverty alleviation in smallholder agriculture in Africa.

This aim of this paper is to show the social organisation of these externally induced technological innovations, and particularly, how these relate to farmer-produced niches in the domain of SFR in Luoland. Building upon anthropological research methods—notably extended case study method—and meta-analysis of other economic and biophysical studies conducted in the region, the study traces the emergence of such localised practices (niches) of soil fertility management, focusing on the particular ways in which the socio-technical constitutive elements are combined in such local practices. The paper in this way contributes to the theoretical understanding of innovation processes and developments of niches. The paper further contributes theoretically to the academic debate on technology development by building upon the notions of socio-technical regimes and niches as examples of two distinct and coexisting technology development trajectories within the technological landscape. These not only coexist but mutually transform each other through various interactions at field and village level as well as with technology institutions. Each of these trajectories is characterised by specific design principles and dynamics of knowledge production. Our “socio-technical” approach perceives technology development as incorporating both the social/institutional and the natural/technical (Geels & Kemp, 2000; Hebinck, 2001; Jansen & Vellema, 2011; Mango, 2002; Rip & Kemp, 1998).

The first part of the paper is a description of the study area and the research methodology that was used for data collection. The second part of the paper follows the SFRRP from its inception to implementation in order to question whether such projects can indeed make a difference and contributes to poverty reduction, as claimed by its proponents. It describes the project’s discourse; its aims, means, technologies, mode of implementation and perceived outcomes. The third part of the paper places the proposed second soil fertility paradigm in the context of the recent debates concerning technological development.

2. Site description and research methods

2.1. Site description

The empirical data for this paper were collected in three villages in the highlands of North eastern part of Siaya district (Figure 1). Siaya district is located in the highlands of Western Kenya, an area which covers 85,000 km² and is characterised by high population densities. The district is populated by the Luo ethnic group, a Nilotic people who first migrated to this area from Sudan via Uganda in the 1500s (Cohen & Atieno-Odhiambo, 1989, p. 17). The highlands currently accommodate 12–15 million people, about 30% of the country’s total population (Republic of Kenya, 2010). The farming system is under considerable pressure from an increasing population, while crop yields and economic returns from farming are declining (Mango, 1999, 2002). The results are insufficient food production, increasing rural poverty, malnutrition and lack of income.

The farming system is characterised by mixed crop and livestock production at subsistence level (Mango, 2002; Nziguheba et al., 2010). Maize is the main staple crop. Africa zebu cattle are kept by most households but in very small numbers due to lack of grazing land. Tethering is the main method of keeping these animals. A few homesteads keep improved dairy cattle under zero-grazing dairy farming. Manure generated from the zero grazing dairy units are used to fertilise soil for both crop and fodder production. However it is worth noting that it is not sufficient. Yala division where the research villages lie receives an average annual rainfall of between 1,800 and 2,000 mm (Mango, 1999). The rainfall has a bimodal pattern with the long rains occurring from March to June and the short rains from September to November (Mango, 1999, 2002).

Figure 1. Map of Western Kenya.



The bi-modal rainfall allows two planting seasons. The first planting season takes place during the long rainy season which is March and June (Mango, 2002). During this season late maturing maize varieties (preferably local maize) are planted. Hybrid maize is planted but by few households only (Hebinck, Mango, & Kimanthi, 2015). Intercropping of maize and beans are preferred. The second planting season is immediately after harvest of the long rainy season crops and happens in mid-August. The short rains that follow last only up to the beginning of November. Early maturing local varieties of maize are planted during this time in addition to second crops such as sweet potatoes and cassava.

The three villages where this study was undertaken are Muhanda, Nyamninia and Luero. The latter was a pilot village where ICRAF/KEFRI/KARI has tested Soil Fertility and Replenishment Project-technologies since 1995. The project that emanated from the pilot was evaluated by an international team of experts¹ during the period 2003–2005 (Place et al., 2003, 2007b). Follow up studies were conducted by PhD studies conducted by Kiptot (2007). Nyamninia, notably Sauri village, was adopted by Jeffrey Sachs as a Millennium Village Project and which has adopted much of the agroforestry technologies developed earlier by ICRAF. The Millennium Village Project in turn is recently described and analysed by Nziguheba et al. (2010), Kimanthi (2014) and Kimanthi and Hebinck (in press).²

2.2. Research methodology

This study employed anthropological techniques of data collection for a period of over 15 years by the authors³ themselves combined with a meta-analysis of economic and biophysical studies that

have been conducted in the region over the years. Extended case study method formed the basic methodology for research (Arce & Long, 1992; Long, 1968; Mitchell, 1983; Van Velsen, 1967). The case study strategy was preferred above standard survey techniques as these do not unravel the social dynamics of knowledge production and exchange. Moreover, the case study methodology renders data on the basis of which theoretical arguments can be constructed for the reconceptualization of soil fertility issues and approaches. Investigation of farmers' strategies for replenishing soil fertility requires a historical and a holistic explanation of the processes within the farm and the soils people are producing over time. Interviewing through recurrent visits by the authors combined with direct and participant observation, and the study of physical artefacts and the land husbandry practices formed the methodological backbone of this study. The longitudinal set up of the study allowed for capturing variations of farmers' husbandry practices at different times. This enabled us to come to grips with the different sources of knowledge for replenishing soil fertility in the region that underlie these variations.

Through ethnographic interviewing (Hammersley & Atkinson, 2007; Pottier, 1993) and participant observation, we traced the niches within the wider socio-technical landscape and documented the various SFR practices. Farmers' narratives, allowed picturing individual plot histories. This helped in tracking down the transformations that have been taking place in these plots with regards to nutrient management and farmers' claims. The selection of the cases were purposive and were informed by a focus on areas where farmer and researcher knowledge seemed to differ: the effectiveness of fertiliser (where some farmers said it spoils the soil), where *Striga* was observed (researchers strictly tie this in with low soil fertility), and effectiveness of natural fallowing (farmers still practice it but researchers argue that it is perhaps the least effective). A literature review of socio-economic studies conducted by other researchers and biophysical work (agronomic trials) complemented our anthropological studies. This calibrating of results minimised potential biases that might come from the generalisation of results from the case studies.

3. Agro-forestry technologies for SFR

Since 1987, agro-forestry research in East and Central Africa has been designed and implemented under the umbrella of the Agro-forestry Network for Eastern and Central Africa (ECA AFRENA) (AFRENA, 1996, 1997). Maseno Regional Agro-forestry Research Centre in Western Kenya, a collaborative venture between KEFRI, KARI and ICRAF, hosted one of the AFRENA programmes. This programme was mandated to carry out agroforestry research related to soil fertility, wood production, and higher value added tree products. By far, the major component was related to soil fertility research, to test technologies on-farm, to train partner organisations, and to disseminate results to the region's farmers (Young, 1997). The earliest research focused on alley farming in the early 1990s, but was abandoned following unenthusiastic responses from farmers (Kiptot, Hebinck, Franzel, & Richards, 2007). A renewed attention on soil fertility came into being in 1995 following initial successes in identifying useful shrub species for improved fallow and biomass transfer systems. This was followed by the selection of sites for testing relevant soil fertility replenishing technologies. Testings involved setting up on-farm trials to identify which agro-forestry technologies were appropriate. From the outcomes of these trials, it was decided to implement a project in clusters of pilot villages in the region in order to minimise costs of scaling up while trying to provide equal opportunity for uptake by all community members. These sites were envisaged to be demonstration villages that could be used as springboards to impact on extension and policy makers and eventually lead to wider adoption among the farmers of Western Kenya.

The soil replenishment strategies to be considered were based on four principles generated by research. These are:

- (1) That there was a need for external inorganic phosphorus input.
- (2) That the households could produce the nitrogen and potassium required through organic sources on their farms.

- (3) That large economic gains to households could be realised through the tradition of improved agricultural practices (integrated pest management strategies, high value trees and crops, improved seeds and good husbandry) on the replenished soils and
- (4) That soil conservation was a prerequisite for any sustainable soil fertility improvement strategy.

The overall objective of the programme was to reduce poverty among farmers in Western Kenya through a collaborative effort and through strategies that could raise soil fertility levels. The effort included incentives and means for farmers and communities to achieve the transfer of knowledge and technologies maintain the levels of those being used and further invest in soil fertility improvements (AFRENA, 1998, p. 4). Agro-forestry technologies developed at the regional research centre in Maseno had to reach the end users—the farmers. The project assumes (as will be discussed later in the paper) that these collaborative efforts could help to break the poverty cycle now pervasive in Western Kenya. To foster sustainability, the programme liaised with the local private sector to seek ways of strengthening markets for credit, inputs, and outputs. In particular the programme established links with the Sustainable Community Oriented Development Programme and started selling farm inputs in small, affordable packages to farmers with the aim to increase the availability of inputs and improve marketing of outputs. Together with local and international NGOs mandated to implement smallholder agricultural credit schemes, it was hoped to catalyse adoption and impact (Kiptot et al., 2007). The programme made rock phosphate inputs available free of charge to pilot villages for one season. This was intended to increase awareness and stimulate demand. Thereafter, it facilitated the acquisition of rock phosphate by local input suppliers. Farmers themselves invested labour, land and assisted in the construction of soil conservation structures (where necessary) and in producing organic nutrient inputs. The organic materials were produced mainly from agro-forestry technology species whose plant material (seeds) were initially provided to communities by the project directly or indirectly through the development agencies.⁶ There was significant investment by the project in training communities on the management of the technologies and in creating sustainable germ-plasm supply systems.

4. The agro-forestry technologies in practice

Typical of these SRP technologies is that it did not unfold as a straightforward process of technological design. It evolved gradually, step by step and in continuous trials both on-farm and on-station. The technologies generated by ICRAF and others were developed sometimes together with farmers, sometimes based on what farmers “traditionally” were doing in the field of soil fertility, and sometimes enriched with exogenous resources (including results from experimentation by farmers in Zambia). The SRP-technologies that will be discussed here are green manuring and improved fallow.

4.1. Green manure biomass transfer

Manuring with green biomass is one of the technologies that have been proposed to farmers by researchers in Western Kenya. Green manuring refers to the transfer and working into the soil of biomass, using the foliage of selected trees, shrubs and other non woody plants rich in water, sugar, starches, protein and nitrogen as organic fertilisers (Kahnt, 1983). One of the most popular agro-forestry practices in the research area is a hedge to demarcate boundaries of fields, farms and compounds. These hedges protect soils and crops as well as producing fodder, mulch and green manure. *Tithonia diversifolia* (wild sunflower) is one of the most common species that is found in hedges in Western Kenya. *Tithonia* is also found along roadsides and on fallow land. It produces large quantities of biomass that can be incorporated directly into the soil as green manure or used as mulch. It is a wide spread practice that farmers cut leaves and soft twigs of *Tithonia* from the hedges which are then chopped into small pieces. These are either put in a planting hole or spread evenly over the surface before incorporation into the soil. The leaves must be mixed well with the soil or left to decompose for at least one week before planting commences (Amadalo et al., 2003). Maize

and other seeds may not germinate well if planted immediately after applying the green manure. Farmers continuously apply this green manure during the growing period of the crop either by placing it along the rows of plants or by incorporating it into the soil.

Tithonia as biomass manure was farmers' own discovery, and later taken up by CARE-Kenya in 1992 after a research needs assessment with the farmers (CARE/KEFRL, 1996). This was long before ICRAF started the SFRRP. An extension worker who has been with CARE-Kenya in the research area since 1986, mentioned that they set up an adaptive research department in 1992 on realising that farmers were not keen to take up tree growing as per their recommendation. "The farmers priority was first to meet their household food security needs" (personal communication, June 2000). However, because CARE-Kenya was not dealing with crops at the time, it was difficult for them to do something in this area. CARE-Kenya then set up an adaptive research wing linked with an extension approach popularly known as the village-approach. CARE-Kenya's extension workers helped farmers to form groups with whom they could work in the village. This group democratically elected a group resource person (GRP) who is trained at various seminars by CARE-Kenya. The GRP in turn trained the rest of the group members, who were called adaptive research farmers (ARF).

CARE-Kenya adaptive researchers in the research villages came across *Tithonia* during their research with farmers to identify potentially useful weed species for soil fertility. The use of *Tithonia* as biomass manure is not so much a new technique in Western Kenya. It is over 100 years since the shrub, a popular ornamental, first arrived in the region from southern Mexico (AFRENA, 1996, p. 8). Like with maize, *Tithonia* became incorporated in farming practices and procedures. CARE-Kenya hoped that by tapping local knowledge, they could increase the range of options available to farmers for reversing the area's declining soil fertility. They then discovered with the farmers that *T. diversifolia* (wild sunflower) and *Lantana camara* (Tick berry) produced large masses of foliage that could be used as green manure. Our interviews with farmers also reveal that farmers themselves had also made these observations when they planted maize in areas where these weeds had been cleared (Mango, 2002). Researchers from ICRAF/KEFRI/KARI took this a step further and began trials at the nearby Maseno station to investigate the potential of these species. *Tithonia* was preferred because it produces large amounts of biomass within a very short time (AFRENA, 1996, p. 8). ICRAF then established a collaborative mission with CARE-Kenya.

Agronomic trials carried out by ICRAF scientists between 1990 and 1996 revealed that *Tithonia* leaves contain 50% more phosphorus than legumes, and similar levels of nitrogen and potassium, even though *Tithonia* is not a nitrogen-fixing plant (Jama et al., 2000). They also discovered that combining *Tithonia* biomass with rock phosphate on soils low in phosphorus to be an effective way of restoring soil fertility. This inexpensive and readily available alternative to purchased fertilisers is increasingly becoming important in improving yields of maize and high-value crops such as tomatoes, kale and French beans (Franzel, Nanok, Wangia, & DeWolf, 2008). This technique has been welcomed with enthusiasm by farmers in Western Kenya, where *Tithonia* is abundant and the soils are degraded.

The on-farm and researcher-led trials carried out by scientists from ICRAF and KEFRI indicated that one hectare of maize responds best with five tonnes of *Tithonia* biomass (Jama et al., 2000). On-farm research conducted by researchers together with farmers shows that it takes about 4 min to cut and apply 1 kg of fresh *Tithonia* from off-farm resources; one person can harvest 83–120 kg a day (Jama et al., 2000). In terms of labour requirement, the result of labour analysis shows that the application of 5 tonne *Tithonia* would require about 370 work days/ha while the application of inorganic fertilisers or animal manure costs between 1 and 7 work days/ha (Jama et al., 1997). As a consequence several developments took place. First, the rates of *Tithonia* tested were reduced to manageable amounts. Second, farmers were encouraged (and indeed took the initiative) to plant *Tithonia* on their own fields which would reduce labour required per kg of biomass by half (Jama et al., 2000). Lastly, as we shall expand upon later, there was increased utilisation of tithonia on higher value crops (Mango, 2002).

Most experiments have shown that a combination of *Tithonia* and rock phosphate perform better than *Tithonia* only, whether the crop is maize or vegetables. For example, one trial found that the average maize yield can be 1378 kg/ha for the combination of *Tithonia* and rock phosphate and 807 kg/ha for *Tithonia* only (Jama et al., 2000). The bean yield was 809 kg/ha for the treatment combining *Tithonia* and rock phosphate, while the control produced 528 kg/ha. Economic analysis of researcher managed trials found that biomass transfer is rarely profitable on maize when all inputs are valued (Shepherd & Soule, 1998). Despite that yield increases are significant, labour costs are very high; only households who have low opportunity costs of labour will find it in their interest to use biomass transfer on maize. Consequently, there has been significant movement towards using the system on vegetables (Kiptot et al., 2007; Mango, 2002). Rommelse (2000) found that net returns to biomass transfer systems, especially those integrated with phosphorus, can be 10 times as high for vegetables than for maize. Indeed, in our discussions with farmers during the research period they appear to realise this. A study by Place et al. (2002) of 360 households in Western Kenya found out that while only 7% of initial experimentation of biomass transfer was conducted with vegetables, this increased to 21% four years later). Studies in the Siaya pilot project area showed that about 15% of farmers were continuous users of the technology with another 15% testing (Place et al., 2002).

During our research activities, we observed that in addition to initiating the testing of biomass transfer on vegetables, farmers have also made other innovations with *Tithonia*. First, some have added *tithonia* to their compost heaps to enrich the resulting material. Second, a few have experimented with producing liquid manure from *tithonia* which can help in enabling nutrients to reach the plant roots (Mango, 1999, 2002).

4.2. Farmers experiences with green manure technology

Studies conducted in the research area show that most farmers in Western Kenya apply less than the recommended rate of 5 tonne of *Tithonia* biomass per hectare (AFRENA, 1996; Mango, 2002). As cutting and transporting are laborious tasks, most farmers planted *Tithonia* along borders, boundaries and contour lines. This ensures a constant nearby supply of biomass, reducing the labour needed to carry it to the fields. A similar study by Kiptot (2007) and Kiptot et al. (2007) show that most farmers mentioned that biomass transfer required much more labour than the other technologies used for improving soil fertility. In our observation, farmers who used *Tithonia* on high value crops like kale, beans, and tomatoes reported good responses. They mentioned that kale produced more leaves, which are big and dark green, beans produced big pods and the tomato plant produced several big fruits and had a longer life span. Longer harvesting periods mean higher prices as competing supplies are reduced. However, they complained about the labour input. At the same time they acknowledge the fact that for small-scale farmers, organic based technologies are more attractive options for improving soil fertility than mineral fertiliser.

During our in-depth interviews it was revealed that while researchers would like to test this technology on hybrid maize, most farmers and in particular male farmers prefer to use it on high value crops because of the higher returns for their labour. This discrepancy represents a major research gap that needs urgent redress. However, ICRAF scientists that we discussed this issue with were also quick to mention that when many farmers grow the vegetables at the same time, then they lack markets to sell them. In our own observation this was the critical gap that was unforeseen by ICRAF scientists during the project design.

4.3. Improved short duration fallow technology

In order to restore soil fertility, land should remain under fallow for several years, as soil regeneration processes are slow. An alternative technology is to introduce new tree species for fallowing, which produce biomass more rapidly (Prinz, 1986). These species can produce wood and enhance soil fertility by bringing up nutrients from lower soil layers through litter fall and by atmospheric nitrogen fixation. At the end of the fallow period, the trees are harvested and the biomass that cannot be used as wood for fuel is returned to the soil, enhancing its fertility (Jama et al., 2008).

Natural fallows, which usually consist of a combination of broad-leafed weeds and grasses, are used to restore soil fertility or to provide fodder for livestock but their effectiveness is low (in fact, economic analysis by Rommelse (2000) found these systems to give the lowest financial returns of many land use systems tested. Though uncultivated fields are not always because of a fallowing strategy, farmers in the research villages do still use natural fallows with some regularity. The problem from researcher point of view is that short duration fallows are not found to provide much physical or chemical improvement—there may be biological improvement from changing the pest or disease risk however. Further, economic analysis normally finds the natural fallow option to be the worst performing (Rommelse, 2000).

Scientific results of research over the past 15 years have shown that improved fallow systems with fast-growing tree or shrub legume species like *Sesbania sesban* have a high potential to restore soil fertility and have become a central agro-forestry technology for soil fertility management (Franzel et al., 2008; Young, 1997). These technologies can be useful to resource poor farmers in Western Kenya who cannot afford to buy fertilisers and do not have livestock for manure. *S. sesban* had been the main focus for this technology partly due to its long traditional history with farmers and for its compatibility with crops, deep rooting, and supply of additional wood products and large benefits to maize planted after the fallow. More recently other species such as *Crotalaria grahamiana* and *Tephrosia vogelii* have been tested with some success in the region and they are now more popular due to ease of establishment (Rommelse, 2000).

Improved fallow can take different forms. The first involves the establishment of a six-month fallow. The preferred crop, usually maize, is planted during the long rainy season (March–June). After the harvest, an improved fallow species such as *crotalaria* is planted on the same piece of land during the subsequent short rains (September–November). Researchers estimate the optimum density for *crotalaria* to be about 26,000 plants per hectare. At the end of this season the fallow is cut down, and a crop of maize is planted on the same land in the next long rainy season (Amadalo et al., 2003).

The second technology is based on a fallow period of 8–9 months, with land taken out of production for a single season, as above. Species such as *S. sesban*, *C. grahamiana* or *T. vogelii* are planted between the maize rows during the long rains. When the maize crop is harvested, the fallow is left to grow right through the short rains and is cut at the end. The land is then cleared for a new crop of maize during the following long rainy season. In both cases, farmers lose only one growing season (the short rains), which is a period when crops might easily fail because of reduced rainfall. According to researchers, this loss is supposed to be compensated by a threefold yield increase in the following season. However, both the long and short rains are unreliable and farmers do not want to take the risk of leaving their entire field fallow. Instead they prefer to grow these shrubs on a small part of their farms or as a hedge around the field. The mean fallow size among 300 farmers that were sampled by Place et al. (2002) was only 0.04 hectares.

According to ICRAF scientists short-duration improved fallows of 6–12 months increase the yield of subsequent maize crops by 1–3 t/ha in the first season compared with continuous maize cropping or natural weed fallows, with subsequently lower benefits in years two and three (De Wolf & Rommelse, 2000). The processes by which improved fallows achieve these benefits are by: (a) accumulation of large amount of nitrogen rich biomass which is easily decomposable and hence releases nutrients rapidly into the soil, (b) improved soil organic matter and soil structure (noted by easier tillage operations), reduced erosion and improved weed suppression in dense fallows such as *C. grahamiana*, (c) *S. sesban* fallows, which have a very deep root system and thereby effectively capture mineral nitrogen which has been leached below the crop rooting zone. This leads to a better recycling of nitrogen and reducing nutrient losses, (d) leguminous fallows additionally enrich soil fertility through the process of biological nitrogen fixation. The roots left in the soil decompose gradually, releasing nutrients to the subsequent food crops several seasons later. At the end of the fallow period the trees or shrubs are cut down to provide fuel-wood, stakes for supporting climbing plants,

or building poles. Besides replenishing soil fertility through their litter and nitrogen fixation, improved fallows of *S. sesban* are known to reduce levels of the parasitic weed *Striga hermonthica* in the soil significantly (Jama et al., 2006).

As is the case with *tithonia* biomass transfer systems, yield increases from improved fallows are found to be significant, sometimes without phosphorus supplements. For example, yields from *tephrosia* fallows averaged 1.7 tons/ha over three seasons following the fallow against 1.1 tons/ha for continuous cropping systems (De Wolf & Rommelse, 2000; Walker, van Noordwijk, & Cadisch, 2008). According to scientists, because labour is “saved” during the fallow phase of the system, economic returns to the fallow system can be significantly higher than that from continuous maize cultivation. It is also found to be much more profitable than a natural fallowing system (Rommelse, 2000). Studies in the Vihiga and Siaya pilot project area found that 22% of farmers were continuous users of improved fallows (Place et al., 2002).

At the outset of soil fertility research programme, the main improved fallow practice tested by researchers was the planting of *S. sesban* seedlings in uncultivated fields. Farmers in the research sites quickly helped to alter this by demanding species that could be direct seeded and then established the trees in cultivated fields, towards the end of the rainy season when the trees would not compete with the crop (Mango, 1999). In our own observation some farmers further took the initiative to mix species in fallow plots to take advantage of the benefits from different species. For example, they use *crotalaria* for its high biomass production and canopy cover, but like *tephrosia* for its ability to reduce the incidence of pests and moles.

4.4. Farmers’ experiences with improved fallow technology

In collaboration with extension workers and researchers from ICRAF, KARI and KEFRI Maseno, farmers in Western Kenya have been experimenting with the above methods for improving fallows. However, in our interview with them, they mention that it is a labour demanding method in terms of cutting the fallows and in establishment when seedlings are used. Further, they note that “you must have planted a lot of the shrubs in order to realise your objective”. Farmers were encouraged to apply an unknown amount of *Minjingu* rock phosphate (Jama et al., 2000). *Minjingu* rock phosphate was being imported from Tanzania and is believed to have a high phosphorus content (28–32%) (Jama & van Straaten, 2006). It was a cheap source of phosphorus fertiliser. The blanket application of this phosphorus rich mineral, left farmers in doubt about the performance of the improved fallow technology. They believed that without the rock phosphate, the yield will not be as high as researchers argue. One farmer from Sauri village that we interviewed in the long rainy season of the year 2000 stated that,

the fertility of the plot is not really guaranteed if you rely on the shrubs alone without adding inorganic fertiliser. Thus we would prefer using local maize instead of hybrid maize with these trials. Using local maize in a soil with much reduced soil fertility is far better than hybrid that gives nothing.

5. Agro-forestry innovations: a solution for women farmers?

In earlier economic studies conducted by scientists about a third of the women interviewed mentioned that they did not have sufficient knowledge of improved fallow technology (Mango, 2002; Place et al., 2002; Rommelse, 2000). Other issues included women’s lack of access to land, inability to mobilise sufficient labour and knowledge of how and where to plant them, and family life cycle. Broadly spoken, the introduction of a new technology or even a change in mind-set can alter the on-farm division of labour, shifting some tasks and responsibilities from women to men or vice versa (Kiptot, 2015). Men’s and women’s different priorities and preferences for tree species choices stem from their roles and responsibilities. In the research villages where we worked, younger women tended to be tied down by caring for young children and as such were unable to find time to attend meetings and seminars where such technologies are taught and their use demonstrated. Older women complained mostly of poor health and also the time the trees and shrubs take to mature and

release the biomass (cf Franzel et al., 2008; Kiptot & Franzel, 2011; Kiptot, Franzel, Hebinck, & Richards, 2006; Kiptot et al., 2007; Wanjiku et al., 2003). They were not just keen to wait. More common, however, were shortage of land and labour constraints, where agricultural intensity and population density are high (Franzel et al., 2008; Place, Adato, & Hebinck, 2007a; Place et al., 2003, 2007b). However, ICRAF and some partners commitments to reaching out to the poor in pilot areas have led to similar testing/use rates of these technologies between male and female headed households. This in our view presented a knowledge gap with regards to gender and technology development.

6. Discussions and theoretical reflection

This paper can theoretically be situated on issues of knowledge production and exchange, the role of human agency and the cultural repertoires of farmers, extension workers and scientists. These dimensions have been explored in this paper through an understanding of the encounters between various bodies of knowledge embraced in one domain of agricultural production: soil fertility aspect. Soil fertility issues are commonly shared and identified as problematic by the actors involved. However, as the analysis has shown, despite these concerns being shared, this cannot be said of the proposed solutions. It would be rather more accurate here to talk of knowledge conflicts and claims. The encounters between scientific and local bodies of knowledge—depicted in this paper with regard to ways of reproducing soil fertility—constitute an important and dynamic force that continuously produces and reproduces heterogeneity. These clashes and frictions between scientific and local knowledge have been treated here as the likely outcome of planned intervention and fits well with the developed framework for analysing the dynamics of technology development and design in terms of so-called socio-technical regimes (Hebinck, 2001; Mango & Hebinck, 2004; Rip & Kemp, 1998). This concept evolved from the work of academics at technical universities in their attempt to understand technological change from a social science perspective. The concept proves to be useful in this paper where we have explored and linked processes of social and technological change with respect to soils and SFR. The theoretical and practical advantage of the notion of socio-technical regime is that it proposes a non-linear perspective on change and explores the unfolding of divergent technological trajectories over time. Socio-technical regimes are multiple or heterogeneous and consider change processes at the level of regimes as initiated “from above”, “from within” and “from below” (Hebinck, 2001). The usefulness and practical application of notion socio-technical regime is that it allows for an analysis of the underlying technological discourses and practices of the different regimes and technological trajectories. It also helps to identify alternative ways of responding to processes of social, cultural and economic change in societies. Taking SFR as a case in point, we encountered socio-technical regimes in Western Kenya that are a mixture of technological changes “from within” and “from below”.

Technological change “from within” is one that is triggered from the research centres by scientists themselves. An example of this in this paper is the case of agroforestry technologies, which is proposed by scientists from ICRAF as a second soil fertility improvement paradigm alongside the dominant fertiliser regime (Sanchez, 1999, p. 3). Improved fallows, involving fast-growing species—usually legumes capable of fixing nitrogen in the soil—are planted for rapid replenishment of soil fertility. A key characteristic of the “from within” approach is that it departs from a perspective that problematizes development with a view to legitimise interventions at the level of markets, technology and knowledge. “From within” goes together with the need to provide training to facilitate the technology transfer and ease adoption processes (Kimanthi & Hebinck, *in press*). Technological change “from below”, on the other hand, pivots on localised practices, which are embedded in local institutions and local cultural repertoires (Hebinck et al., 2015). In contrast to the “from within” trajectory, “from below” hinges on recognising and attributing agency to local people who live and work in their villages and in homesteads and who interact during project cycles with researchers and implementers (Fressoli et al., 2014). “From below” can be associated with the notion of “niche” as proposed by Rip and Kemp (1998) and Wiskerke and van der Ploeg (2004). These niches then represent local ways of reproducing soil fertility often combined with “traditional” crop production practices. The niche may very well be the level where alternative technologies are developed, some of them giving rise to the emergence of new regimes that coexist with the predominant regime. The important difference

between regimes and niches is that different social processes are involved. A regime is characterised by relatively stable networks that manage to reproduce themselves constantly. Within these networks, the direction of technological processes and progress is relatively clear cut and beyond dispute. Niches, on the other hand, are formed by less stable networks in which a variety of experiments are carried out that generate debates and negotiations. In niches, the learning processes are open-ended and less obvious, progress is made through trial and error, and there is no dominant design (Hebinck, 2001). Niches, to paraphrase Rip and Kemp (1998) provide a seed bed for the emergence of socio-technical “configurations that work”. Fressoli et al. (2014) associate the development of niches with innovations at the level of the grassroots.

A good illustration is the cases where farmers have themselves successfully identified in their own socio-technical landscape a very competitive shrub, *T. diversifolia* (wild sunflower), as a source of green biomass manure for improving soil fertility. Such farmer innovations are representative of technological change “from below” and are the hidden novelties that emerge independently in the socio-technical landscape. On the other hand, fertiliser has entered “from above” with homogenised packaging and content with strict guidelines on use. In the context of experimentation in integrated soil fertility management systems, however, this imposed technology is now being scrutinised within the communities.

The different bodies of knowledge associated with the types of technological innovations that have emerged in Western Kenya over the years underpin the argument above that processes of social transformation involve knowledge encounters and the co-existence of socio-technical trajectories or regimes. For example, practices based on fertilisers, agro-forestry and manure all co-exist. This heterogeneity is continuously produced and reproduced, providing (at least theoretically) a breeding ground for continuing experimentation and the enrichment of knowledge. This is happening with the green biomass manure using shrubs such as *T. diversifolia*. These processes resonate with the argument for the co-existing regimes whereby niches challenge the predominant regime. Despite having localised roots, green biomass manure certainly possesses its own dynamics and definitely has a role to play in resolving soil fertility issues alongside the use of fertilisers. Knowledge generation from farmers, researchers, and NGOs has been complementary, facilitating the spread of information on its practice. Green biomass manure and improved fallow technologies as expressions of the new soil fertility paradigm, also play a significant role in improving soil fertility alongside the dominant fertiliser regime. At a more abstract level, one can argue that provided their discourse is taken seriously, the experiences and dynamics of improved fallow technology and green biomass manure will undoubtedly broaden the horizon of technology development. The niches though likewise require recognition as examples of grassroots innovation. Niches deserve some kind of support in the form of documenting experiences and constructive engagements with research institutions. Geels and Kemp (2000) and Wiskerke and van der Ploeg (2004) refer to this as “strategic niche management”. Given the discontinuities between these particular niches and the “modern” regime in Western Kenya, it would seem that for the time being such strategic management will remain within the localities themselves. It is unlikely to have a widespread impact on agricultural intervention practices.

7. Conclusions

Given the relative success of the Green Revolution in increasing food production, many argue that intensive packages of improved varieties and fertiliser should be widely applied as the model for agricultural development and as a means of ensuring household and national food security (Borlaug, 1988). Although this sounds appealing, this paper shows that there are numerous constraints that curtail adoption of this approach in Western Kenya.

The high and increasing costs of mineral fertilisers heightens the urgency of the search for alternatives. Scientists recognise that lowering the costs of restoring fertility is vital to the future of agriculture in the region and beyond. But aside from the cost argument, there are other good reasons for diversifying farmers’ soil fertility options. In a region like Western Kenya, nutrient and other soil

constraints are multiple. That means farmers need a cocktail of techniques in which synergies can occur. Also, farmers face multiple socio-economic constraints (finance, labour, land) each of which favours different types of soil fertility options. On both counts, commercial fertiliser alone is clearly not the answer.

Low-cost technologies and local ways to supplying nutrients to crops are needed on a scale wide enough to improve the livelihood of farmers. In this paper, we have analysed alternative and practical approaches of increasing domestic food production using improved fallows with *S. sesban*, *C. grahamiana* and *T. vogelii* and also through the use of green biomass manure transfer from the prunings of the shrub *T. diversifolia*. This approach builds upon farmers' traditional production strategies and on collaborative national and international research efforts and represents regime change "from within" and "from below".

Long fallow periods were historically used to regenerate the level of organic matter and nutrients, until increasing pressure on land reduced this possibility. Thereafter, application of animal manure became the most important source for soil fertility improvement. However, due to the decline in cattle population, quantities of manure produced have become insufficient for restoring soil fertility on all fields (Mango, 1999, 2002). Most farmers find inorganic fertiliser too expensive, unavailable at the right time, and quite unsuitable as it spoils their soil when frequently used. The paper has also focused on the most recent technologies that are emerging from research and those that have been developed by farmers themselves aimed at improving soil fertility. It was also shown how farmers and researchers attempt to re-establish tree-soil-crop interaction, which was lost over time due to deforestation emanating from increased population.

These technologies constitute what other researchers call the second soil fertility paradigm and are based on sustainability considerations (Sanchez, 1999). This paradigm focuses mainly on improved fallow technologies using trees and shrub legumes capable of fixing nitrogen through their roots and from the biomass from their leaves. Biomass transfer is another potential technology for restoring soil fertility and improving crop yield. Biomass can be obtained from *T. diversifolia*, which is found in hedges in the area. As we mentioned earlier, on-farm research demonstrated a good response from maize when prunings are applied as green manure. However, the technology is rather labour intensive (Place et al., 2007b). The quantity of biomass needed can be reduced when combining it with inorganic fertiliser. Crop yields will further increase when rock phosphate and farmyard manure are added. The single most important reason why farmers try improved fallows is because their soil is poor. Moreover, even those with moderately good soils will try improved fallows if they see the benefits of them, in order to save money they would otherwise use for fertiliser, or to reduce risks associated with fertiliser use. Some farmers with adequate access to farmyard manure and fertiliser try improved fallows on a minimal scale.

Unlike the Green Revolution projects that come in the form of packages and are highly linked to markets, SRP-technologies have emanated from farmers' own quest for alternatives to solve the agrarian and environmental crisis that faces them. Farmers have turned to look at their own environment after being let down by the institutions involved in Green Revolution projects. Unlike such projects, SRP-technologies do not have prescribed packages, leaving farmers free to experiment in any way they wish. Furthermore, these technologies, unlike those that are transmitted through Green Revolution like projects such as the recent Sauri Millennium Villages project, is not highly linked to markets. This serves well the interests of farmers with limited resources.

8. Recommendations

With regard to soil fertility, more emphasis should be given to organic sources of fertilising soil, given that farmers' confidence in inorganic fertilisers has waned ever since Green Revolution programmes were propagated. It is only by embracing such processes of niche development within the wider socio-technical landscape that appropriate technologies-independent of the predominant fertiliser regime-can be developed to complement soil fertility management. Second, the soil fertility

programme, based on considerations of sustainability using leguminous trees and shrubs and biomass transfer, has shown positive results on experimental plots and should therefore be encouraged alongside other options, even though their sustainability in the wider socio-technical landscape is doubtful. Technically, one could say that agro-forestry technologies have demonstrated their usefulness as alternatives (or complements) to fertiliser. As such they add to the existing portfolio of organic options such as animal manure and compost. A big question with these new and evolving technologies is how extensive and durable these technologies will be in the rural communities. These are hindered somewhat by the level of informational support required in managing the systems and their reproduction (i.e. germplasm). Hence, it has been seen that the number of farmers using the systems drop following the departure of technical support. In the longer run, it will be the farmers themselves generating the bulk of new information on how best to manage these agro-forestry systems and a major challenge will be to devise mechanisms that can promote horizontal information flows between communities.

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Notes

1. The second author of this paper was part of the evaluation team.
2. The second author co-supervised the PhD and Master research projects by respectively Evelyne Kiptot and Hellen Kimanathi.
3. The lead author is a native of the region and had an advantage of visiting the research sites several times over the years.
4. The project has also helped to catalyse credit operations in some communities (Place et al., 2007b).

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