Adoption Driver and Constraints of Resource Conservation Technologies in sub-Saharan Africa

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Most economies in sub-Saharan Africa (SSA) are agriculture-based and about two-thirds of Africans depend on agriculture for their livelihoods. Most farmers are smallholders with an average farm size of between 0.5 to 2 ha, and many earn less than US$1/ day. Depending on the agro-ecological zone, African soils can have a fragile fertility based on low amounts of organic matter due to low and/or erratic rainfall and related constrained biomass production. While shifting cultivation and extensification is still an option for many smallholders, population density reduces in other areas fallow periods leading to low fertility regeneration and soil degradation where farmers' are increasingly under pressure to intensify land use. Depending on the tenure period and arrangement, farmers might also be under pressure to conserve their land. However, both, intensification and conservation might not be easy to combine, as farmers operate under a variety of constraints related to capital and labour, availability or accessibility of inputs, lack of knowledge etc. Especially conservation measures often reduce short-term profits, as they require extra labour, land or capital. Thus technology uptake is often discouraging from the conservation point of view, while farmers have to find a compromise between their different objectives, possibilities and constraints.

Since decades, research has tried to assist farmers and it is often said that there is a huge body of technological information and the technical know how are "in the shelves" of the National Agricultural Research Systems (NARS), supported among others by the FAO and the centers of the Consultative Group on International Agricultural Research (CGIAR) and other institutions. Many of these technologies were sufficiently tested in research stations but found limited adoption in farm communities. Also the shift in the nineties to more on-farm research did not result in the envisaged break-throughs. Scientists tend to blame poor research-extension linkages, but it appeared that still today scientists (especially soil & water conservationists) have lagged behind in analyzing how farmers' socio-economic conditions and perceptions of technology characteristics affect their adoption decisions.

The Regional Office for Africa of the UN Food and Agriculture Organization (FAO), the International Water Management Institute (IWMI), and the Institute for Geography, Humboldt University, Berlin, Germany, organized in August, 2004 an international expert consultation. This was supported by the German Volkswagen (VW) Foundation. The aim was to get a state-of-the-art understanding of the adoption constraints and drivers of farm and rangeland restoration and conservation methods. Specialists in soil and water conservation, rainwater harvesting and rangeland restoration from West, East and Southern Africa discussed in various working groups a large number of the so called "best practices" with respect to their adoption potential and limitations, advantages and disadvantages. While the experts acknowledged that there are many manuals on the theoretical advantages of these technologies, their site requirements as well as some success stories of adoption, there are hardly any published reports on adoption failures and lessons learnt. The participants stressed therefore the need for more information on experiences with these "best practices" in view of their potential biophysical and socio-economic bottlenecks, which could affect adoption, or crucial adoptions drivers in need of attention and support. This discussion led to a first set of **Technology information sheets**, which assume that the reader knows about the technologies in general, but s/he is looking for further decision support on the selection of an appropriate technology in his/her own biophysical and socio-economic environment. The best overview on technical aspects of soil and water conservation technologies including rainwater harvesting can be found in the WOCAT database [http://www.fao.org/ag/agl/agll/wocat/wocatqt.asp]. Our data should be considered as complementary with more emphasis on adoption drivers and constraints. *All sheets are still drafts and we welcome any suggestions for improvements as well as additional sheets*[1].

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CONTEXT AND ISSUES

Traditional agricultural systems in SSA are characterized by slash-and-burn (or shifting cultivation) wherein farmers use bush fallow and indigenous means to restore soil fertility. With increasing population, the pressure on agriculture to provide food and livelihoods is equally increasing. Each region in SSA has its own related challenges: While in the densely populated East African Highlands, farm sizes are often too small to make a living, farmers in the Sahel have larger areas but face food shortage attributed to drought and very poor soil conditions (Fig. 1). In these drier areas of SSA, erratic rainfall events and frequent long dry periods have created uncertainty for rainfed agricultural producers and livestock owners.

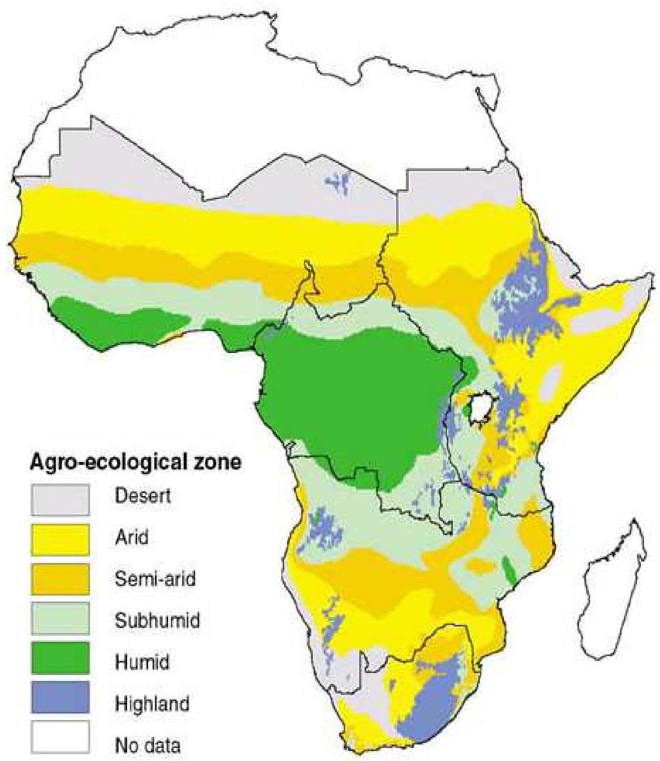

Fig 1. Agro-ecological zones of SSA (Source FAO/IIASA, 2000)

Given the ever growing population also in arid and semi-arid regions of SSA, and the decreasing possibilities to increase or change the cultivated area, standard recommendations across Africa's savannahs are to make the best use of rainwater and to maintain the productivity of the land. Emphasis has been put on the following strategies:

1. Conserving rainfall water in the rooting zone of crops (rainwater harvesting),
2. Managing the field to use water more efficiently (soil & water conservation),
3. Regeneration of the rangeland potential (rangeland restoration)

ORIGIN OF PRACTICES

Rainwater harvesting (RWH), Soil Water Conservation (SWC) and Rangeland management have been promoted and used in many regions of the continent. Much of the progress in rainfed agriculture in countries such as Burkina Faso, Niger, Tanzania, etc. is due to local adaptive research and innovative dialogue which have allowed traditional and introduced techniques to be adapted to local conditions. Often, the efficiency of traditional practices for land rehabilitation and conservation was increased not by introducing completely different ones, but by identifying those elements, which could be improved in the local context (Thiombiano, 2004a).

Table 1 tries to categorize common practices according to their origin

- **Traditional practices:** As strongly mentioned by FAO (2004) in the Global Ingenious Agricultural Heritages Systems (GIAHS) program, producers and rural communities have strong knowledge of their environment and how to manage it according to their tradition and objectives;
- **Exogenous practices:** Practices mainly introduced through national and international agricultural research institutions, NGOs and individual initiatives. These techniques are sometimes well integrated or even modified according to users needs, but sometimes this is not the case;
- **Improved practices** that could be originating both from traditional and exogenous practices as results of research activities or intensive modification by land users.

It is quite obvious that the nature of practices used to conserve or restore farm- and rangelands is a function of the biophysical, cultural and socio-economical aspects in a given environment. However, the three categories of practices may have a different philosophical background. While traditional practices can see soils as a good to be exploited, the exogenous and improved practices might emphasize values of the larger society in nature conservation. From the total number of practices reported in the reviewed literature (Table 1), 75% were developed locally (Thiombiano, 2004a).

Table 1. Best practices for farmlands restoration and conservation in West Africa

Practices	Indigenous	Introduced	Improved
1. Stone rows	+++		
2. Grass strips	+++		
3. Weed strips	+++		
4. Mulching	+++		+++
5. Zai/Guendo/Tassa	+++		
6. Branch rows/patterns	+++		++
7. Conservation tillage	+	+++	+++
8. Alleys cropping		+++	+++
9. Earth bunds	++	++	+++
10. Permeable dams		+++	+++
11. Hedgerow barriers	+++		+++
12. Composting	+	+++	+++
13. Mineral fertilization		+++	+++
14. Integrated soil fertility management	++	+++	+++
15. Shelterbelts		+++	+++
16. Agroforestry	++	++	++
17. Deep ploughing with Treno Plough		+++	+++
18. Erecting live dunes fences		+++	+++
19. Cover plants (conservation agriculture)	+++	++	+++
20. Mixed cropping	+++		+
21. Fallow	+++		++
22. Construction of catchment channel		+++	++
23. Erosion control reservoirs	++	+++	++
24. Half-moon micro-catchment		+++	++
25. Trench		+++	++
26. Polders (Lake Chad)	+++		
27. Crop rotation	+++		+++
28. Organic manure fertilization	+++		+++
29. Banquettes isohypses *cloisonnées*	+++		++
30. Oukine (wetland management)	+++		+
31. Anti-salt dams	+++		
32. Terracing system	+++		++

Sources: Thiombiano (2004a)

SPREAD OF SOIL WATER CONSERVATION, RAIN WATER HARVESTING AND RANGELAND RESTORATION TECHNOLOGIES

Many of these technologies "in the shelves" have been developed and verified in farmers' fields in different countries. In Tables 2 to 4 an attempt was made to group some technologies according to their spread as reported in the Expert Consultation. The tables showed that there are still many opportunities for information sharing to reach more countries.

Table 2: Geographical Distribution of Selected SWC Technologies

SWC Systems	**Occurrence (examples)**
Stone bunds / stone rows	West Africa
Matuta, Ngoro pits; Konso-bench, Fodder legumes, Bag garden, Cover crops, Caag, Gawan	East Africa
Portulacaria afra cuttings, Intercropping with animal traction, Tulongeni (project)	South Africa
Meskat, Jessour	Northern Africa
Life fences, Improved fallow, Flood diversion, Ridges	West and East Africa
No till farming; Green manure, Mulch, Phosphate rocks	West, East and Southern Africa
Enarenado, Catalonian terracing	Canary Islands, Spain
Negarim; Ecological restructuring, Delving	Other regions

Table 3: Geographical Distribution of Selected RWH Technologies

RWH Systems	**Occurrence (examples)**
Stone rows	West Africa
Sand storage dam; Conservation Tillage, Fanya juu, Chololo pits, Tera; Haffirs	East Africa
Vallerani system	West and Northern Africa
Demi-Lune/ half moon, Earthen dams; Road-run-off	West and East Africa
Fanya chini	Eastern and Southern Africa
Zai/Tassa (micro-catchments)	East, West and North Africa

Table 4: Geographical Distribution of Selected Rangeland Restoration Technologies

Rangeland Restoration Systems	**Occurrence (examples)**
Dry-season vs. wet-season movements	West and Central Africa
Community resource management	West Africa
Replanting and Re-seeding	West Africa

Debushing & patch creation, Re-seeding and cultivation; Controlling *Rhigozm trichotomum;* Organic blocks	South Africa
Tumbukiza pits	East Africa
Vallerani plough	West and North Africa
Revitec®	Spain

ADOPTION CONSTRAINTS AND DRIVERS

Each technology requires particular biophysical conditions (e.g. slope, soil texture) which are in general well described in common manuals and relatively easy to verify. The situation is more complex from the social, cultural and economic perspectives. Thus, often the bio-physical requirements are less limiting for technology dissemination than socio-economic factors. In general, adoption of resource conservation technologies is a function of the characteristics of the technology proposed, farmers' perception of its advantages and need, as well as availability and distribution of production factors (i.e. land, labour/time, capital, knowledge, skills, etc). Other factors are farmers' attitude towards experiments and risk, institutional support/knowledge sharing and the policy environment. Participatory research, starting from the discussion of possible technologies to joint trial monitoring and evaluation will help to assess the importance of the individual adoption factors for the farmer under his/her specific conditions. Some of these factors are briefly discussed below:

a) Returns to Land, Capital and Labour

Generally, the major objective of farmers' is to maximize returns on investment and particularly for those production factors, which are in short supply but are required by the (new) technology. An example is illustrated in Table 5 where rainwater harvesting (RWH) increased sales by 65 %, however, this was based on a 50 % increase in family labour input with only a 10 % higher return on the invested time than without the new technology. Therefore, the choice of the appropriate criteria for the technology adoption analysis should be determined by:

1. The production factor requirements of the technology;
2. The relative availability of these production factors in the farm economy of the target group.

It is crucial to base this analysis on local conditions and farmers' seasonal perspectives of "factor scarcity". Especially the returns to labour (gross margins per hour or man-day), in addition to returns to land (gross margins per hectare) are a critical but often neglected variable to understand farmers' reasoning.

Table 5: Labour productivity in sorghum fields 1993-1994 (Bam Province Burkina Faso)

	Yield Kg/ha	Total Sale (return to land) *FCFA/ha	Labour required Hours	Labour productivity (return to labour) FCFA/day
Family fields				
With RWH	547	30,060	1101	220
Without RWH	330	18,150	713	200

Source: Modified after Kunze, 2001; *1US$ = 500 FCFA

But even where the financial incentives may appear attractive, a consideration of non-financial factors is required to understand the actual and potential adoption of conservation technologies. A number of studies have sought to identify barriers to adoption beyond the obvious divergence between on-farm costs and wider social benefits (FAO, 2001a). Examples are:

- Large investment costs may discourage adoption.
- The perceived risk of adopting the technologies may serve as a barrier.
- Long gestation periods for the benefits to materialize.
- Barriers may be particular to culture and recent history.

These and other factors will be briefly described in the following sections. Table 6 highlights some shortcomings or advantages of individual technologies that may not be apparent in a financial analysis alone.

Table 6: Selected factors influencing the attractiveness of conservation agriculture practices at the farm level in West Africa (FAO, 2001a)

Soil management techniques	Financial Attractiveness (net returns)	Initial effect on yield	Incremental investment	Incremental labour required
Conservation agriculture				
Mulching	++	+	+	-,+
Ridging	-,++	+	+	--,+
Strip cropping	-,++	-,+	+	+
Alley cropping	-	-	-	--,-

Woody fallow	+,++	+	--,-	--,+
Vegetative and structural				
Vetiver grass lines	-,+	-	--,-	-,++
Fanya Juu bunds	-	-	+	++
Stone faced terraces	-	+	+	-
Tree shelter belts	-	-	--	+,++

Note: the table uses a +/- scale with four possible ranging from **- -** to + +, with the latter the most preferred score.

b) Capital and Credit Availability

Farmers' may be unable to raise sufficient funds to invest in the technology (because of lack of capital, limited access to credit, or temporary cash flow problems). This also concerns funds to pay extra labour when the technology requires activities during peak-periods of normal fieldwork. National policies, which support smallholder credits, can be an important adoption driver to overcome wealth constraints to investment in new technologies. Informal savings and credit groups at community level have long proved to be worthy and effective. They may even enhance opportunities for collective action in natural resource management. The level of investment required should be an important criterion for SWC development, since it impacts much on adoption.

c) Labour Peaks and Opportunity Costs

Although the lack of fertile land can be the prime constraint to technological adoption, such as in the case of planted fallows in densely populated Rwanda, labour is still considered a major constraint especially to "low external input" technologies. Consequently, it is very important to take into consideration all of the changes in labour implied by any suggested technology. Labour availability and labour bottlenecks are two of the most important types of diagnostic information that aid in selecting appropriate technologies and in defining target groups with high adoption potential. If labour is scarce at particular peaks, extreme caution must be used in experimenting with technologies that further increase the labour demand at that time. As many roles and tasks are for cultural reasons gender-specific, any labour analysis has to be gender sensitive.

Annual migration patterns of youths from rural areas to urban centres have reduced in many regions seasonal farm labour availability emphasizing the temporal importance of labour productivity. A case study of an estimate of labour required for construction and maintenance of rock bunds is presented in Table 7. The data showed that in each case significant labour input is required but also that different technologies can have very different requirements. Maintenance, on the other hand, requires little input. Consequently, the set-up of such "best practices" is a luxury for families who are short of labour unless they can pay for additional (hopefully available) help, or can use the services of the local community.

Table 7: Labour input for construction and maintenance of rock bunds in 1993

Activity	Type of construction	Labour input (person-day/ha)
Construction	Rock bunds	97
	Stone dikes	183
	Stone dams	279
Maintenance	All types	1.7

Source: Kunze, 2000

Often it is mistakenly assumed that farmers' (family) own labour input is an unrestricted (free) resource. However, the amount of farm work a self-employed person is willing to do depends on a range of factors. These include the potential gain of doing extra work, other (on- or off-farm) job opportunities and his/her own motivation and personal need for regeneration or social time. Negligence of these "opportunity costs" results often in wrong adoption assessments. Labour opportunity costs reflect the potential return to labour, which could have been received if the labour had been used for a realistically existing alternative. For example, if a family member needs a day for repair of a stone line, the family is going without the money the person could have earned in town in this period.

d) Land Tenure and Time Horizon

Evidence from many parts of the world suggests that lack of control over resources is one of the major reasons for the degradation of natural resources.

In open access rangelands, the "tragedy of the commons" paradigm holds that an individual behaving in his own self-interest will continue to exploit a common resource, even when it is being overused and degraded because the benefits from such behavior accrues to him alone, while the constraints are divided among members of the community as a whole (Hardin, 1968; Pamo and Pamo, 1991). Thus, the resource base is ultimately doomed to destruction (Tedonkeng and Pieper, 2000). This paradigm seems to have been over-simplified and fails to consider a number of alternative incentives to individual behavior. However, “tragedy of the commons” abounds, as witnessed by degraded conditions of many rangelands under free and open assess system in sub-Saharan Africa and elsewhere in the world.

Certain technologies such as SWC or rangeland restoration are inherently long-term, requiring security of tenure over land for an extended period of time. Many farmers are resource-poor and may lack land security, thus, are unable to invest in such technologies. But even where tenure security is given, benefits might only accrue after some years. This might be the reason while studies of the privatization of land have not shown that this will automatically lead to increased investment and more sustainable practices (FAO, 2001). To facilitate in such cases any adoption of SWC measures short-term benefits or incentives are required, even if they compromise the long-term effects (Steiner and Drechsel, 1998).

e) Perceptions and Values

Farmer’s individual perception of the degree of a given problem may influence his/her decision on possible solutions. The same applies to farmers’ preferences for certain technology based on real experience or perceived characteristics (see h) below). There are also certain taboos, cultural norms or practices in various socio-cultural settings in Africa that can influence farmers’ perceptions and technology adoption. Indigenous knowledge and local traditional practices may be considered part of this social and cultural framework. For example, under customary land practices in many SSA countries especially in the Sahel region of West Africa, women do not have title right to land (i.e. they are not land owners), but are widely involved in RWH and SWC activities. Another example is the matrilineal inheritance pattern in West Africa, where a son has little incentive to invest in his father’s farm. Generally, land access and usage depends on the socio-economic conditions of each social group. This also includes the policy environment and related incentives. Where the community supports land regeneration or the society might have resources to safeguard “ecology” or “nature” this may influence the values in the communities and steer the adoption of technologies, even if other adoption factors are less favourable.

f) Risk and Stability

Farm enterprises are among those systems where disturbances are frequent. Yield fluctuations may occur due to erratic rainfall, floods, insect attacks and diseases etc. To the extent the farmer succeeds in minimizing such risks and uncertainties, he succeeds in maintaining his returns.

Common examples of risk management are large herds of livestock, or the use of mixed (local) crop varieties instead of a promoted one. Risks and uncertainties affect the farmers' attitude towards innovations and their adoption behaviour and have to be analysed in a participatory way. Especially low-wealth farmers are often reluctant to adopt technologies because they need stable income especially when returns to adoption are unclear or will only bear fruits in future. An example for an innovation related risk is the introduction of a soil protecting green manure as a (partial) substitute for cowpea or groundnut in the minor rainy season (e.g. Rwanda). This might reduce the availability of protein rich food for the family, seeds for the next season and also effect the gender specific distribution of income. All can cause instability at different levels and may result in non-adoption of technologies.

Also interventions actually aiming at risk reduction might be counter-productive to conservation measures, like improved livestock health programs or additional boreholes for stock water.

g) Access to Information and Extension Services

Poor performance of extension services or poor research-extension linkages are often blamed for limited spread of technologies. This is in many cases wrong as real winners often spread without much effort through informal communication networks. However, to start this process at least some farmers have to experience the advantages of the technology (e.g. through on-farm trials or demonstration plots). Knowledge sharing about the technology could then be facilitated through communication infrastructure, media access and a functional network of continuously updated extension agents. Additional access to market information will be beneficial as it increases the chances for better pricing of farm produce and higher capital availability.

h) Perceived Attributes of an Innovation

To understand farmers' perceptions of a technology, a number of attributes of such technology should be analyzed. These are:

- Comparative advantage (not only higher yields, but also better soils, taste etc.)
- Compatibility with previous and current farming methods
- Complexity (how simple or difficult is the technology?)
- Triability (can the technology be tested?)
- Visibility (is the impact obvious and convincing?)
- Trouble-free (are there any (cultural, gender, technical, etc.) difficulties?)

An important question is how much yield increase is required for farmers to adopt a given technology. According to Baum et al. (1999), the *net benefit* should usually be between 50 and 100 %, which corresponds to a Benefit-Cost ratio of 1.5 - 2. If the technology is new to the farmer and requires that they learn some new skills, a minimum rate of return near to 100 % is a reasonable estimate to assume adoption. And if the technology simply modifies a current farmer practice (such as a higher/lower fertilizer rate), then a minimum rate of return as low as 50 % may be acceptable. A new technology with a rate of return below 50 % is unlikely to be accepted.

i) Policy Support

The preceding analysis of the financial and other factors associated with the adoption of conservation technologies and related practices has already captured many opportunities how policies could support adoption. Governments can use macro-economic policy, trade regulations, input subsidies, regulations or education and extension to alter the decision-making environment in which farmers choose one practice over another. However, many programmes promoting conservation have been relatively ineffective because of contradictory signals and incentives from other policies or subsidy programmes. For example, policies designed to promote sustainable agriculture can be undermined by other, typically richer, policy measures in support of highly erosive cash crops or by weak or slow-to-respond research and extension efforts (FAO, 2001).

TECHNOLOGY INFORMATION SHEETS

The initially mentioned international expert consultation led by FAO, IWMI and the Humboldt University of Berlin resulted in a number of **Technology Information Sheets,** which are presented on this web site. The sheets are supposed to summarize information on dissemination experiences with these technologies. **All sheets are still drafts and require further input** from the scientific community, NGOs etc. **Readers are also encouraged to add further sheets**. Some general characteristics of the so far compiled technologies are presented in Figs. 2 to 4 below.

Among the different adoption drivers and constraints captured, the major bottleneck for the adoption of SWC technologies appears their need for labour (Fig. 2). Only 40 % had relatively low labour requirements, about 60 % require secured land tenure and 30 % a larger capital input. Although all technologies claim yield improvements, the time frame for this to happen does vary significantly. In a previous expert consultation organized by FAO in 1995, land tenure security was identified as the most challenging constraint to the adoption of SWC technologies (Bationo and Lompo, 1999).

Only 10 to 20 % of the captured RWH technologies can claim low labour or capital requirements. Secured land tenure is essential for the uptake of 50 % of these technologies (Fig 3). This applies even more for the long time frame of rangeland regeneration. Due to the size of the areas concerned most rangeland restoration technologies are also capital intensive (Fig 4).

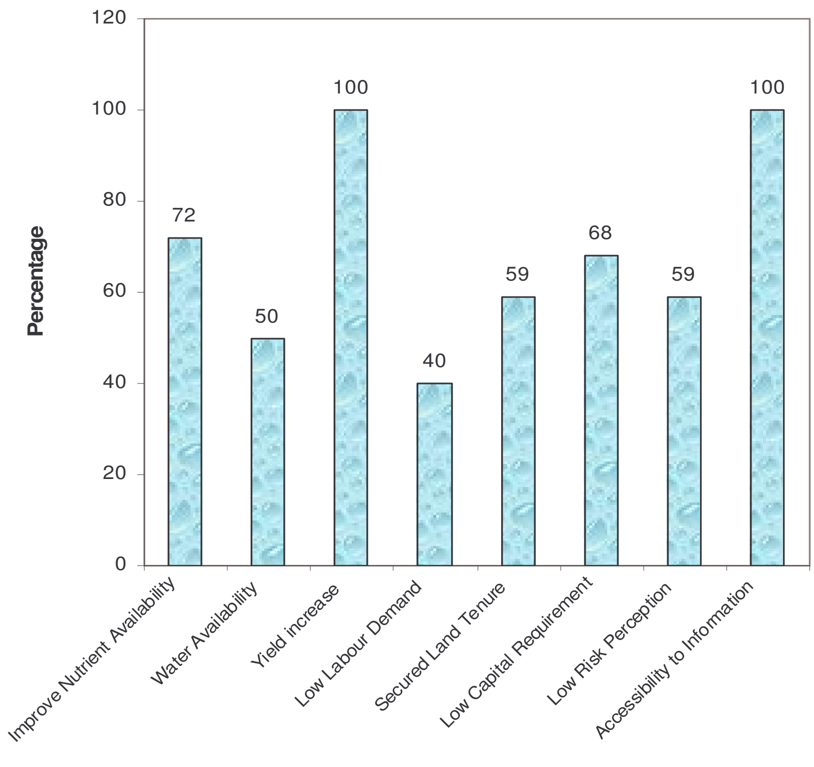

Fig 2. Adoption Drivers for Soil Water Conservation Technologies

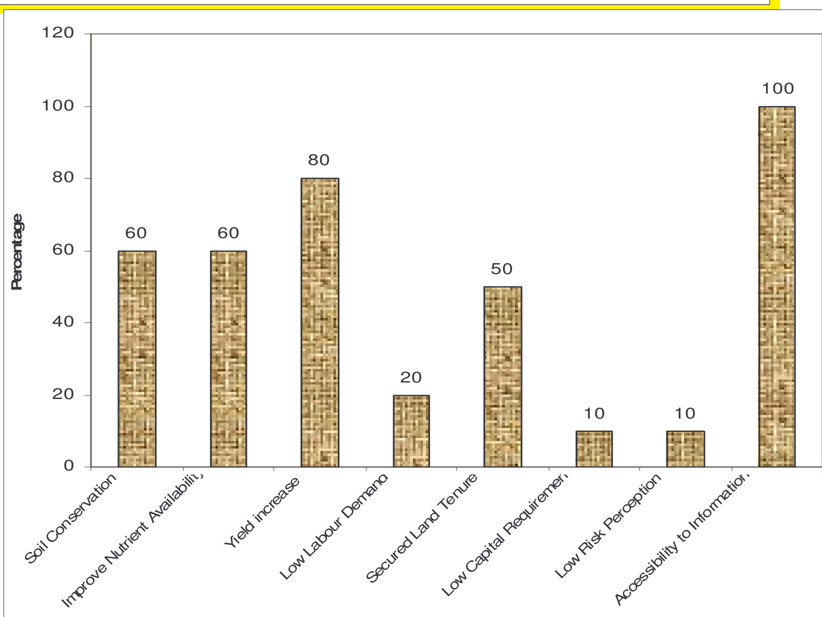

Fig 3: Adoption Drivers for Rain Water Harvesting Technologies

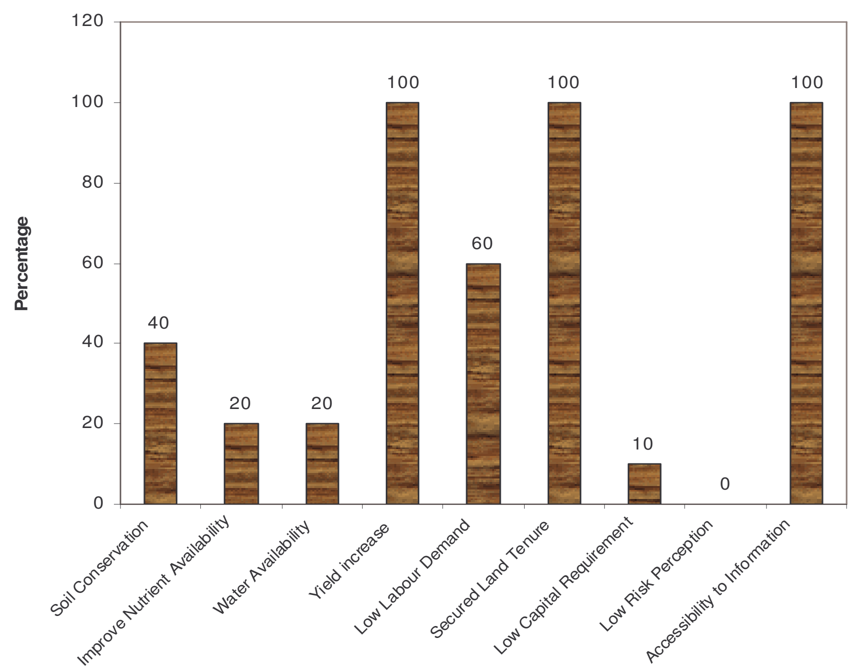

Fig 4: Adoption Drivers for Range Land Technologies

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