AGWATER SOLUTIONS
Improved livelihoods for smallholder farmers

REGIONAL ANALYSIS OF TREADLE PUMPS

Potential for expansion in Sub-Saharan Africa

JULY 2012

Introduction

Sub-Saharan Africa (SSA) faces great challenges in development, including the highest poverty rate in the world, food insecurity, and malnutrition. Given that agriculture is the single most important source of rural livelihood in Africa, an agricultural growth strategy will go a long way to reducing hunger and poverty on the subcontinent. Among the numerous challenges to enhancing agricultural production in SSA is the large spatial and temporal variability and availability of water resources. Currently, agriculture in SSA is predominantly rainfed. The limited access to water in arid areas or during dry seasons and drought spells often presents restrictions to improving agricultural productivity. Therefore, enhanced agricultural water management has been regarded as a promising solution to boost levels of agricultural productivity in SSA.

Treadle pumps are an example of a promising agricultural water management technology. They are human-powered devices designed to draw groundwater to the surface from a depth of approximately seven meters or less. Originally developed for domestic water pumping, these hand-operated or feet-pedaled pumps have been adapted for use in irrigation where greater volumes of water are required. Treadle pumps work by drawing water from a river or shallow groundwater and discharging it into a canal for gravity irrigation, or by using pressure to force it into a pipe leading to sprinklers or hoses. The major advantages of treadle pumps are their low cost, low maintenance requirements, and portability, which make them more accessible for smallholder producers in SSA. The major disadvantages are that they are generally unsuitable for use with deep wells, and that they are regarded as drudgery, requiring many labor hours for irrigation.

Methodology

This brief is based on a study that uses an integrated modeling system that combines geographic (GIS) data analysis, biophysical and economic predictive modeling, and crop mix optimization tools to assess the regional potential for smallholder agricultural water management in SSA and South Asia (SA). It focuses on the potential for the expansion of treadle pumps throughout SSA.

The assessment process includes two components: ex-ante GIS and predictive modeling analyses. The ex-ante analysis uses a set of suitability criteria to identify areas where the technology could potentially be applied, pixel by pixel, across the region. The formulation of assessment criteria and the scoring scheme were developed through expert consultations and validation and reflect the best available expert knowledge. For treadle pumps, the environmental suitability criteria for ex-ante GIS analysis are shown in Table 1.

A pixel with a score greater than 55 is considered to have irrigation potential. The application areas derived from the suitability analysis were also compared with the labor-constrained application areas obtained from rural population analysis at the basin level; the minimum of the two application areas in a river basin was selected as the final ex-ante estimates for the areas with irrigation potential in the river basin.

The results derived from ex-ante GIS analysis are further refined in an analysis that involves the application of two biophysical and economic predictive modeling tools: the Soil and Water Assessment Tool (SWAT) and the model of Dynamic Research Evaluation for Management (DREAM). Currently, agriculture in SSA is predominantly rainfed and farming activities concentrate in the rainy seasons. This analysis assumes that treadle pumps would enable producers to extend crop production into the dry season, when the irrigation demand is highest. Under this assumption, the SWAT and DREAM models were run to simulate the hydrology, estimate crop water demand and agricultural productivity in the added dry growing season, and forecast price shifts in agricultural commodities as a result of increased supply. The results produced from the SWAT–DREAM predictive analysis allow for quantitative water balance and cost–benefit analysis of irrigation activities. This further constrains the potential for irrigation expansion compared to the ex-ante analysis, based on physical scarcity and economic viability.

Other key assumptions in the predictive modeling assessment include the following:

- *Water Availability*. Both groundwater and surface water can be used for irrigation. The groundwater abstraction rate is restricted so as not to exceed the recharge rate. Moreover, 20 percent of runoff is reserved for environmental flows.

- *Cultivation of Particular Crops*. The assessment assumes that treadle pumps are used for the cultivation of a series of crops based on evidence from field studies including: tomatoes, onions, peppers, cabbages, beans, peas, potatoes, sweet potatoes, sugarcane, ground nuts, maize, wheat, and rice.

Table 1. Ex-ante GIS analysis criteria for treadle pumps

Criteria for treadle pumps	Scoring scheme
FAO fluvisols	False = 0, 1 - 15 % = 11, 16 - 50 % = 22, 51 - 100 % = 33
Market access	5 km = 10 minutes = 33, 10 km = 20 minutes = 22, 20 km = 40 minutes = 11, 30 km = 60 minutes = 0, 60 km = 120 minutes = 0
Distance to surface water	< 0.5 km = 33.333, > 0.5 km = 0

- *Fertilizer Input*. Agricultural production in SSA is characterized by the wide presence of low-input farming systems. However, because there exists strong synergy between water and nutrient management—that is, farmers need to provide an appropriate amount of nutrients to the soil, especially nitrogen, to ensure irrigation is effective in improving crop yields—medium rates of nitrogen fertilizer applications were assumed in the crop simulation. The assumed amount of nitrogen fertilizer applied to each crop type is shown in Table 2. The estimated yields of selected crops cultivated under irrigation and assumed nitrogen fertilizer applications (as opposed to the estimated yields in low-input farming systems in SSA) are shown in Table 3.

- *Production and Irrigation Costs*. Assumed costs of production for the selected crops are shown in Table 2. A cost for irrigation of US$259 per hectare per year was also assumed, with average amortized capital investment costs of $69/ha-yr (original capital investment: $369 and a reinvestment period of eight years) and labor and operating costs of $190/ha-yr. The cost–benefit results are very sensitive to these cost assumptions. A sensitivity analysis in which irrigation costs were increased or decreased by 50 percent was, therefore, conducted.

Table 2. Nitrogen fertilizer application rates and non-irrigation production costs assumed in the crop simulation and crop mix optimization

Crops	N fertilizer (KG/ha)	Costs (US$/ha-yr)
Tomatoes	100	3,500
Onions	100	3,500
Peppers	100	3,000
Cabbage	100	4,000
Beans	0	1,000
Peas	0	500
Potatoes	80	3,000
Sweet potatoes	60	2,500
Groundnuts	0	1,000
Sugarcane	80	1,500
Wheat	50	700
Maize	60	600
Rice (paddy)	80	1,000

Source: IFPRI Team based on project inputs and secondary sources

It is expected that irrigation will boost agricultural productivity and increase the supply of agricultural commodities, while also lowering their prices. To account for the effect of price changes on the economic profitability of irrigation development, the DREAM model is used to forecast price shifts. Baseline data for the model were obtained from FAOSTAT Food Balance sheets, FAO PriceSTAT, and the IFPRI IMPACT model.

It was found that the estimated irrigation potential is also sensitive to changes in initial crop prices. A 30 percent increase and a 30 percent decrease in initial crop prices were implemented as additional sensitivity analyses.

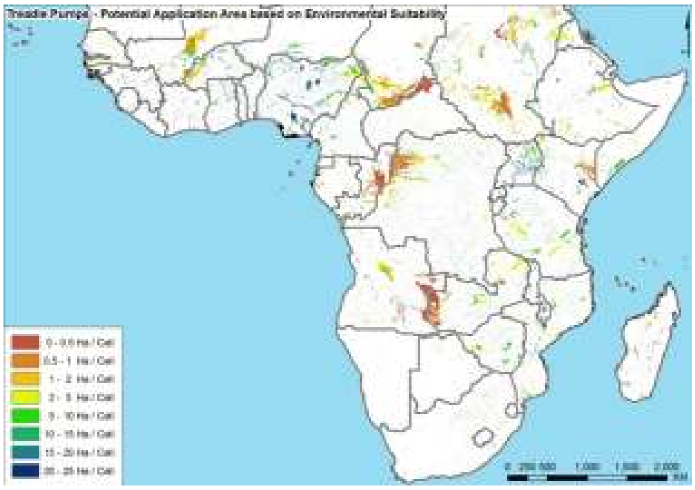

Figure 1: Suitable area for expansion of treadle pumps, ex-ante results
Source: IFPRI Team

Potential for expansion of treadle pumps in SSA

The ex-ante assessment shows that the potential for the expansion of treadle pumps is 36.7 million ha, potentially reaching a rural population of 377 million people (Table 4). The potential for treadle pump expansion is highest in the Gulf of Guinea region, with potential expansion of 10 million ha reaching 97 million people, driven primarily by the large potential in Nigeria.

The Eastern and Indian Ocean, Sudano–Sahelian and Central regions also show considerable potential for expansion of the technology, with 86, 89, and 64 million people potentially reached in these regions, respectively. Apart from Nigeria, other countries showing large potential for expansion include the Democratic Republic of the Congo, Sudan, Tanzania, and Ethiopia.

Taking river basin hydrology, yield improvements, costs of the investment, and price impacts of expanding crop production into account results in lower potential for the adoption of treadle pumps in the region compared to the ex-ante assessment (Figure 2).

Table 3. Yield improvement of estimated high-input (HI) yields of selected crops cultivated under irrigation and assumed nitrogen fertilizer applications compared to low-input (LI) rainfed yields

Country	Sweet potato		Green bean		Maize		Paddy rice		Groundnut	
	LI	HI	LI	HI	LI	HI	LI	HI	LI	HI
	Rainfed yield (t/ha)	Irrigated yield (% increase)	Rainfed yield (t/ha)	Irrigated yield (% increase)	Rainfed yield (t/ha)	Irrigated yield (% increase)	Rainfed yield (t/ha)	Irrigated yield (% increase)	Rainfed yield (t/ha)	Irrigated yield (% increase)
Central Africa										
Angola	2.2	547	0.2	385	0.3	1,195	-	-	0.1	2,432
Cameroon	8.1	68	0.5	-62	1.3	215	1.0	327	0.3	647
Central African Republic	6.8	36	-	-	1.1	274	1.2	218	0.8	155
Republic of Congo	-	-	0.5	-55	0.8	378	0.7	348	0.4	410
Democratic Republic of Congo	-	-	0.4	59	0.9	349	0.7	441	0.8	153
Equatorial Guinea	2.6	309	-	-	-	-	-	-	0.8	137
Gabon	6.8	58	-	-	0.9	329	1.0	223	0.7	142
Eastern and Indian Ocean countries										
Burundi	6.4	157	0.4	102	1.0	349	-	-	0.7	289
Ethiopia	-	-	0.6	40	1.1	262	-	-	0.5	446
Kenya	6.8	155	0.5	88	1.0	352	-	-	1.4	72
Madagascar	6.0	171	0.5	63	1.1	298	1.0	496	-	-
Rwanda	5.9	202	0.4	138	0.7	615	1.3	277	1.1	151
Tanzania	1.5	990	0.5	66	1.8	140	1.8	184	0.6	308
Uganda	4.5	215	0.5	15	1.8	128	1.4	263	0.7	288
Gulf of Guinea										
Benin	7.3	56	0.4	-81	1.2	226	1.3	200	0.6	202
Côte d'Ivoire	4.9	153	-	-	1.0	302	1.6	159	0.7	195
Ghana	6.5	73	-	-	1.1	268	1.5	163	0.7	185
Guinea	7.6	49	-	-	1.1	254	1.3	220	0.7	173
Guinea-Bissau	-	-	-	-	1.0	284	1.2	177	1.2	47
Liberia	-	-	-	-	-	-	1.2	243	0.6	271
Nigeria	14.2	-15	-	-	1.5	167	1.4	191	1.7	30
Sierra Leone	2.8	327	-	-	1.1	270	1.1	282	0.7	186
Togo	6.1	81	0.3	-72	1.2	246	1.1	240	0.5	275
Southern Africa										
Botswana	-	-	0.01	1,466	0.1	4,322	-	-	1.0	163
Lesotho	-	-	0.4	291	1.8	148	-	-	-	-
Malawi	11.8	23	0.3	148	1.5	183	1.2	309	0.7	326
Mozambique	30.9	-57	0.2	98	1.1	277	0.3	1,384	0.4	524
Namibia	-	-	0.2	329	0.8	429	0.0	-	0.4	529
South Africa	9.1	88	1.4	-23	1.7	176	-	-	1.1	189
Swaziland	1.8	956	0.2	405	0.9	410	3.4	61	-	-
Zambia	8.1	76	-	-	1.1	301	0.9	448	0.4	602

Table 3. Yield improvement of estimated high-input (HI) yields of selected crops cultivated under irrigation and assumed nitrogen fertilizer applications compared to low-input (LI) rainfed yields (cont'd)

Country	Sweet potato		Green beans		Maize		Paddy rice		Groundnut	
	LI	HI	LI	HI	LI	HI	LI	HI	LI	HI
	Rainfed yield (t/ha)	Irrigated yield (% increase)	Rainfed yield (t/ha)	Irrigated yield (% increase)	Rainfed yield (t/ha)	Irrigated yield (% increase)	Rainfed yield (t/ha)	Irrigated yield (% increase)	Rainfed yield (t/ha)	Irrigated yield (% increase)
Zimbabwe	2.2	546	0.4	49	1.6	163	2.2	129	0.7	270
Sudano-Sahelian region										
Burkina Faso	9.8	9	-	-	1.3	221	1.4	179	0.5	292
Chad	6.2	57	0.3	-68	0.8	434	0.8	326	0.6	272
Eritrea	-	-	0.3	20	0.7	507	-	-	-	-
Gambia	-	-	-	-	1.2	246	1.4	126	0.7	140
Mali	14.3	-21	-	-	0.8	433	0.8	396	0.7	213
Mauritania	1.9	284	0.9	-94	0.9	396	-	-	0.6	225
Niger	13.9	-9	0.4	-42	0.5	904	1.8	147	0.2	791
Senegal	5.3	68	-	-	1.1	287	0.7	394	0.7	149
Somalia	-	-	0.3	-77	0.7	525	-	-	0.7	179
Sudan	2.6	251	1.9	-86	0.8	448	1.6	124	0.5	376

Source: IFPRI Team
Note: LI rainfed yields are derived from the Spatial Production Allocation Model (SPAM).

The results of the SWAT–DREAM assessment for treadle pumps are summarized in Table 5 for the baseline scenario. The results indicate a potential area expansion of 24 million ha, which is two-thirds of the area potential shown in the ex-ante analysis. The rural population reached declines to 243 million, compared to 377 million in the ex-ante assessment. Total net revenues as a result of the expansion of treadle pumps throughout the region would be $19 billion per year, with revenues highest in the Eastern and Indian Ocean Countries, followed by Southern Africa and the Gulf of Guinea.

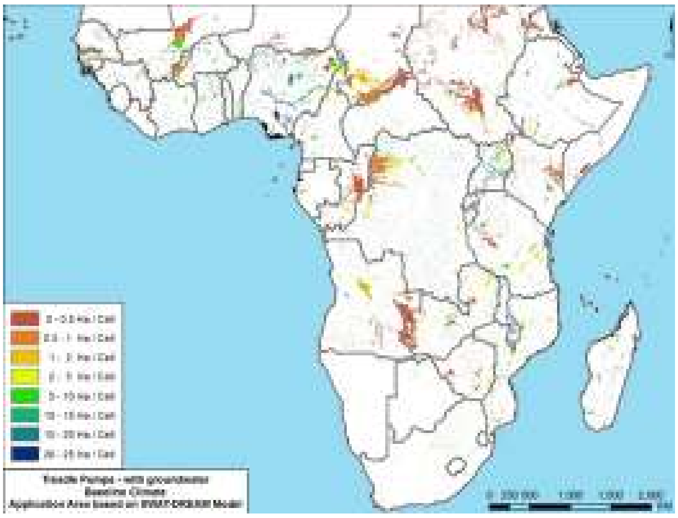

Figure 2: Suitable area for expansion of treadle pupms, SWAT-DREAM results
Source: IFPRI Team.

Table 4. Ex-ante potential for the expansion of treadle pumps in SSA, assuming 100 percent adoption

Country Name	Potential application area (1000 ha)	Rural population reached (thousand people)
Central Africa	6,313	63,873
Eastern and Indian Ocean Countries	8,491	85,571
Gulf of Guinea	10,130	97,181
Southern Africa	4,536	41,140
Sudano-Sahelian	7,221	89,444
All SSA	36,691	377,209

Source: IFPRI team

Moreover, this expansion would be accompanied by an increase in water consumption of 55 billion m^3/yr an increase of 81 percent over current water consumption levels.

Table 5. Predictive modeling results for the potential expansion of treadle pumps, baseline scenario results

Country	Application area (thousand ha)	Net revenue (US$ billion/yr)	Rural population reached (thousand people)	Water consumption (billion m³/yr)	Water consumption Increase %
Angola	846	0.70	8,628	3.13	398.6
Cameroon	713	0.18	7,127	1.23	135.5
Central African Republic	314	0.16	2,761	0.65	551.4
Congo	249	0.26	1,943	0.18	35.8
Congo, DRC	2,896	1.27	30,116	4.86	1,395.9
Equatorial Guinea	2	0.001	29	0.002	1.8
Gabon	73	0.04	686	0.05	89.5
Central Africa	**5,092**	**2.61**	**51,290**	**10.09**	**358.8**
Burundi	55	0.11	556	0.18	48.5
Ethiopia	1,746	3.04	18,154	5.83	327.4
Kenya	826	1.12	7,598	2.12	127.2
Madagascar	801	0.19	7,687	1.68	54.6
Rwanda	65	0.14	588	0.17	132.2
Tanzania	1,255	1.24	13,057	3.84	218.3
Uganda	1,631	1.29	16,636	2.48	369.3
Eastern and Indian Ocean Countries	**6,378**	**7.13**	**64,275**	**16.30**	**172.4**
Benin	203	0.12	2,149	0.42	178.8
Côte d'Ivoire	418	0.25	4,764	0.88	164.6
Ghana	809	0.73	6,469	2.04	718.2
Guinea	62	0.04	749	0.16	34.6
Guinea-Bissau	7	0.03	84	0.01	8.6
Liberia	141	0.10	1,612	0.28	1,291.3
Nigeria	5,389	2.23	49,579	9.20	71.3
Sierra Leone	155	0.11	1,862	0.48	52.0
Togo	179	0.10	1,999	0.23	207.5
Gulf of Guinea	**7,363**	**3.71**	**69,269**	**13.69**	**88.1**
Botswana	34	0.02	283	0.06	47.8
Lesotho	13	0.02	106	0.01	31.9
Malawi	772	2.35	7,256	2.85	481.6
Mozambique	917	0.26	8,257	1.61	164.5
Namibia	9	0.004	86	0.02	13.7
South Africa	441	0.71	3,528	1.19	19.5
Swaziland	17	0.02	184	0.05	7.2
Zambia	858	0.82	8,238	4.05	362.7

Table 5. Predictive modeling results for the potential expansion of treadle pumps, baseline scenario results (cont'd)

Country	Application area (thousand ha)	Net revenue (US$ billion/yr)	Rural population reached (thousand people)	Water consumption (billion m^3/yr)	Water consumption Increase %
Zimbabwe	107	0.09	985	0.45	30.6
Southern Africa	**3,168**	**4.30**	**28,923**	**10.29**	**91.1**
Burkina Faso	849	0.45	11,371	2.13	174.8
Chad	483	0.21	5,123	0.67	96.2
Eritrea	4	0.004	35	0.01	16.9
Mali	466	0.03	5,313	0.47	7.8
Mauritania	6	0.005	80	0.01	0.8
Niger	133	0.11	1,591	0.12	5.8
Senegal	103	0.13	2,112	0.11	8.6
Somalia	6	0.004	66	0.02	0.6
Sudan	291	0.63	3,613	0.92	6.6
The Gambia	7	0.003	206	0.01	15.4
Sudano-Sahelian region	**2,347**	**1.57**	**29,510**	**4.47**	**15.4**
All SSA	**24,347**	**19.30**	**243,267**	**54.84**	**80.5**

Source: IFPRI Team

The results of the sensitivity analysis (Table 6) show that the estimated application areas, net revenues, and rural population reached increase with decreasing irrigation costs and higher food prices, and vice versa. With a 50 percent reduction in the cost of irrigation, the application area would increase by close to 1 million ha, net revenues would increase by $3 billion per year, and the rural population reached would increase by 9 million, compared to the baseline. Conversely, application area decreases by 2.5 million ha, net revenues decline by $3 billion, and the number of people reached declines by 25 million when irrigation costs increase by 50 percent.

Under the different crop price scenarios, a 30 percent increase in initial crop price results in an additional potential application area of 0.6 million ha, an increase in annual net revenues of $14 billion, and an additional 6 million people reached, while a decrease in the initial crop price results in a lower application area (by 8 million ha), a reduction in net revenues (by $13 billion), and a decline in rural population reached (82 million), compared to the baseline.

In terms of water use, water consumption increases significantly under scenarios that result in an increase in treadle pump expansion.

Table 6. Predictive modeling results for the potential expansion of treadle pumps, scenario results

	Baseline	-50% irrigation cost	+ 50% irrigation costs	-30% initial crop price	+ 30% initial crop price	Farmer financing
Area (thousand ha.)	24,347	25,162	21,830	16,003	24,972	18,669
Rural population reached (thousand people)	243,267	251,841	218,006	161,661	249,360	186,324
Net revenue (US$ billion)	19.30	22.55	16.28	6.59	33.36	16.19
Water consumption (billion m^3/yr)	54.84	55.37	51.54	39.02	56.97	43.15
Irrigation water consumption increase (%)	80.46	81.25	75.62	57.25	83.59	63.31

Source: IFPRI Team

Note: Results shown are for all of SSA

A 50 percent decrease in irrigation costs or a 30 percent increase in initial crop price would increase water use by an additional 1 billion or 2 billion m^3/yr, respectively, compared to the baseline. Groundwater resources are important to the expansion of treadle pumps. The baseline scenario assumed that limited groundwater was available to support the expansion of treadle pumps. However, when groundwater is excluded as a water source, area potential for treadle pumps drops to 19 million ha for all of SSA.

The impacts of climate change on the application potential of treadle pumps across SSA were also estimated under two climate scenarios projected by the CSIRO-Mk3.0 model (Csia) and the CNRM-CM3 model (Cnra) (Table 7). In a preliminary analysis, the two scenarios were identified as the "driest" and "wettest" scenarios, respectively, among 12 future climate change scenarios projected by general circulation models for SSA. We use the A2 SRES emissions scenario. The results in Table 7 show that changes in the estimated application area due to climate change range from -7 percent to +9 percent.

Table 7. Ex-ante and predictive modeling results for the potential expansion of treadle pumps under climate change

	SWAT+DREAM		
	Baseline	Csia	Cnra
Area (thousand ha)	24,347	22,579	26,647
Rural population reached (thousand people)	243,267	225,845	266,592
Net revenue (billion dollars)	19.30	17.18	18.29
Water consumption (billion m^3/year)	54.84	50.87	59.97
Irrigation water consumption increase (%)	80.46	74.64	87.99

Source IFPRI Team.
Note: Results shown are for all of SSA. Climate factors were not part of the ex-ante analysis criteria for treadle pumps

Conclusions

Treadle pumps have a large potential for expansion in SSA in terms of application area, net revenue, and rural population reached, although the estimated numerical values of these measures are highly sensitive to the assumptions made in the assessment.

The expansion of treadle pumps may be constrained by various factors, including the physical scarcity of water in the dry season. Both "hard" and "soft" constraints on water availability were imposed in the assessment. Under these constraints, the expansion of treadle pumps in SSA would consume an additional 55 billion m^3 of water per year, an 80 percent increase over current water use.

The largest potential competitor of treadle pumps will be motor pumps that significantly reduce labor costs and are increasingly becoming available in SSA. However, motor pumps remain somewhat more expensive and rely on external fuel sources.

Treadle pumps can be the way forward for poor farmers.