FOOD SECURITY RESEARCH PROJECT

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WORKING PAPER No. 9
FOOD SECURITY RESEARCH PROJECT
LUSAKA, ZAMBIA
February 2004

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FSRP Working Paper No. 9

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ACKNOWLEDGMENTS

The Food Security Research Project is a collaboration between the Agricultural Consultative Forum (ACF), the Ministry of Agriculture, Food and Fisheries (MAFF), and Michigan State University's Department of Agricultural Economics (MSU).

We wish to acknowledge the financial and substantive support of the United States Agency for International Development (USAID) in Lusaka. Research support from the Global Bureau, Office Agriculture and Food Security, and the Africa Bureau, Office of Sustainable Development at USAID/Washington also made it possible for MSU researchers to contribute to this work.

An earlier version of this paper was solicited by the African Conservation Tillage Network and presented at the Second World Congress on Conservation Agriculture in Iguassu Falls, Parana, Brazil, in August 2003.

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ABSTRACT

Soils in Sub-Saharan Africa are showing signs of the increasing stress that population and livestock pressure bring. Most farmers use no external inputs, yet, with increasing land scarcity, there is reduced time for fallows to boost soil fertility and quality. Modern production systems, imported and often subsidized, include mechanical tillage and inorganic inputs in mono-cropping regimes, as with maize in eastern Africa. When these practices (either low input or high input) are combined with drought and periodically heavy rainfall, the result is declining ability of the soil to sustain agricultural production and gradual degradation of soil quality. Farmers and agencies working to improve farm productivity have experimented with a broad range of soil and water conservation technologies. While these technologies typically do succeed in increasing output, they do so at a cost, often of increased labor use. Thus, assessment of their attractiveness requires a detailed case-by-case comparison of changes in output and input costs and benefits. Several studies have been conducted to determine the impact and implementation strategies for these technologies. However, almost all such studies in Sub-Saharan Africa are fragmented, often country specific. After reviewing common responses in key agro-ecological regions, this paper examines the farmer's financial incentives for adoption in selected cases in Sub-Saharan Africa. The authors found a paucity of economic analysis in Sub-Saharan Africa, yet there are initial indications that some farmers will find these technologies profitable and will likely adopt.

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1. INTRODUCTION

With annual population growth rates between 2.6% and 2.9% (World Bank, 2001), Sub-Saharan Africa countries face increasing demographic pressure on soils, water and forests, the natural resource base. Deforestation claims 2.9 million hectares per year, shrinking forest cover by about 0.5% per year as steadily expanding population seeks more firewood and more farmland. However the growth in farmland has not kept up with population growth. Consequently, cultivated land per capita has fallen by 40% since 1965, from 0.5 to about 0.3 ha per person (Cleaver and Schreibner, 1994). With a high percentage of the population engaged in agriculture, the shrinking per capita land base needs to be accompanied by increased productivity of land to avoid increasing poverty in rural areas. This is generally not the case in Sub-Saharan Africa in recent years (Rosegrant et al., 2001).

Productivity gains continue to be constrained by a longer term declining trend in soil fertility as soils are mined of nutrients. Some estimates suggest that half of all farmland and 80% of Africa’s pasture land show signs of serious erosion and soil degradation (Cleaver and Schreibner, 1994). Nutrient balances over the past 30 years suggest that Africa has sustained annual net losses of nitrogen, phosphorus and potassium in the order of 22 kg, 2.5 kg and 15 kg respectively (Smaling, 1998). Failure to replenish soil fertility – from organic or inorganic sources – leads to unsustainable output and incomes in agriculture. The resulting soil mining can account for 33% to as high as 80% of farm income in some locations (Raymond, 1992; Van der Pol, 1992; De Jager et al., 2001). Old systems of replenishment via shifting cultivation and long-term fallows break down as population pressure reduces the interval between fallows as well as their duration.

Although several studies have been conducted to determine the viability of conservation agriculture in Sub-Saharan Africa, almost all such studies are fragmented – often country specific – and with undue emphasis on output effects. However, assessment of the attractiveness of these technologies in Sub-Saharan Africa requires a detailed case-by-case comparison of changes in output and input costs and benefits. This paper reviews a set of responses known collectively as “conservation” or “sustainable” agriculture. Though definitions vary, these technologies typically involve agricultural management practices that prevent degradation of soil and water resources and thereby permit sustainable farm productivity without environmental degradation (Wysocki, 1990; ECAF, 2002).

2. SOIL AND WATER CONSERVATION STRATEGIES

Farmers, researchers, agribusiness firms, governments and non-governmental organizations (NGOs) interested in African agriculture have experimented with a wide range of resource-friendly technologies that aim to conserve and rejuvenate Africa's increasingly depleted natural resource base. These responses to growing resource constraints typically focus on two key limiting natural resources – soil fertility and water. Focusing on these two dimensions, Scoones, Reij and Toulmin (2001) provide a useful typology for categorizing the wide array of practices adopted in the name of conservation agriculture (Figure 1).

Figure 1 Strategies for Soil and Water Conservation

Water availability

Soil fertility	**Low**	**High**
High	**(W)** Water harvesting 1. Terracing, contour ridging, planting basins, bunds, tied ridges 2. Irrigation (pumps, canals, low-cost drip and sprinklers)	**(M)** Maintenance
Low	**(SW)** Soil and water harvesting 1. Water harvesting (above) 2. Soil fertility enhancement (right)	**(S)** Soil harvesting and fertility management 3. Contour ridging, terracing, woodlots, hedgerows; stone dikes, planting basins 4. Low til technologies 5. Organic material build-up (residue retention, composting, manure applications, agroforestry) 6. Organic fertilizers (leguminous crop rotations, improved herbaceous fallows, composting, manure) 7. Inorganic fertilizers to reduce soil mining and reduce extensification

Source: Adapted from Scoones, Reij and Toulmin (2001).

Differences in soil regimes and agroclimatic conditions vary widely across locations as do costs of labor, organic fertilizers and construction materials, leading to a wide array of site-specific conservation agricultural practices. For good illustrations of this vast range of practice see the many case studies described by Critchley (1991), Ganry and Campbell (1993), Critchley, Reij and Willcocks (1994), Buresh, Sanchez and Calhoun (1997), Mortimore (1998), Whiteside (1998), Twomlow and Hagmann (1998), Pretty (1999), Jabar, Pender and Ehui (2000), Reij, Scoones and Toulmin (1996), Pretty and Hine (2001), Mrabet (2002), Franzel and Scherr (2002), and Shapiro and Sanders (forthcoming).

The most contentious issue across this broad array of resource-conserving conservation agriculture involves the use of inorganic fertilizers. Two opposing views characterize the philosophical landscape. One group, led most forcefully by Nobel prize laureate Norman Borlaug and the Sasakawa Global 2000 group (Quiñones, Borlaug and Dowswell, 1997), advocate use of inorganic fertilizer as the lowest cost means of restoring soil nutrients, increasing crop yields and thereby relieving pressure on forests that extensive cultivation endangers. Borlaug (1996) says,

> I am convinced that the most environmentally friendly action that can be taken in Sub-Saharan Africa is to promote moderate and proper use of chemical fertilizers in an aggressive manner. Increased chemical fertilizer use should help to reduce soil erosion by increasing plant biomass and vegetative ground cover and, assuming that crop residues are returned to the soil, contribute to improving the organic matter content of the soil. ... There simply is not enough organic fertilizer available to provide sufficient nutrients to the soil to satisfy the growing food demand of Africa.

These are propositions supported by others as well (Larson and Frisvold, 1996).

Countering this basic thrust, advocates of organic and low-external input agriculture maintain that any petroleum-based fertilizers are inherently unsustainable (Reintjes, Haverkrot and Waters-Bayer, 1992). These authors and others note that organic strategies of composting, manuring, residue retention, leguminous crop rotations and improved fallows with herbaceous shrubs can provide up to 280 kg of nitrogen per hectare per year (Giller and Wilson, 1991). Among cash constrained smallholders, most of them dependent on irregular rainfed water supply, they insist that chemical fertilizers normally prove too costly and too ineffective to offer large-scale solutions. Moreover, organic fertilizers provide carbon along with nutrients, thereby enriching soil organic material and sustaining a wide array of beneficial soil microbiological activity.

Many pragmatic practitioners adopt a middle course, boosting soil organic material and nutrients via organic methods of residue retention, minimum tillage, crop rotations and improved fallows but then topping up fields with strategic doses of inorganic fertilizers such as rock phosphates and inorganic nitrogen (Sanchez et al, 1997). "Conservation farming" in Zambia is an example of this middle ground (Haggblade and Tembo, 2003). Some researchers call for variable doses of inorganic fertilizer in combination with minimum tillage, or micro doses in combination with conservation tillage practices (e.g. Snapp, Mafongoya, and Waddington, 1998).

A key difference between the two extremes is the generally higher labor demands of the organic soil fertility enhancements as compared to the higher financial capital demands for the use of inorganic inputs. Because of the labor intensity of many organic fertility enhancement techniques, the optimal economic solution for the farmers typically involves a tradeoff between the cost and availability of labor required for organic methods and the availability of finances and cost of purchased external inputs. As the impacts of HIV/AIDS begin to be felt with the loss of household members, this trade-off becomes even more critical for adoption. Research on low inorganic doses combined with some organic attempts to seek a route to sustainability that is accessible to farmers is becoming increasingly important.

3. FINANCIAL INCENTIVES TO HOUSEHOLD ADOPTION

While the effects of conservation agriculture may occur through time both on a single farmer's land and across a landscape, adoption of conservation agricultural technologies will depend on the financial incentives and risk decisions facing individual households, particularly in the first year of adoption. Lack of short-term profitability will generally discourage farmers from adopting, unless there is a major reduction in risk with the change in technology. For example, in Critchley (1999), researchers interviewed 74 "farmer innovators" in three countries of eastern Africa. When asked about their initial motivation to innovate with technologies that combine production with conservation technologies, the most frequent response was for "cash" or "increased income" (mentioned by 33% of the farmers).[4] Returns that come in gradually over time might meet this criterion, but not necessarily. Some of the studies presented provide analysis of profitability for the longer term, as with Manyong et al. (1999) with eight year analysis.

For adoption, farmers may not take into account the potential effects on others. This is not to ignore the important downstream, downhill and general environmental effects (increased carbon sequestration for example as indicated in Pretty, Morison and Hine (2003)) that may occur on existing watersheds with the adoption of soil and water conservation technologies. There are those externalities requiring possible collective action because the public and private incentives differ, usually leading farm households to under-invest in soil and water conservation (SWC) technologies, compared to the socially optimal investment. Recognizing this important aspect of SWC, we leave the measurement of external benefits and costs to others. Adesina and Coulibaly (1998) note this as an important area for further analysis. Thus, this section examines household-level financial incentives in order to determine where and when households will adopt SWC out of their own self-interest.

To evaluate household profitability of conservation agriculture technologies compared to more conventional tillage systems, various factors come into analysis: changes in yields (both levels of yields and variability in yields), changes in input uses (land, labor, purchased inputs, and other inputs), prices for both inputs and outputs, including capital costs. Since these technologies are generally a package of different activities, as are the more traditional cultivation systems, analysts must be clear about the aspects of comparison and the control groups. All of this makes it difficult to compare results since researchers may be using on-station results, on-farm trial results (researcher managed), or simply on-farm observations.

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[4] See Critchely 1999 for further information on how these "innovators" were identified and interviewed.

4. POTENTIAL BENEFITS TO HOUSEHOLDS FROM CONSERVATION AGRICULTURE

4.1 Yield Results

Yield is a major factor in farm-level profitability and the most documented in the literature. Yields frequently increase substantially under conservation agriculture, both in the first year and over time. Pretty, for example, concludes from his review of 45 such technologies in Sub-Saharan Africa, “A 50 to 100% increase in basic grain yields is clearly possible with sustainable agriculture.” (Pretty, 1999). Table 1 confirms this assessment across a wide variety of locations and technologies.

Yet this review of evidence cautions that even where large percentage gains in yield occur, absolute increases may prove very small, as the many examples from the Sahel indicate. The large yield gains, of one tonne or more per hectare, typically occur where sufficient moisture regimes meet significant increases in soil fertility (Table 1). Yields may vary dramatically by season as in the Nigeria cowpea research on three tillage systems (Akinyemi, Akinpelu, and Olaleye, 2003). Water stress during the second season resulted in no significant advantage of any particular tillage system, whereas in the first season there were clear benefits to hand hoe ridging. The Zambia research of Haggblade and Tembo (2003) covered a season in which the water conservation aspects of conservation farming provided a major advantage over other tillage systems; the results will be different with different rainfall patterns, indicating the need for such analysis to cover several periods.

An additional caution is needed. The yield results will vary by soil type as well as climate and other conditions. As shown in Table 2, across soil types within the same region and using identical technology, yields can vary by a factor of three. Thus, for any given farmer, the results will depend on the soil type, and researchers are still working to develop the recommendation domains for different technologies based on soil types as well as other criteria (see Haggblade and Tembo 2003). Other research indicates that the definition of recommendation domains might not reflect the perception of the farmers of needs and might need to be reevaluated in light of their perceptions. For example, if farmers do not perceive that there are soil fertility problems, financial profitability may be insufficient to motivate adoption of new technologies.

4.2 Risk Reduction

In more traditional cropping systems, yields can vary widely from year to year, as rainfall varies. The output gains with conservation agriculture cited above can also differ widely from one year to another, particularly in regions of sparse or sporadic rainfall, as shown in Table 2. By building up soil organic matter, conservation agriculture technologies may help improve water retention and reduce yield variations. Physical control of water and water harvesting – via tied ridges, planting basins, contour grass strips or stone bunds – similarly reduce risks inherent in rainfed dryland agriculture (Moyo and Hagman, 1994). Yield risk reduction remains a primary incentive for water conservation and management strategies.

Table 1 -- Yield Gains under Conservation Agriculture

	Yield Gains under Conservation Agriculture		
	absolute (kg/ha)	percentage gain	Reference
Soil and Water Conservation			
Water harvesting			
Tied ridges, Burkina Faso			
sorghum, 1983	84	19%	Shapiro and Sanders (2002)
sorghum, 1984	184	53%	
Tied ridges, Ethiopia			
sorghum	1,750	146%	Shapiro and Sanders (2002)
maize	1,500	125%	
mung bean	300	75%	
Tied ridges, Zimbabwe (maize)	-	100%	Pretty (2000)
Soil and water harvesting (SW)			
Planting basins (zai), Burkina Faso			Roose, Kabore and Guenat (1993)
sorghum, 1992-3	39	65%	
SW plus compost or manure			
Planting basins (zai) + leaves, Burkina			Roose, Kabore & Guenet (1993)
sorghum, 1992-3	112	188%	
Planting basins (zai) + compost, Burkina			Roose, Kabore & Guenet (1993)
sorghum, 1992-3	372	624%	
Planting basin (tassa) + manure, Niger			
millet 1991-1996	388	310%	
Planting basin (zai) + manure, Mali			
sorghum 1992/3-1993/4	719	212%	Wedum et al. (1996)
Water harvesting + soil conservation + organic material			
sorghum and millet, Burkina	780	90%	Pretty and Hine (2001)
sorghum and millet, Ethiopia		50%	
sorghum and millet, Mali	1,400	467%	
sorghum and millet, Niger	200	71%	
sorghum and millet, Senegal	260	76%	
Zero tillage + mulch, Nigeria			
maize, 1978	5,949	8%	Osuji, G.E., as reported in Opara-Nadi (1993)
maize, 1979	5,887	12%	
maize, 1980	5,678	5%	
SW plus inorganic fertilizer			
Tied ridges + fertilizer, Burkina Faso			
sorghum, 1983	411	91%	Shapiro and Sanders (2002)
sorghum, 1984	546	158%	
Planting basins (zai) + fertilizer, Burkina			Roose, Kabore & Guenet (1993)
sorghum, 1992-3	762	1281%	
SW plus organic and inorganic fertilizer			
Planting basins (zai) + fertilizer + compost, Burkina			Roose, Kabore & Guenet (1993)
sorghum, 1992-3	979	1645%	
Planting basin (tassa) + fertilizer + manure, Niger			Hassane, Martin and Reij (2000)
millet 1991-1996	640	511%	
Planting basins (conservation farming) + residue retention + fertilizer, Zambia			
cotton, 2001/2	460	56%	Haggblade and Tembo (2003)
maize, 2001/2	1,500	100%	

Table 1 -- Yield Gains under Conservation Agriculture (continued)

			Yield Gains under Conservation Agriculture		
			absolute (kg/ha)	percentage gain	Reference
Leguminous crop rotations					
	lablab, compost and manure on maize,		2200	0.7	Pretty and Hine (2001)
Improved fallows with herbacious legumes					
	Sesbania sesban, Zambia 2001		2600	2.4	World Vision (2001)
	Sesbania sesban, Zambia 2002		2600	2.0	World Vision (2002)
	Tephrosia vogeli, Zambia 2001		1500	1.4	World Vision (2001)
	Tephrosia vogeli, Zambia 2002		1700	1.3	World Vision (2002)
	maize, Kenya		120	0.5	Pretty and Hine (2001)
	agroforestry + contour grass hedges, Malawi		1050	1.5	ibid.
Relay cropping with cover crops					
	Mucuna with maize, Benin		279	0.3	Pretty and Hine (2001)
Composting or organic fertilizer					
	organic cotton, Senegal			0.0	Pretty and Hine (2001)
	organic cotton, Tanzania			0.0	ibid.
	banana soil and nutrient management, Uganda			0.9	ibid.
	banana soil and nutrient management, Uganda			3.0	ibid.
	maize, soil conservation + organic farm		2000	1.0	ibid.
Inorganic fertilizer					
	Maize				
		Benin, 1989-1993	1870	1.9	Quinones, Borlaug and Dowswell (1997)
		Ethiopia, 1993-1995	3740	2.2	ibid.
		Ghana, 1987-1994	1950	1.5	ibid.
		Tanzania, 1989-1994	2912	2.1	ibid.
		Togo, 1990-1993	2244	1.9	ibid.
		Zambia 2001	4600	4.2	World Vision (2001)
		Zambia 2002	2300	1.8	World Vision (2002)
Intensification via improved varieties					
	cassava, Ghana		11143	0.8	Pretty and Hine (2001)
	sweet potato, Ethiopia		29000	4.8	ibid.

To the extent that there may be increased risk with conservation farming, as with possible water-logging with planting basins, it may be optimal for a farmer to maintain different cropping systems for risk aversion. In semi-arid areas, a drought can mean total loss of production, but recent experience in Zambia (Haggblade and Tembo, 2003) shows that planting basins can improve the possibility of maintaining some production with very low rainfall. Likewise when there are sudden rainfalls, having some land under more conventional tillage may avoid total loss of crop. Combinations of tillage systems or other variations with partial adoption may be the best option for farmers who are highly risk averse.

5. COSTS TO HOUSEHOLDS

There are many different technologies that can go into conservation agriculture but in general, these methods require more labor time than conventional methods. Conservation agriculture requires that households invest labor in physical structures (e.g., planting basins) and organic inputs (e.g. composting) coupled many times with cash purchases of selected external inputs. Examples of the estimates of some of these costs are given in Table 3. Preparation and management of woodlots to serve as guards against soil and wind erosion may require 90 to 200 days per hectare (Table 3). Dry-season field preparation of water harvesting technologies such as planting basins require between 50 and 75 person days of labor per hectare (Table 3). As one reviewer concludes, “Zai is a simple technique, but it requires hard work” (Fatondji, Martius and Vlek, 2001).

Minimum tillage technologies, which improve soil structure and fertility, typically demand additional labor at weeding time because they fail to bury weeds during land preparation through the complete soil inversion involved in conventional plowing. This increased weeding labor may involve 10 to 30 person days of labor per hectare (Table 3). In Zambia, the CFU is developing simple implements for herbicide application to reduce labor demand, but that technology also has a cost.

Composting and mulching require that farmers physically prepare and move voluminous quantities of organic material. As one reviewer of cover crop rotations notes "labor input is very much affected by management of the often voluminous residue," (Vissoh et al., 1998). The addition of a dosage of 3 tonnes per hectare of organic compost requires prior preparation of about 11 cubic meters of material (Roose, Kabore and Guenat, 1999; Kaboré and Reij, 2003). Preparation of this volume of compost requires roughly 30 person days per hectare, its distribution a further 25 person days (Table 3). The cutting of shrubs and removal of branches following improved herbaceous fallows requires 10 to 40 person days per hectare (Table 3).

There may also be cost reductions with conservation agriculture. For farmers using mechanical and animal draft power, there may be a reduced time for tillage, thus reducing fuel consumption or time needed for animals in the field. These cost savings were a major force behind commercial farm adoption of conservation farming in the US and elsewhere. For the small-holder farmer in SSA, the freeing up of animal draft time in one farmer's field means that there is more time available for tilling additional land (Stevens et al., 2002). In Kenya, an intercropping system of maize with legumes and grasses enabled farmers to reduce the use of pesticides needed to deal with stem borers in maize (Pretty, Morison and Hine, 2003). Much research has gone into using green manure to reduce purchased input costs, although the flip side is the potentially high labor cost mentioned earlier.

Table 2 -- Yield Variations in Planting Basins Across Seasons in the Sahel

	Location and year						Average
Millet yields in Illela, Niger	1991	1992	1993	1994	1995	1996	
Millet yields (kg/ha)							
a. control	-	125	144	296	50	11	125
b. basins + manure	520	297	393	969	347	553	513
c. basins + manure + fertilizer	764	494	659	1486	534	653	765
Absolute gains							
b-a	-	172	249	673	297	542	388
c-a	-	369	515	1190	484	642	640
Percentage gains							
(b-a)/a		138%	173%	227%	594%	4927%	310%
(c-a)/a		295%	358%	402%	968%	5836%	511%
Sorghum yields in Burkina Faso		Pouyango			Taonsongo		
		shallow altisols			deep brown soil		
		1992	1993		1992	1993	
Sorghum yields (kg/ha)							
a. control		63	22		150	3	60
b. pit only		150	29		200	13	98
c. pit + leaves		184	83		395	24	172
d. pit + compost		690	257		654	123	431
e. pit + mineral fertilizer		829	408		1383	667	822
f. pit + compost + fertilzier		976	550		1704	924	1,039
Absolute gains							
b-a		87	7		50	10	39
c-a		121	61		245	21	112
d-a		627	235		504	120	372
e-a		766	386		1233	664	762
f-a		913	528		1554	921	979
Percentage gains							
(b-a)/a		138%	32%		33%	333%	65%
(c-a)/a		192%	277%		163%	700%	188%
(d-a)/a		995%	1068%		336%	4000%	624%
(e-a)/a		1216%	1755%		822%	22133%	1281%
(f-a)/a		1449%	2400%		1036%	30700%	1645%
Sorghum yields in Mali					1992/3	1993/4	
a. plowed fields					397.2	280	339
b. zai pits plus manure					1494.4	620	1,057
Absolute gain (b-a)					1097.2	340	719
Percentage gain (b-a)/a					276%	121%	212%

Source: Roose, Kabore and Guenat (1993), Hassane, Martin and Reij (2000), Wedum et al. (1996).

Minimum tillage technologies, which improve soil structure and fertility, typically demand additional labor at weeding time because they fail to bury weeds during land preparation through the complete soil inversion involved in conventional plowing. This increased weeding labor may involve 10 to 30 person days of labor per hectare (Table 3). In Zambia, the CFU is developing simple implements for herbicide application to reduce labor demand, but that technology also has a cost.

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6. RETURNS TO HOUSEHOLDS

Given the higher labor costs incumbent in many conservation farming technologies, financial returns must examine the clearly higher yields against the typically higher labor inputs required to achieve them. Therefore, we have attempted to assemble evidence on returns not only to land but also to labor.

In assembling this evidence, we have discovered that while many studies of conservation agriculture report its impact on yields, far fewer measure and value the increased inputs required to achieve these output gains. Hence, compared to the voluminous evidence on yield gains, the evidence on the financial returns to conservation agriculture remains comparatively sparse. Studies that do measure cash costs usually report simple returns to land (net returns per hectare or a marginal rate of return per hectare) over a single season, a few over several years. Many fewer studies evaluate changes in labor usage and returns to labor.

Though results vary widely across locations and technologies, returns to land typically do increase under conservation agriculture (Tables 4 and 5). Not surprisingly, investments in soil fertility and moisture availability enable crop intensification that increases yields and returns to land. There are several possible benefits related to the timing of activities. Conservation farming may enable farmers to shift labor demand to non-peak times, as with use of labor and draft animals in the dry season. Conservation tillage practices may enable farmers to plant as soon as rains come to take advantage of early moisture (Langmead 2001), and harvest crop early, when crop prices and demand for the crop are high (Astatke, Jabbar, and Tanner, 2003; Haggblade and Tembo, 2003).

The few studies measuring returns to labor suggest that conservation agriculture can prove financially viable to households (Tables 4 and 5). Where this occurs, not only do farm households improve their individual welfare, but society at large also gains from reduced soil erosion, water loss, and foreign exchange expenditure. In these instances, we find encouraging examples of win-win opportunities. Nonetheless, we find the paucity of evidence on returns to labor troubling. As in all disciplines, we must guard against a possible selection bias in reported results and hope that future empirical studies will focus more carefully on comparing output increases with increased labor inputs required to achieve them.

In the context of conservation agriculture, inorganic fertilizer appears to offer highly competitive returns according to the smattering of evidence available in the conservation agriculture literature (Table 4 and 5). Though we have not examined the large independent literature on inorganic fertilizer in Sub-Saharan Africa, we have reported returns to inorganic fertilizer when reported in studies of conservation agriculture. Because yield responses and costs vary considerably by crop and location, generalization becomes difficult. Nonetheless, even the conservation agriculture studies reported in Tables 4 and 5 find that inorganic fertilizer produces positive returns, many times higher than those achieved under organic farming. Tantalizing though perhaps more robust is the further tentative indication that organic and inorganic fertilizers prove complementary. In three of the four crops studied by Dima and Odero (1997), the combination of organic and inorganic fertilizers produced the highest returns to land.

Table 3 -- Labor Requirements in Conservation Agriculture

	Labor requirements (persondays per hectare)				
	Field prep	Compost	Weeding	Other	Total
Soil and Water Conservation					
Tassa (planting basins), Niger	50	15		25	90
Zai (planting basins), Burkina Faso	75	25		29	129
Conservation farming, Zambia					
conventional hand hoe	59		68	37	164
CF basins	70		79	74	223
conventional plowing	7		48	55	110
Stone bunds, Burkina Faso					
Stone bunds, Ethiopia					
Woodlots, Ethiopia					
tabia woodlots	10		32	45	87
kushet woodlots	112		24	69	205
Soil Fertility Enhancement					
	digging	filling			
Composting	16	13			29
		cutting		removing	
Improved fallow, Zambia		shrubs		branches	
sesbania sesban		6.5		4	
cajanus cajan		6		6.7	
tephrosia vogelii		17.3		25.3	

Sources: Hassane, Martin ane Reij (2000), Kabore and Reij (2003), Haggblade and Tembo (2003), Jagger and Pender (2000), World Vision (2002).

Table 4 -- Financial Returns to Farm Households from Soil and Water Conservation Technologies

	Returns to land ($ per ha)	Returns to labor ($ per day)
Tassa (planting basins), Niger		
Millet, low grain price		
control	23	0.76
tassa + manure	70	0.74
tassa + manure + organic fertilizer	99	0.95
Millet, high grain price		
control	0	0.03
tassa + manure	48	0.10
tassa + manure + organic fertilizer	46	0.11
Zai (planting basins), Burkina Faso		
Sorghum and cowpea		
control = damaged, unfarmed land	0	0.00
zai plus composted manure	127	0.99
Conservation farming, Zambia		
Maize*		
conventional hand hoe	141	1.00
CF basins	231	1.87
conventional plowing	58	1.09
CF animal-drawn rippers	81	1.53
Cotton*		
conventional hand hoe	106	0.75
CF basins	183	1.73
conventional plowing	73	0.93
CF animal-drawn rippers	73	0.93
Maize		
Conventional tillage w/fertilizer (100 urea; 100 NPK)	73	2.90
Conventional cultivation w/o fertilizer	50	1.85
Min tillage w/fertilizer (100 urea; 100 NPK)	77	3.04
Min tillage w/o fertilizer	54	1.94

* Returns to peak season labor for households without adequate draft power of their own.

Sources: Hassane, Martin and Reij (2001), Kabore and Reij (2003), Haggblade and Tembo (2003), Keyser and Mwanza (1996).

Table 5 -- Financial Returns to Farm Households from Soil Fertility Enhancing Technologies

			Returns to land ($ per ha)	Returns to labor ($ per day)
Nitrogen fixing improved fallows, Zambia (5-year time series)				
	Maize, low (1996) output price			
		continuous unfertilized cultivation	6	0.47
		2-year sesbania fallow	170	1.11
		organic fertilizer	229	1.04
	Maize, high (1998) output price			
		continuous unfertilized cultivation	6	0.79
		2-year sesbania fallow	215	1.64
		organic fertilizer	544	2.18
Weed-suppressing improved fallows, Benin (8-year time series)				
	Maize			
		control	-66	x
		mucuna rotations	69	2x
Improved fallows, Northwest Cameroon				
	Improved maize varieties			
		control	3	
		+ 100 kg inorganic nitrogen fertilizer	82	
		+ mucuna fallow	135	
		+ mununa + 100 kg N fertilizer	137	
		+ tephrosia fallow	69	
		+ tephrosia + 100 kg N fertilizer	106	
		+ sesbania fallow	87	
		+ sesbania + 100 kg N fertilizer	113	
Organic fertilizer (manure) applications				
	Beans			
		no fertilizer	158	
		organic fertilizer, 16.8 tons per ha	334	
		inorganic nitrogen fertilizer, 196.8 kg DAP	229	
		organic + inorganic fertilizer	96	
	Cabbages			
		no fertilizer	1,384	
		organic fertilizer, 39.4 tons per ha	3,080	
		inorganic nitrogen fertilizer, 196.8 kg DAP	2,211	
		organic + inorganic fertilizer	3,191	
	Carrots			
		no fertilizer	462	
		organic fertilizer, 24.4 tons per ha	457	
		inorganic nitrogen fertilizer, 195 kg DAP+110 kg urea	1,241	
		organic + inorganic fertilizer	1,255	
	Potatoes			
		no fertilizer	1,298	
		organic fertilizer, 12.5 tons per ha	1,838	
		inorganic nitrogen fertilizer, 500 kg DAP+280 kg urea	2,100	
		organic + inorganic fertilizer	2,229	

Sources: Franzel, Phiri and Kwesiga (2002), Vissoh et al. (1998), Adesina and Coulibaly (1998), Dima and Odero (1997)

Given the improvements in soil organic material contribute to improved water and nutrient retention as well as improved microbiological activity, and given the well-established links between inorganic fertilizer and water, this synergy is not surprising.

A critical factor determining benefits is the price or value of the output for the farm household. In SSA, there can be very high variability in output prices from season to season and year to year. For example, in Niger, the price of millet may be 50% times higher in the off-season than in the harvest season (Abdoulaye and Sanders, 2003). Maize prices in Mozambique in the production regions in any given year may fluctuate by 500% (Santos, et al 1998), undermining the incentive to invest in the crop production and land quality. In Ethiopia, a major benefit of the minimum tillage discussed in the Astatke, Jabbar and Tanner (2003) piece is the early harvest of wheat such that farmers were able to obtain relatively high prices for the output. Agricultural prices and policies can affect the incentives and thus influence household decisions, as Barbier (2000) noted for the case of Malawi and pricing policy that advantaged "more erosive" crops (maize, tobacco) over "less erosive" crops (pulses, groundnuts).

Adesina and Coulibaly (1998) note the effects of major policy shifts on the prices for inputs (especially inorganic fertilizer) and outputs with the devaluation of the Franc CFA in 1994. They use a policy analysis matrix (PAM) to estimate social as well as private profitability. In that analysis, technologies with improved fallows based on agroforestry and inorganic fertilizers were profitable, both privately and socially. This highlights the need to view any financial analysis as conditioned upon the relative prices of inputs and outputs used, including the opportunity costs of labor and capital. Enabling farmers to analyze profitability as prices change would increase their capacity to innovate and adapt the options available.

7. CONCLUSIONS

The sheer volume and diversity of ongoing efforts in conservation agriculture offer eloquent testament to human inventiveness as well as to the widespread recognition of serious problems of soil and water conservation in African agriculture. Farmers, researchers and policy makers have all invested considerable time and resources into development of viable water-conserving and fertility-enhancing agricultural technologies for Africa.

These collective efforts have generated a range of technologies that can substantially increase on-farm yields. To achieve these gains, however, the conservation agriculture technologies typically require significant increases in on-farm investment and input use, particularly of farm labor. Financial profitability, therefore, hinges on comparison of increased input costs with the increased value of output. While many participants measure increase in yield, far few relate the value of increased output with increased costs required to achieve these output gains.

The handful of available budgets does suggest soil and water conservation efforts can prove financially profitable to individual households across a range of locations and technologies. In doing so, they meet a demanding standard – offering farm technologies that are both financially attractive to households and environmentally sustainable. In the presence of the limited available empirical evidence, often based on very small sample sizes, it is difficult to generalize other than to suggest that assessment will require case-by-case analysis to determine viability of specific technologies in specific locations. Given the high yield variability in results and the potential for yield effects over time, undertaking a more long term research agenda would be valuable to understand the effects on farmers' fields and livelihoods over time.

We remain nervous about the paucity of available empirical evidence on financial viability of conservation agriculture technologies in Africa. Possible selection bias in favor of the best performers remains a concern as does a pervasive failure to evaluate output gains against increases in labor required to achieve them. Future studies will need to focus more closely on labor requirements and returns to labor. Also lacking are studies that look at the technologies over time and from a society-wide perspective. If these technologies are highly socially profitable, there are reasons to evaluate contributions of public sector programs to sponsor and support some of the costs of adoption of these technologies.

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