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Impact of Sand Dams on Agriculture Production in Kitui District, Kenya

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Abstract: The challenge for successful farming under semi-arid conditions is access to water on a timely basis. This paper draws on data from two surveys in Kitui district, Kenya to examine the potential benefits of sand dams in ephemeral streams as a means to providing water required for improved agriculture. The analysis demonstrates considerable potential for operational sand dams to increase soil productivity, expand crop diversity, increase farm income and enhance food security at the farm level.

Keywords: Africa, Kenya, water, agriculture, rural development

1.0 The Challenge of Farming in Kenya's Semi-arid Areas

Agriculture is a key sector for the many people in Kenya's rural areas. Water plays a fundamental role in agriculture: it is essential for livestock and it forms a large part of all plant tissues. For successful agricultural activity there has to be adequate water available on a timely basis. In areas where agriculture is rain-fed and farming systems in semi-arid areas face erratic rainfall, seasonal dry spells and periodic droughts create uncertainty in both crop and animal production. For these farmers increased water infiltration into the ground through water harvesting can improve yields, reduce risk of yield losses and increase the recharge of ground water.

Farming under erratic rainfall conditions is pervasive in Kenya: 82 per cent of the land area is designated as semi-arid, holding in excess of one-third of the population (Mutiso and Mutiso, 2004: 5). Where mean annual precipitation in some of these areas appears to be adequate for crop production, a combination of poor distribution throughout the crop growing season and high evaporation may result in agricultural drought at critical periods of crop growth. Under these conditions a key challenge is to create an enabling environment for water harvesting that is economically viable for dry land farming. There is a need for a comprehensive, integrated approach to unlock the full potential of sustainable water management for poverty reduction and economic growth.

The construction of sand dams in a community is one approach to addressing this need. A major constraint in cultivation in most semi-arid areas is the rapid dissipation of precipitation in flash floods, limiting water input throughout a growing season. Sand dams are impermeable structures constructed across ephemeral rivers. The dam increases the storage capacity of the river channel by accumulating the base flow and storing it in the sand backed up against the dam within the river bed. This form of storage can last for a long time, in many cases up to the next rains, even with continued use. In addition, impeding surface water flow in this way promotes the flow of water to the banks upstream from the dam.

2.0 Sand Dams Survey Data Collected in Kitui District

With support from international donors SASOL Foundation has been working since the mid 1990s with members of communities in one of Kenya's semi-arid regions, Kitui district in Eastern Province, to construct in excess of 400 sand dams. Two of the donors funded surveys for the purpose of evaluating this ongoing project.[1] In a 2001 survey, funded by Department for International Development [DFID], the sample included sub-locations in two divisions – Central and Chuluni – in which 320 sand dams had been constructed. Using the 1999 National Census as a population base this survey sampled ten percent of the households in the villages with a sand dam. In the tables reported here this sample will be identified as *Survey 2001*. In 2005 Mennonite Central Committee and Canadian

[1] To see the use of these surveys by donors to assess of the sand dam projects see Isika, Muyangu and Mutiso, (2002) and Rempel, Nyaga, Manzi and Gaff, (2005).

Food Grains Bank funded a socio-economic evaluation of 387 sand dams that had been constructed by SASOL. A stratified random sample was used to systematically collect data from 187 households that formed part of the 30 sand dam communities evaluated. Tables reported here will be identified as *Survey 2005*.[2]

This paper draws on selected questions from these two surveys. Respondents were asked to compare their situation, at the time of the survey, with conditions prior to the construction of a sand dam. The analysis is based on this before and after self-assessment by sand dam participants in each of the two surveys of changes in agriculture production that they attributed to water harvesting related to the construction of their respective sand dams.

The 2001 DFID Survey in Central Division also included communities that did not have a sand dam. Where these respondents could not make a self-assessment of how a dam affected their respective households, a number of questions in the two surveys overlap. This allows for some comparison of communities with sand dams and those without dams. All claims of correlation or statistical significance are based on chi-square tests applied to response distributions or a comparison of means tests based on *2005 survey* data and from these two *2001 surveys* with three types of households: 651 households in no-dam communities, 620 households in communities with a sand dam that had water at the time of the interview, and 162 households in communities with sand dams that did not have water at the time of the interview.

The two project assessments of project outcomes and impacts documented that, on average, households in communities with sand dams were collecting significantly more water than prior to the

[2] On the basis of the two project evaluations conducted Mennonite Central Committee and Canadian Foodgrains Bank have provided funding to enable SASOL Foundation and Excellent Development to construct 400 more sand dams in three districts in Eastern Province.

dam and were traveling a shorter distance, hence using less time, to fetch water. This paper analyzes how these and related outcomes have affected agricultural production in these communities.

Section 3 provides a brief overview of agricultural production in Kitui district, focusing primarily on the villages surveyed. The fourth section describes the water harvesting dimensions of sand dams. In the fifth section relevant literature is surveyed to formulate a set of hypotheses to be tested. Section 6 presents the relevant data and statistical tests utilized to test these hypotheses. We conclude with a discussion of improvements recommended to enhance further the agriculture potential inherent in sand dams as an approach to water harvesting.

3.0Agriculture in the Areas Surveyed in Kitui District

During the past three decades food production in Kenya has increased by 2.8 per cent annually; population growth, in contrast, has averaged three per cent (World Bank, 2007). Opportunities to increase food production by expanding land area under cultivation have now been largely exhausted. The potential for intensification is greatest in areas under irrigation and areas with reliable rainfall. As a major portion of Kenya's land area is semi-arid, intensification through better water harvesting methods combined with improved agricultural practices is important as well.

Sustainable agriculture seeks to combine development and conservation to improve farming systems and to enable productivity to be maintained indefinitely. For semi-arid areas key strategies involve extending rain water harvesting and improving on-farm water management. The sand dam is deemed to have good sustainability potential in that agricultural systems can be improved without environmental degradation. For Kitui district water is the primary constraint limiting further intensification of agriculture. Crop production in these areas varies from opportunistic planting after exceptional rains to small-scale mixed farming along the margins of ephemeral rivers and on the plains when floods recede.

Addressing water supply is strategic for food security, improved health and development initiatives in arid and semi-arid areas. Food security, which is the command over available food, tends to vary with household size, life-cycle, land under food crops, quantities of food harvested, and general utilization of available resources to acquire food. This being so, intertwining these factors would not only avail food in the various households but also, indirectly, to other members of the community. Water is necessary for drinking, cooking food, washing and cleaning, growing plants, rearing livestock and serves as an input for many productive development activities.

Kitui district has a bimodal rainfall of 300 - 800 mm per annum, which places it within a semi-arid category. Rain falls in two distinct seasons, March to May and October to December. The district's topography is characterized by undulating land and a flat Yatta plateau. Altitude varies from 400 to 800 meters above the sea level. It is classified ecologically under zone V and VI, where agricultural production is basically subsistence with crops such as green grams, cowpeas, pigeon pea, millet, common bean and sorghum grown. There is also agro-pastoral where crops together with animals such as small herds of cows (Boran cattle) and goats are kept. An indicator of the nature (type) and intensity of agricultural activities is the agricultural possessions in the various households. The data from the two surveys show the people in the study area to be agro-pastoralist, combining the keeping of livestock with crop farming. The indicators collected are the number and type of livestock kept: goats and sheep, cows, donkeys and chickens. The farming implements are comprised of jembes, mattocks, spades, ploughs and carts and wheelbarrows (see Table 1).

We observe the households in communities with sand dams have significantly fewer cows, chickens and ducks than their no-dam counterparts and significantly more donkeys and ox ploughs.

These differences suggest communities with sand dams choose to intensify their farming relative to relying on cattle and poultry as a form of assurance in time of drought. This is a hypothesis to be tested.

Table 1: Evidence on Average Levels of Asset Ownership (number): *2001 Survey*

Asset	No dam households	Sand dam households	Total
Chickens and ducks*	5.8	4.9	5.3
Sheep and goats	3.7	3.7	3.7
Donkeys*	0.6	0.9	0.7
Cows*	2.0	1.8	1.9
Jembes, spades & mattocks	4.7	4.9	4.8
Ox ploughs*	0.5	1.2	0.9
Carts & wheel barrows	0.5	0.5	0.5
Plant machines	0.4	0.2	0.3
* Observed differences between households in these two types of communities are statistically significant at the 5% level (chi-square).			

The number of households keeping goats and sheep is higher than the number keeping cows. In part, this may reflect a risk-minimizing strategy. Where cows can generate more milk and meat if fodder is good, goats can be liquidated more readily in time of misfortune. Also, goats are browsers while the cows graze, hence goats are best able to survive the harsh climatic condition of semi-arid areas in Kitui District. Crop farming takes preference over livestock rearing as shown by the relatively high number of implements used. Population pressure also has played a role in reducing the place of livestock as the land available for grazing is limited.

Farms in the sample are relatively small: using mid points of the distributions reported it is estimated households, on average, had 7.5 acres of land. The differences between communities with and without sand dams were small, 7.4 versus 7.6 acres. Households with sand dams rented more land: 0.7 acres versus 0.3 acres for households in communities without a dam.[3] This type of farming is mostly for

[3] Applying chi-square test to distributions in tables based on ranges of land area, the observed differences for both land owned and land rented are statistically significant.

food production; only the surplus in good rainfall seasons act as a source of income. This is confirmed by the responses to a series of questions on goods and services deemed necessary by the households: 87 per cent listed food and 72 per cent listed water (83% for no dam communities; 63% for households with sand dams). Having more land, in contrast, was listed by only ten percent of the households.

The main occupation of the heads of the households surveyed also demonstrates the importance of agriculture: 74 per cent listed farming as their primary activity. For the question on land use, 89 per cent identified farming and seven per cent listed livestock grazing. We observe most of the land is dedicated to crop farming and quite secondarily to livestock keeping. Inadequate rainfall for such an area injects significant food security problems. Expanding traditional knowledge to incorporate new approaches to water and land management practices within their existing agricultural system will enable more sustainable agriculture and, therefore, improved food security.

Tomato Production in Kamale

An example is the cultivation of tomatoes in Kitui District (Kamale area) which has gained a lot of popularity among many subsistence farmers and whose price does not depreciate that much because the demand is very high. Tomato as a food crop was not easily available in the market as it was supplied from neighboring District whose potential for production is high. Prices of tomatoes were so high; most families exempted them from their diet.

One would say it may not benefit the locals as the prices have gone down, but the question, is the cost of production that high not to warrant any returns? One farmer from that area said selling all the tomatoes from his small size of farm earns him between 100,000 to 150,000 Kenya shilling when the prices are normal and thus enabling shelter and food for the family unlike his expectation. This has become possible due to the availability of water especially where sand dams have been made.

To date most families consume tomatoes as they produce both for sale and consumption enabling a much needed balanced diet. Production of such crops as tomatoes, onions, kales, etc., especially during the long dry season, is a supplement for a situation of no food at all in such a season. Food production just for consumption is a great step towards achieving food security for we cannot jump before we leap. Information obtained one farmer, Kyalo of Kamale area.

The potential impact of access to water in this setting is illustrated with the example of Kamale. Maximizing farm output on a small piece of land with available water is likely to provide a higher yield compared to the cultivation of larger areas where crop production is limited by water. Intensifying crop production in such areas with a small piece of land would be characteristic of most farmers in these arid and semi-arid areas as they farm primarily for household subsistence farmers. Crop production and livestock keeping would be intensified in terms of quantity and quality of production.

4.0 Sand Dams as an Approach to Water Harvesting

The search for water is a significant preoccupation in Kitui district as there are only a few water sources such as seasonal rivers to serve them. During the dry season river beds become important sources of water, as well as sand for construction purposes. As sources of water are limited and typically some distance apart during the dry season, the frequency of water fetching trips, the number of persons per trip and the time devoted to water fetching varies significantly between wet and dry seasons. Given that agriculture is a major source of household incomes for the families in the district, water scarcity – linked to limited rainfall that is poorly distributed, is erratic with excessive runoff, and a lack of permanent rivers – leads to limited economic development and food insecurity.

This scarcity has led to development of various ways of curbing the water problem, such as wells, boreholes, water pans, earth dams and sand dams. Wells and boreholes are extractive and deplete the existing aquifers. The construction of earth dams and pans require intensive and expensive equipment. Also, they are affected by siltation with the process of distillation being equally expensive as they remain directly exposed to high evapo-transpiration rates. Sand dams harvest surface run off for sub-surface storage under sand and in existing soil media. Sand dams built in series along a stream bed can interconnect this saturation and create a continuous aquifer within the sides of the river channel.

The primary feature of a sand dam is the construction of a stone and cement barrier in a stream bed for the purpose of collecting and holding sand that washes along the stream during the rains. The water is stored in this sand and can be accessed with a traditional scoop hole or with the construction of a well. Complementary project outputs for an operational sand dam are the organization of a sand dam community to construct and maintain a dam and building of capacity within such a community to limit soil erosion, undertake terracing, seed grass, plant trees and construct latrines. These activities allow a sand dam to mature where it fills with sand rather than silt from soil erosion on the slopes contiguous to the dam. These activities also limit contamination of the sand and water that accumulates in the sand dam. In addition, to making the sand dam operational, the trenching, terracing and planting activities encourage additional water harvesting activities on the farm sites in the vicinity of the sand dam.

The evaluation of the sand dams constructed by local communities with assistance from SASOL Foundation concluded community spirit, with a tradition of undertaking group activities, proved to be an important determinant of such complementary activities required for an operational sand dam. Community spirit also affected the distribution of benefits from a sand dam through the provision of plots for vegetable growing, resolving issues of potential conflict, as well as assisting each other within the community in various other ways.

It is important to note that the construction of a stone and cement barrier in a stream bed does not assure an operational sand dam. The 2005 evaluation, undertaken during the dry season in a drought year, found the development potential was being realized with water available in 50 per cent of the dams. Of the 30 dams examined, one had failed, three had water but it was saline, several had been constructed recently and there had not been sufficient water flow to move sand up to the dam site, while the remaining dams that did not have water were filled with silt rather than sand as they had not been protected adequately by their respective communities. The subsequent analysis will focus on the sub-set of sand dams observed to have water at the time of the survey.

5.0 Potential Impacts of Sand Dams for Agriculture

An operational sand dam provides two immediate resources integral for improved agriculture: water and labor. With a good accumulation of sand the water stored will increase the overall supply available to the community. In addition, the availability of water extends further into the dry season, in some cases up to the next rains. As observed in Table 2, the respondents in the *2001 survey* reported the quantity of water they utilized increased significantly with an operational sand dam.[4] Similarly, the respondents in the *2005 survey* reported the amount of water collected per week, with an operational sand dam, increased by 272 liters. This contrasts with an increase of 121 liters for respondents with

Table 2: Quantity of Water by Households during the Dry Season, Before and After the Construction of a Sand Dam (per cent): *2001 Survey*

Amount in liters	Communities without a sand dam	Communities with no water in the dam		Communities with water in sand dam	
		before	after	before	after
Less than 40	30	17	17	22	11
40 to 59	18	28	20	17	17
60 to 79	20	18	24	23	24
80 to 99	14	17	25	15	21
100 +	18	20	14	23	27
Total	100	100	100	100	100
Number of respondents	711	178	172	671	642
Observed differences between households in communities with a sand dam and the other two communities prior to construction of a dam are statistically significant at the 5% level. Also, differences between the two sets of communities after dams were constructed are significant, as are the differences before and after for the households in the communities with water in the sand dam.					

4 As the quantities of water fetched among the three sets of communities varied significantly prior to the construction of sand dams (Table 2), there are more determining variables in play here than merely the building of an operational sand dam.

dams that did not have water at the time of the survey and 180 liters for respondents with dams that had water, but it was salty.[5] Finally, the water stored in the sand recharges groundwater in the banks of the stream on the upper side of the dam.

A knock-on effect of more water available in the proximity of the community is reduced time spent collecting water, especially during the dry season. The allocation of time for the various activities that have to be done is important. Most agricultural activities in semi-arid areas are not allocated enough time because people, especially women, spent significant time looking for water and food for the family. This negligence results in adverse effects in both livestock and crop production.

The allocation of more time for agricultural activities, both in the wet and dry season, has an effect on the quantity and quality of production. For example, sorghum, a crop whose yield is normally affected by a pest, the weaver bird (*Quelea quelea*), requires a farmer to keep off the bird. The crop is important as it is drought resistant and nutritious compared to the maize crop that most farmers prefer. Also, proper grazing for animals, making sure they are healthy, adds to their market value hence increasing the farmer's income.

Data from the two surveys indicates an average saving of 1.5 hours per day during the dry season.[6] In the *2001 survey* the respondents were asked how they spend this extra time that was saved in collecting water. More time spent in agriculture featured prominently: crop farming 25 per cent, livestock watering 42 per cent and bee keeping 19 per cent. More time devoted to vegetable growing (50%) and kitchen gardens (20%) also were listed frequently. Finally, 59 per cent reported they had

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[5] Applying a single ANOVA test these three means are significantly different at the one per cent level (Rempel, Nyaga, Manzi and Gaff, 2005: Table 5).

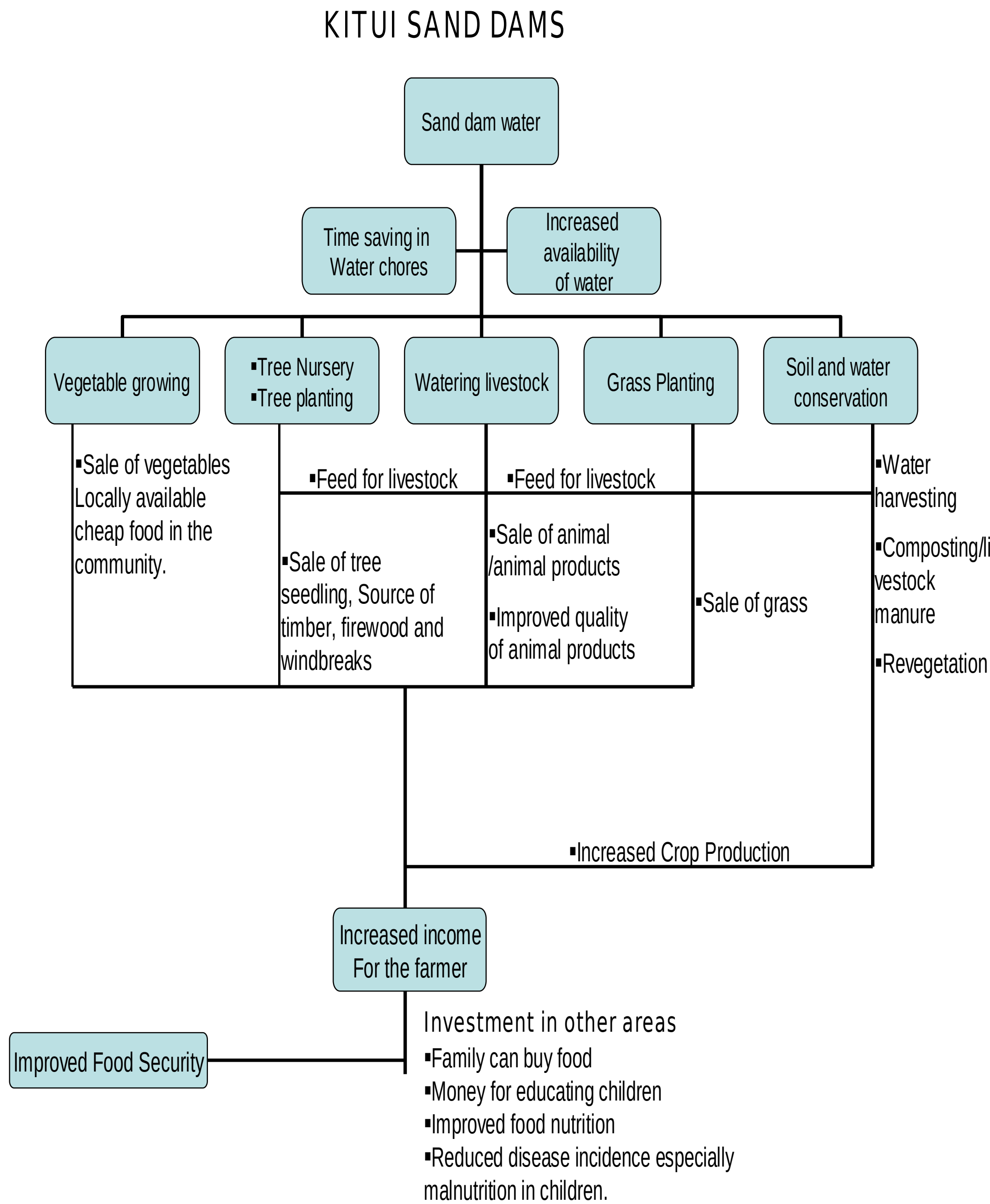
[6] For the 2005 survey the reported saving in time was 1.5 hours per day. In the 2001 survey the 32 percent of the households that reported spending less time fetching water the average time saved was 1.4 hours per day (Lupupa and Rempel, 2007: 22).

more leisure time. In the *2005 survey* the respondents were asked only if they invested some of the time saved in collecting water in agricultural activities. Fifty-five percent answered in the affirmative.

Figure 1 outlines the potential effects of water and time advantages of an operational sand dam for the agriculture sector. To test whether these changes were observed in practice at the farm level we sought to test the following hypotheses:

1) The risk inherent to dry-land farming is reduced, enabling famers to adopt a more intensive approach to farming.
2) A more intensive approach to farming changes cropping patterns, including the introduction of new crops.
3) A combination of more reliable water supply and changes in cropping patterns enables improved livestock husbandry practices.
4) Changes in crop farming and livestock rearing increases household farm income as the supply of farm output available for sale is expanded and the incidence of the adverse effects that food insecurity has on household income is reduced.
5) The changes observed in 1) to 4) above improve the sustainability of agricultural production.
6) The human factors involved in constructing and maintaining sand dams also induced favorable changes in agriculture.

Figure 1: Potential Effects of a Sand Dam on a Community's Agricultural Production



6.0 The Impact of Operational Sand Dams on Agriculture

6.1 More Intensive Farming

Risk management strategies are laid out by farmers to ensure that even under conditions of severe moisture stress some yield from the field is obtainable. Land preparation and planting are high risk operations affecting crop establishment and hence carry adverse effects on the later stages of plant growth and development. The most important factors affecting these two activities are availability of labor time, especially since they are done during the dry season when the women in most households are usually concentrating on obtaining water. The time saved from water chores spreads this risk by ensuring the traditional aspects of managing them, proper land preparation and timely planting to utilize the rain available, are improved.

Second, for optimum yield timely and proper management of the crop from planting to harvesting is crucial. These management strategies include timely weeding, control of pest and diseases, and harvesting. The utilization for agricultural activities of time saved in the fetching of water allows for better quality and quantity of production in agriculture. In summary, reducing the risk of crop failure can enhance the economic value of agriculture

It is our expectation that reduced risk made possible by more water and more time in communities with an operational sand dam will enable famers to adopt a more intensive approach to agriculture. The *2001 survey* provided some indirect evidence where people reported how the availability of water affected the activities in which they were engaged (see Table 3). We observe first that prior to dam construction activities are similar across the three types of communities. For the two sets of communities with a dam both agriculture in general and goats and sheep in particular decline, with a significantly larger decline in the communities where the sand dams did not have water. This suggests a shift out of agriculture into alternative income earning activities made possible by water and time, such as brick-making and selling of vegetables. Evidence of more intensive agriculture is in the activities of vegetable growing and kitchen gardens. Both increase in these two sets of community with the increase significantly larger in communities with an operational sand dam.

Table 3: Proportion of Households in Three Types of Communities that Were Engaged in Specific Agricultural Activities Before and After Construction of a Sand Dam (per cent): *2001 Survey*

Activity	Community without a dam (n = 651)	Communities with no water in the dam (n = 620)		Communities with water in the sand dam (n = 162)	
		before	after	before	after
Agriculture	98	90	83	94	90
Goats & sheep*	63	59	46	50	44
Cattle	54	39	33	35	35
Vegetable growing**	18	19	41	17	34
Kitchen garden	12	4	9	9	14
Tree nursery	8	7	22	8	20
Bee keeping*	4	11	7	8	8

* Observed differences between households in the two types of communities in changes before and after sand dam construction are statistically significant at 5%;
** significant at 10% level (chi-square).

The questions posed in the *2005 survey* are more generic: 70 per cent reported investing more labor in agriculture, both cropping and livestock rearing, after a sand dam became operational. For communities with sand dams that did not have water at the time of the interview this increase was 27 per cent only, which is significantly lower. Where this may appear to contradict the results obtained in the *2001 survey*, other parts of the *2005 survey* indicate vegetable growing is where the largest change in production occurred. The *2005 survey* provides support for the suggestion that selling of vegetables became an alternative source of income for women: in communities with water in their sand dams 30 per cent of the households reported allocating more labor there (versus 5% in the other communities).

A second test of the hypothesis on increased intensification of agriculture is a set of questions in the *2001 survey* that probed whether an operational sand dam had some indirect, knock-on effects. As observed in Table 4, in communities with operational sand dams a significantly higher proportion of the households reported an increase in land values, increased land productivity, an incentive to buy or lease more land and improved livestock reproduction rates. For three of these, though, the number responding

Table 4: Reported Indirect Agricultural Benefits from Constructing a Sand Dam (per cent): *2001 Survey*

Reported Benefit	Unsatisfied households, no water in the dam	Satisfied households, sand dam has water	Number of Respondents
Increase in land values*	50	75	16 & 57
Livestock reproduction rates increased**	44	68	16 & 49
Increased land productivity*	53	81	19 & 48
Increase in tree planting and terracing	55	55	20 & 31
Vegetables more plentiful and cheaper	96	93	42 & 133
An incentive to buy or lease land*	14	20	145 & 574
* Observed differences between households in these two types of communities are statistically significant at 5%; ** significant at 10% level (chi-square).			

is low, indicating the overall impact in the sand dam communities is limited. The largest indirect impact of sand dams is in vegetable production, which occurred in both sets of communities. As vegetables are typically grown on the banks or in the stream bed above the dam, it would appear some recharging of ground water occurred even for sand dams that lacked water at the time of the survey.

6.2 Introduction of New Crops

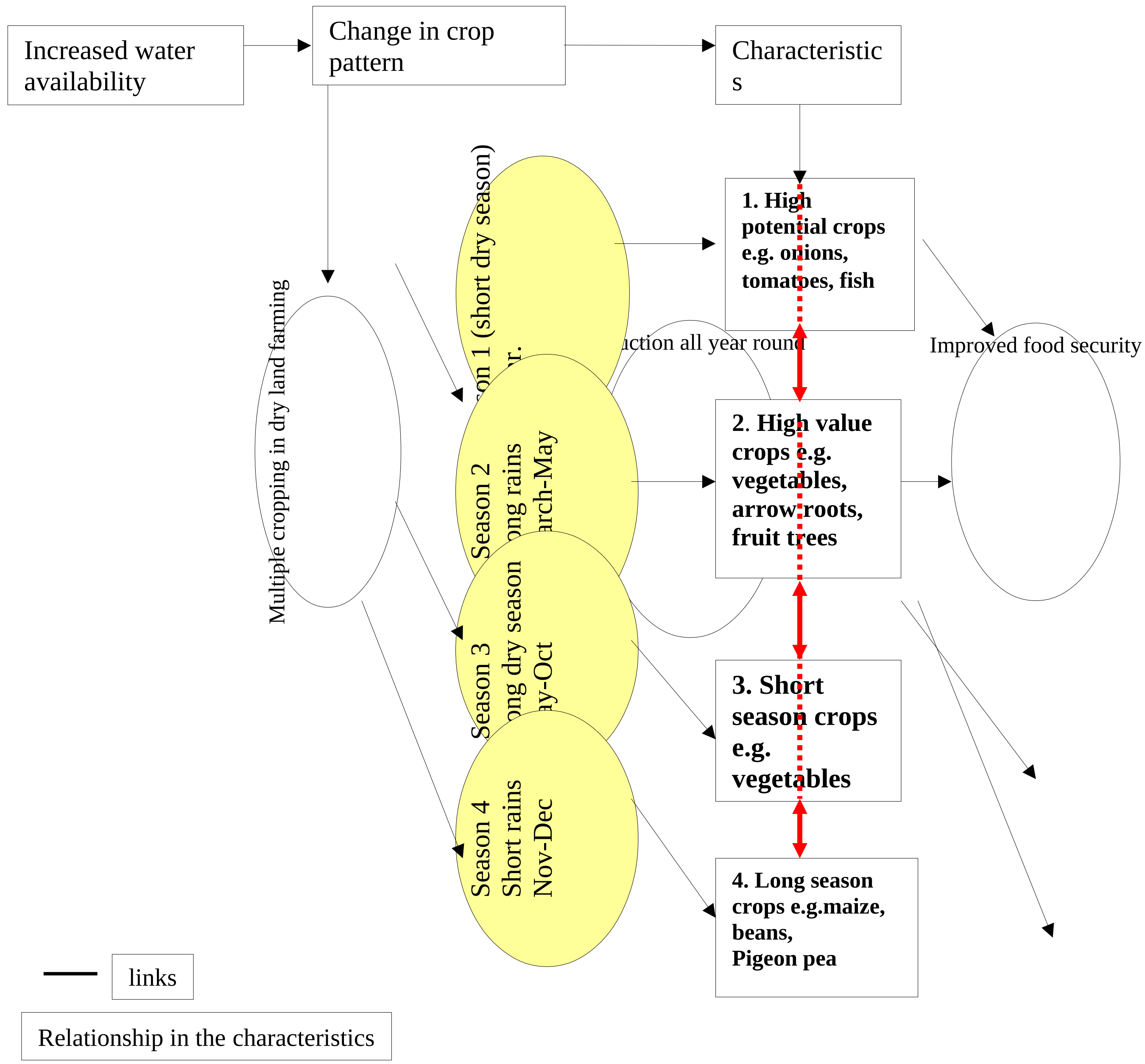
A strategy to minimize risk is to plant several species of plants and a variety of crops. This can stabilize yields, promote diet diversity and maximize returns, even under low levels of technology and limited resources (Harwood, 1979). In such a strategy crops are grown according to intercropping patterns that aim to maintain soil fertility, increase farm productivity and minimize risk of crop failure.

Crop diversification enables farmers to maximize the use of small pieces of cultivable land and to exploit the variability in soil conditions by mixing crops adaptable to different growth conditions. These practices are described as strategies for increasing food security, saving labor and making most effective use of available land and as an adaptation strategy to the semi-arid, agro-ecological environment.

Cultivation prior to the construction of sand dams was normally in the wet season (rain-fed) where the characteristics of the crop were long season, low potential due to inadequate rainfall and fewer types of crops because of lack of water. As this limited range of crops was produced by most farmers, prices tended to decline at the time of harvest. Some farmers have responded to the availability of water by transforming the planting patterns to intensify on the types described by Rowland (1993), with new complementary patterns: high water demanding crops, high value crops that fetch a good price in the market, and high potential long season and short season crops that are a source of income with production in all four seasons of the years. That this occurred is confirmed by a number of households; the ones that had started to grow new crops were doing so mostly in the dry season. The new crops in this pattern included: vegetables like spinach, onions, kales, tomatoes, spices like coriander, tubers like arrow roots, cereals like irrigated maize, and finally fruit trees.

Figure 2 outlines the range of cropping pattern that become possible with an operational sand dam combined with terracing, ridging and planting selected grasses, shrubs and trees to limit soil erosion. The question to be addressed is the extent of the realization of this potential for a more intensive approach to farming that change cropping patterns, including the introduction of new crops.

Figure 2: Changes in Cropping Patterns Made Possible with Rain Water Harvesting



In the *2005 Survey* the respondents were asked whether they had increased the output of specific crops as a result of the project (see Table 5). For the two staple crops, maize and beans, a minority, ranging from 17 to 33 per cent, reported an increase. The increase was attributed almost exclusively to increased yields from the area planted. It is of interest that communities without water in the sand dam at the time of the survey reported slightly larger increases. It would appear the dam had recharged ground water along the stream beds but did not provide the continued supply of water needed for intensive production of vegetables and tomatoes. Consistent with the results reported for increased intensity of agricultural production the dominant effect was observed for vegetables, and secondarily fruit. Here the increases were significantly higher for communities with water in the dam than for the communities without such water.

Table 5: Changes in Cropping Patterns with the Construction of a Sand Dam
(per cent of households)

Reported Benefit	No water in the dam	Sand dam has water
2005 Survey: new crops introduced, planted more and increased yields		
Maize	33	22
Beans	27	17
Other Legumes	28	29
Vegetables*	19	42
Fruit**	22	35
Non-food cash crops	6	9
2001 Survey: new crops introduced		
Spinach	13	9
Onions*	6	12
Kale	25	29
Vegetables	27	31
Tomatoes	15	21
Fruit	13	5
Other crops	10	11
* Observed differences between households in these two types of communities are statistically significant at 5%; ** significant at 10% level (chi-square).		

In contrast, the households interviewed in the *2001 Survey* were asked whether they had introduced specific crops subsequent to the construction of a sand dam (see Table 5). As they all grew maize and beans, these were not included in the questionnaire. Here vegetables in general, and kale specifically, were listed most often, ranging from 25 to 31 per cent of the households. Only for onions were the increases significantly larger for the households satisfied with their dam versus the households who were unsatisfied. Tomatoes specifically were listed more often than fruit in general. Food crops that could be consumed and sold in the area markets were the primary initial responses to the increased availability of water and time made possible by a sand dam.

The ability of various households using the sand dam water to grow new crops improves on the cropping pattern as outlined above (Kangalawe, 2001). The survey results show significant progress in the relative brief experience with sand dams, although the pursuit of alternative crops, such as these listed here, is being pursued by only a minority of the farmers, ranging from one quarter to one-third. Over the years increased production of maize and beans has not kept pace with the demand to feed a growing population and cases of drought have made the situation much worse. As water is a major constraint, the availability of water in an operational sand dam can cause transformation. The reported increase in yields for these two crops indicates this is occurring, albeit for less than half of the households involved. Many farms are located up the slopes, well back from the stream bed.

6.3 Improved Livestock Production

Livestock keeping in semi-arid areas comprises of breeds that are adapted to these regions. Most people in these areas use them as store of wealth, where they are sold to meet the daily food needs and any other family emergencies. The animals are traditionally kept in free range; if area for grazing is limited they are tethered, enabling the selection of food from a diversified system. Animals kept in this manner include chickens, goats, donkeys and cattle. The donkeys for most families serve as beast of burden, especially for the acquisition of the rare resource (water), as it collected from far distances. Oxen, in the case of cattle, are also a means of transport as well as their use in land preparation as draught animals. Free range grazing has some disadvantages: pests and diseases are more likely to spread among animal and it may destroy soil cover leading to severe soil erosion. Where this occurs soil structure is destroyed causing the environment to be degraded.

The survey evidence on the effect of more reliable water supply, more time available for farm activities and changes in cropping patterns on livestock husbandry practices is limited. Several relevant questions were included in the *2001 Survey* but the number of responses was 15 only. The response rate in the *2005 Survey* was better. Post sand dam construction 32 per cent reported increased income from sale of livestock products. Some respondents also reported their wealth had increased with the purchase of additional livestock: 13 per cent purchased cattle, 26 percent purchased more goats and 19 per cent purchased other livestock.

As an agricultural specialist for the SASOL Foundation project Hilda Manzi observed, as sand dams began to mature, the value of the animals was better maintained as the frequency of watering of the livestock during the dry season increased from every other day to daily and the distance the livestock had to be driven to water was reduced significantly. As a result, animals fetched a better price in the market as they did not look wasted. The reduced distance to water for the animals was partially a product of the area surrounding the sand dam becoming greener, providing more feed nearby during the dry season. This was borne out in the *2001 Survey* where 11 per cent of the respondents reported time spent herding animals declined after the sand dam was constructed relative to time spent before the dam.

In addition it was observed that for some households the number of animals kept was declining. Some farmers now realize the benefits of keeping one or two dairy cows compared to a herd of indigenous animals. These indigenous animals only fetch money when sold for meat and there prices tend to fluctuate and go down with increasing adverse condition of weather.

This change is a product of improved availability of water and the availability of improved feed for them through seeding of grass alongside stream beds and on farm terraces. This combination makes the introduction of dairy breeds feasible. The availability of milk provides an additional source of income for small farmers. Again, as reported in Table 4, the *2001 Survey* provided supporting evidence for improved animal husbandry by listing significant improvements in livestock reproduction rates in communities where sand dams had water.

In a complete farming system animals are essential. Their provision of food for the family and organic matter for crops supports this; without this supplementation would be expensive in the short run and unmanageable in the long run. Small livestock also make a valuable contribution to farming systems and to people's livelihoods if kept in manageable numbers. They are of special value to those who are poor and hence should be part of poverty reduction strategies.

6.4 Increased Farm Income

The traditional approach to farming in Kitui district, where livestock were kept as a store of wealth and crop farming was mostly for the provision of food, has changed. With the introduction of operational sand dams, crop farming is now a major source of income with livestock serve as a cushion in times of emergencies and contributing small amounts to daily household food intake. The potential for these changes is a product of increased water supply and labor time released from fetching water. Given this potential from operational sand dams we hypothesize changes in crop farming and livestock rearing increases household farm income as the supply of farm output available for sale is expanded and the incidence of the adverse effects that food insecurity has on household income is reduced.

As we observe in Table 6, estimated average household incomes are consistently higher in communities with a sand dam than in communities without sand dams.[7] We observe further that

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[7] It is recognized that these differences in average incomes may well be a product, at least in part, to differing attributes among these respective communities other than whether or not they have a sand dam.

communities in which the sand dams did not have water at the time of the survey had higher average incomes than that reported for communities with sand dams that had water. These differences apply for all households and for households in which farming was the primary occupation of the household head. The only explanation for this difference we can provide is the suggestion that the poorer communities made greater effort to assure their dam accumulated a good store of sand. Third, these differences are

Table 6: Estimates of Household Average Annual Incomes (KShs)

Community	All households (*2001 Survey*)	Head of household lists farming as primary occupation (*2001 Survey*)	Crop farming is primary source of household income (*2001 Survey*)	Farm income *(2005 Survey)*
Sand dam with water	33,824	25,137	34,363	57,473
Sand dam, no water	39,136	30,330	29,976	36,809
% of total households		73%	48%	
% of farm households			66%	
No sand dam	28,733	22,257	22,608	
% of total households		78%	57%	
% of farm households			74%	
In the 2001 Survey data was data were coded in income ranges. These are estimates average incomes on the basis of an assumption that the mid-point of each range equals average income for households within that range. Given the source of these averages a comparison of means test was not possible.				

reversed for the 57 per cent of the households where crop farming served as the primary source of income. Finally, between 2001 and 2005 we see a substantial growth in average farm income: 129 per cent for households in communities where the dams had water and 21 per cent for communities where the dams did not have water. This increase in income reflects some inflation during this period, but especially where sand dams mature the observed growth in income is impressive.

The information in Table 7 is consistent with indicators in Table 6 that an operational sand dam has created opportunities for sizable increases in farm income. The responds in the *2005 Survey* were asked whether household income from the sale of selected commodities had increased since the construction of a community sand dam. The "yes" responses range from nine percent of the sample for tree seedlings to 36 per cent for crop production. The increases are significantly higher for vegetables, crop production and fruit in the communities that had water in the dam at the time of the survey. Where less than half of the sample can be seen as grasping the agriculture production potential of a sand dam, this minority experienced increased income of sufficient magnitude to raise the overall average farm income of the communities in the sample. Consistent with these observed changes in farming systems in Kitui district it is vegetables and crop production that primarily boost household income while the contribution of livestock products serves as an equally stabilizing factor in the two types of communities.

Table 7: Proportion of Households Reporting Increased Household Income from Sales as a Result of Constructing a Sand Dam (%): *2005 Survey*

Commodity sold	Unsatisfied households, no water in the dam	Satisfied households, sand dam has water	Total
Vegetables**	8	36	25
Fruit**	5	19	13
Crop production**	22	49	36
Livestock	31	31	31
Tree seedlings	8	11	9

* Observed differences between households in these two types of communities are statistically significant at the 10% level (chi-square).

6.5 Improved Sustainability of Agricultural Production

Soil fertility, like the other factors of production, is important if increased crop production is to be realized. Soil organic matter is regarded as one of the critical elements in a farming system and is important for evaluating soil-management systems and, therefore, agricultural sustainability (Chan and Hulugale, 1999; Savadogo 2000). This makes proper management of organic residues a cornerstone for agricultural sustainability.

The planting of trees in the farms opens up the issue of agro-forestry as a means to replenish the organic material in the soil through the decay of leaves. The soil in this case will not be deficient of the most important minerals that are responsible for proper plant growth and hence production. Trees also protect the soil by acting as a wind break that reduces the exposure to wind erosion. Incorporation of shrubs that increase on the soil nutrients as well as provide feed for the livestock would be an added advantage. Finally, planting of trees enables environmental conservation by reducing the exploitation of natural wood land resources for fuel wood and/or timber (Brouers, 1993). The possibility of increased tree planting is opened up with increased water supply in a dam.

The making of terraces on the farms improves soil fertility as it reduces soil run off that may carry away the top fertile soil, which serves as a host for a range of soil nutrients necessary for plant growth as well as increases the soil's moisture storage capacity. Soil conservation is advanced also with the formation of *misonzo*[8] and the seeding of grass.

Given the benefits of these various activities that can promote soil conservation we hypothesize that the combination of the changes observed in 6.1 to 6.4 above improve the sustainability of agricultural production. We propose to measure evidence of more sustainable agricultural practices on the basis of changes in soil conservation outlined in this sub-section.

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[8] *Misonzo* is a local language word for maize stovers or other harvest remains placed in a straight line in the fields to prevent soil erosion.

Soil conservation in the form of making terraces, tree planting, *misonzo* formation and grass seeding improved significantly subsequent to the construction of a sand dam (see Table 8). Terracing was promoted actively by the Ministry of Agriculture so the existence of terraces in the no dam communities need not be seen as unusual. The direction of causation for both the significantly higher formation of terraces and the seeding of grass in communities where sand dams still had stored water may well be from these activities to the existence of water. Both activities were seen as strategic to limited silting of the dam, allowing sand to accumulate. These activities can be associated with the natural resource training offered during the project implementation as well as the availability of time saved from water chores, as most of these activities take place in the dry season.

Table 8: Estimated Average Number of Terraces Constructed, Trees Planted, Misonzo Set and proportion of households that Seeded Grass for Soil Conservation: *2001 Survey*

Activity	No Dam Communities	Communities with Sand Dams			
		Before Dam	After Dam	No Water	With Water
Terraces Built	3.4	3.2	3.7	3.2	3.8
Trees Planted	6.3	9.6	13.5	15.4	13.1
Misonzoes Set	2.8	3.0	3.5	3.6	3.5
Grass Seeded	31%	55%	62%	57%	64%
The application of a chi-square test to the frequency distributions used to estimate these averages show differences to be statistically significant at the 5% level for all activities: no dam versus sand dam communities, before versus after sand dam construction, and sand dams with water versus those without water at the time of the survey.					

The planting of trees was made possible by the increase in water supply. It is of interest that this occurred in both types of sand dams, independent of whether water was available at the time of the survey. Seedlings could be set when water was available and re-planted at the outset of the rains. Communities with dams were more likely to form *misonzo* prior to dam construction than communities without dams. This difference plus the increased incidence of forming *misonzo* subsequent to dam construction are indicators of interest in soil and water conservation practices within these communities.

The *2005 Survey* provides some related evidence that is fairly consistent with that observed in the earlier survey. Specifically, the *2005 Survey* explored soil and water conservation issues as project outcomes and impacts. Visible examination of the sand dams showed 41 per cent had seeded grass and maintained the grass on one of the stream banks above the sand dam; 12 per cent of the dams had grass on both banks. At the time of the survey only 14 per cent of the households had an operational tree nursery. But, 54 per cent were able to demonstrate they had planted trees on their farms. A majority of the households, 68 per cent, claimed they understood the value of planting trees and seeding grass and were acting on this awareness.

At the impact level the *2005 Survey* explored evidence of an understanding of how resources were inter-related. For soil conservation practices 91 per cent answered in the affirmative. For water harvesting practices it was 79 per cent; for improved farming practices and technology it was 66 per cent. These ratios are higher than what was being observed in practice. It was possible that the drought leading up to the survey may have limited the ability of the respondents to act on their understanding of how resources, especially soil and water, are inter-related.

Where soil erosion occurs, soil quality diminishes and crop production becomes more difficult and expensive as soil fertility and soil depth decline. The reduction in soil thickness reduces the water holding capacity and depth through which root development can occur (Goudie, 1987). Soil erosion and low fertility in agricultural lands are perceived as the greatest threat to soil productivity in dry land Africa (Rocheleau et al., 1988). In extreme cases, yields are so low that land has to be taken out of cultivation because of the undermined productive capacity of the ecosystem resulting from the alteration of water and energy balances and the disruption of nutrient cycles (Lal and Stewart, 1990; Deshmukh, 1986). The surveys that form the basis for this study were able to identify adaptive strategies that have been used by the some farmers in Kitui's semi-arid conditions to sustain agricultural land use without further degradation.

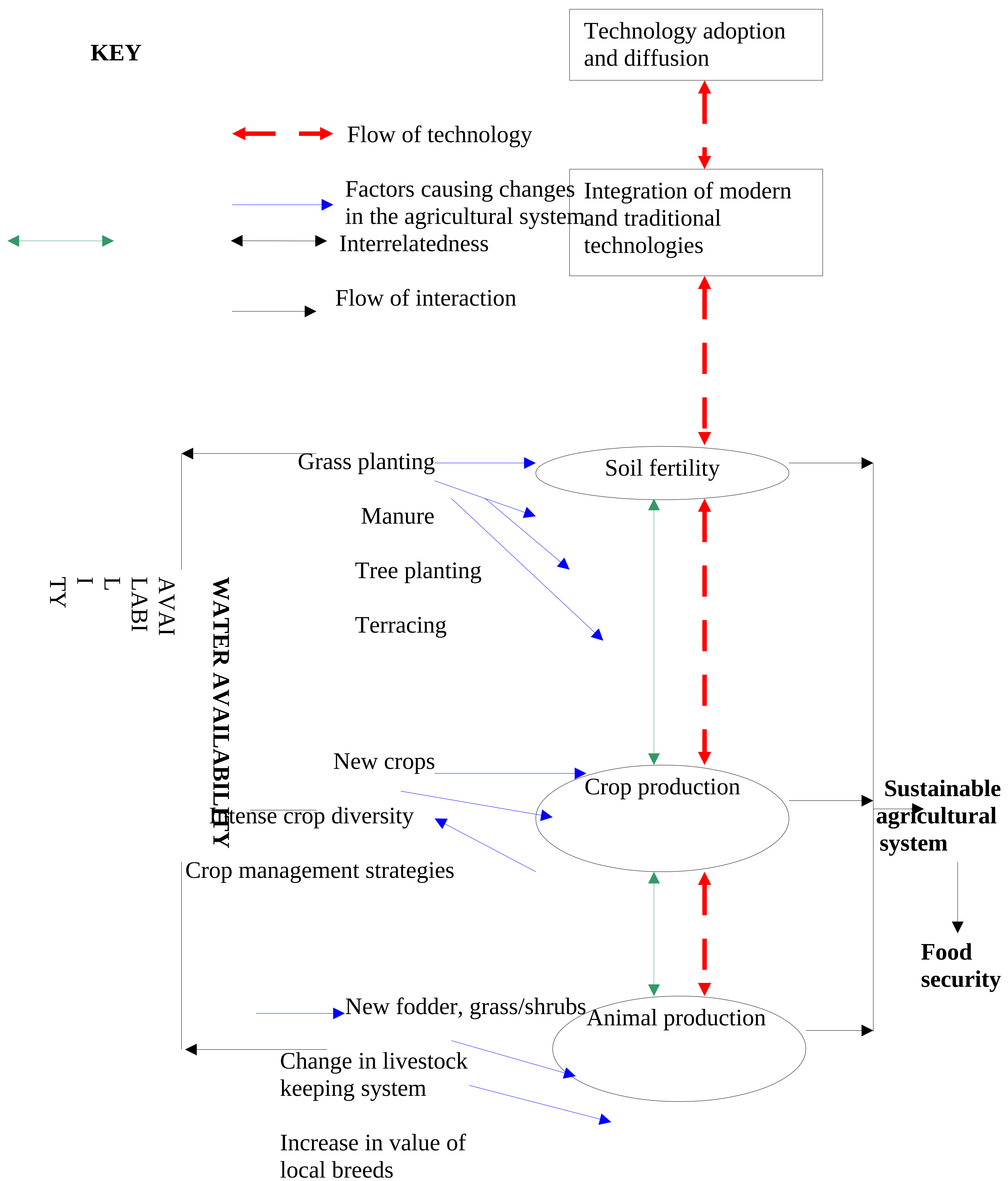
The presence of a changed agricultural system is welcome given its ability to improve food security and improve the environmental. In trying to improve agricultural production there is need to design and manage the agro-ecosystems (see Figure 3), which are both productive and natural resource conserving, and that are also culturally sensitive, socially just and economically viable (Altieri, 1995).

The basic features of sustainable farming systems can be enhanced in the light of new knowledge and new opportunities presented with the construction of sand dams. In the small-farm systems a closer integration of the different components, recycling and optimized use of local resources, can enhance productivity. For example, in a small, integrated farm the livestock component has a central role to play. In addition to providing meat and other animal produce the animals are important for the recycling of residues and wastes, converting these from sources pollution into valuable inputs such as organic fertilizers. The selection of appropriate livestock species is therefore an important consideration in the development of an integrated faming system.

6.6 The Role of Human Factors in Sand Dam Induced Changes in Agriculture

Technology adoption and adaptation is necessary for development. Farming in semi arid areas tends to be left to those who have informal education and those who did not advance beyond primary education; people with additional schooling either move to major towns for employment or are engaged in local employment and business. New technology transfer for farmers with limited or no formal schooling becomes difficult as these people tend to embrace what seems traditional or is easily adapted.

Figure 3: Promoting Sustainability in a Changing Agricultural System



The presence of both traditional and modern technologies provides opportunities for innovations that are more likely to be adopted and to prove sustainable. Farmers have a better understanding of the traditional technologies that exist within the community; extension officers and the various organizations are better placed to implement modern technology. The ideal is an intertwining of the two to conceive technologies that are easy to adopt or to adapt.

Construction of a sand dam indicates a willingness to adopt new technology. Complementary action, to enable a sand dam to mature so that substantial quantities of water are stored, represents another set of technologies that were embraced more effectively in some communities than in others. Additional water supply in the proximity of a community represents a new resource for area farmers. Whether the existence of this additional resource translates into higher farm income and greater food security depends on the willingness and ability of farmers to be innovative. Training related to such innovation was provided leading up to and during the construction of the sand dam. In communities where the farmers either were unable or unwilling to accept the training provided the resource of additional water near at hand was underutilized with limited changes in agricultural production.

Within the respective sand dam communities human factors were observed that made possible the innovation of a sand dam. Differences in human factors explain, at least in part, why some communities made further innovations to enable their dams to mature with accumulated sand while other communities failed to innovate in the same way. Here we hypothesis that there is a connection from the human factors that adopted the innovation of an operational sand dam and changes in agricultural practices that generated higher farm income and contributed to greater food security. We seek to establish this connection by analyzing the data in the *2001 Survey* on the role of schooling in this process of innovation at the farm level (see Table 9).[9]

[9] The *2005 Survey* did not include an education measure for the head of the household so comparable analysis cannot be carried out on the basis of that survey.

Table 9: Interaction Between the Head of a Household's Schooling and Indicators of Farm Level Innovations Made Possible by a Sand Dam: *2001 Survey*

	Schooling attained by household head		
	informal	primary	post primary
Proportion of households with water in dam (%)*	76	78	89
Average annual household income (KShs)*	33,468	32,001	51,568
Average annual farm income (KShs)*	33,118	27,646	23,074
Soil conservation – built terraces (%)	72	67	70
Soil conservation – planted trees (%)	55	58	57
Soil conservation – misonzo (%)*	58	60	40
Soil conservation – seeded grass (%)	53	54	62
Vegetable growing after dam construction (%)	91	91	94
Land productivity increased with sand dam (%)	65	75	
Land values increased after dam construction (%)*	38	83	82
Now more able to pay school fees (%)	63	21	
TOTAL – sand dam communities (%)	33	51	16
TOTAL – no dam communities (%)	20	58	22

* These observed differences among educational groups, relative to the numbers answering no, are statistically significant at the 5% level. The distributions of the two total rows also are significant at the 5% level (chi-square).

Comparing the two total rows at the bottom of Table 9 we observe there is a significant difference in the schooling attributes of the communities that constructed sands versus the ones without a dam. Specifically, there is an inverse relationship between schooling and adopting the innovation of a sand dam. Given that a sand dam has been built, we observe in the first row of Table 9 that there is a significant, direct relationship between schooling and a sand dam maturing into an operational form. It would appear education was a factor in absorbing training provided as part of the project.

As might be expected, household income is correlated positively with schooling. But, the opposite holds for farm income. Households headed by persons who lack formal schooling depend almost exclusively on farm income. This provides them with a vested interest to take advantage as farmers of the benefits to be derived from innovation based on the additional water available. This is borne out in the four rows in Table 9 that report on soil conservation activities. Differences among educational groups are not significant except for setting of *misonzo*. As this primarily requires labor, not financial investment, farmers with more income and more non-farm earning opportunities lag behind.

The primary agricultural change observed was the growing and sale of vegetables. Again, differences among educational groups are not significant. For the two groups reporting, land productivity was positively, but not significantly, correlated with schooling. Land values increasing, in contrast, were clearly correlated with schooling. This may well reflect a greater ability by the farmers with more schooling to purchase and utilize new machinery, seed varieties and fertilizer. It is of interest that it is the households in which the heads did not have formal schooling that reported they now had a greater ability to pay school fees. This is an impact of sand dams that holds promise for the future.

The adoption of sustainable development strategies ensures that the socio-economic benefits of technological innovation are maximized while the wider risks are minimized. The benefits acquired from a sand dam were felt primarily by the farmers who depended on farm income and secondarily by the farmers with a capacity to utilize an available resource. This capacity was derived from the integration of both traditional and modern technologies. There is some evidence that the level of schooling facilitates adopting and adapting more of the modern technologies. The capacity to utilize imported technology appears to depend on the existence of indigenous technological capacity combined with new learning strategies put in place.

7 Enhancing Changes in Agriculture with Improved Water Harvesting

A conclusion to be derived from this study is that community participation in the construction of a dam is an indicator of a willingness to innovate. The technology involved was a variation on traditional knowledge and practice – during the dry season drawing water from scoop holes in the sand of stream beds – and could be adapted for use independent of the schooling achieved by the participants.

Community action to assure sand dams mature is not to be taken for granted. It is complex in that it requires joint action by community members as well as specific innovations. The greatest promise of additional water as a resource was observed in communities where soil and water conservation innovations were implemented. These included such water harvesting technologies as building terraces, planting trees, seeding grass and setting *misonzo*. The economic benefits from agricultural changes were observed in the expanded cultivation of vegetables and fruit, increased yields in staple foods and diversification of crops more generally, and changes in livestock rearing.

In the relatively short time that sand dams have been operational there is strong evidence – even though it is still limited to a minority of the households – that sand dams serve to increase rural incomes and enhance food security within these communities. Building for the future would suggest relatively more emphasis be placed on learning strategies during and post dam construction. This would include more attention to the complementary activity required for a dam to mature as well as extending the range of new agricultural technologies to be absorbed. More importantly, it should expand the proportion of the farmers in these communities who become caught up in building on the potential of accessible water in an operational sand dam.

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