Impacts of Conservation Agriculture with Small-Scale Irrigation in the Sub-Humid Ethiopian Highlands: An Experiment and Modeling Study

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Innovation Labs: Small Scale Irrigation, Sustainable Intensification

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Background

- Agricultural practice: traditional tillage, rainfed, limited irrigation (4-5% of irrigable land)
- Poor rainwater management, loss of soil fertility
- Climate variability is high (CV for rainfall = 15-50%)
- This poses major risk to rainfed crop production, major agricultural practice in the region
- Extensification approach; at the cost of forest and plantation

Population ~ 110 million, 2.5% increase every year

Population ~ 54 million

Population ~ 27 million
Proposed approach and goals

- Intensification approach: conservation agriculture (CA) and enable small-scale irrigation through user friendly water-lifting technique
- Goals: improve water productivity, soil quality, and crop yield while minimizing the adverse effect of agriculture on the environment: scaling-up the intervention and evaluate large-scale impacts

Improve water-lifting technique
Experimental design and site description

- Paired ‘t’ design on a 100 m² plot; 50 m² is randomly assigned to CA and the other half for conventional tillage (CT); 13 –farmers
- In CA practice farmers put organic mulch (grass) on their plots with no-till practice where as CT is the control (traditional) both with rotation
- Drip irrigation was installed for both CA and CT from groundwater source and stored in tanks (500 L) 1.5 m high for gravity irrigation
- Chromic Luvisols; sandy clay loam (51 % sand, 27% clay), hydrologic group C
- Climate; annual rainfall (1350 – 1750 mm), temperature (8 – 30 °C)
Experimental setup and training

- Measurement
- Bed preparation
- Drip layout
- Randomization
- Mulch application

- Discussion with farmers
- On-farm farmers training
- On-farm data template
- iFarmCA App
Data collection summary

Data format/template

- **iFarmCA data upload using iPhone**
- **Data Search**
  - **Username**
  - **Crop**
  - **Plot**
  - **Location**
  - **Begin Date**
  - **End Date**

Other data sources

<table>
<thead>
<tr>
<th>Data</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land use</td>
<td>World Land Use Database (LADA)</td>
</tr>
<tr>
<td>Soil</td>
<td>African Soil Information System (AFSIS)</td>
</tr>
<tr>
<td>DEM</td>
<td>United States Geographic Survey (USGS)</td>
</tr>
<tr>
<td>Population density</td>
<td>Global Gridded Population Database</td>
</tr>
<tr>
<td>MODIS ET</td>
<td>MOD16 Global Terrestrial ET dataset</td>
</tr>
<tr>
<td>Borehole yield and groundwater depth</td>
<td>British Geological Survey (BGS)</td>
</tr>
<tr>
<td>Climate</td>
<td>Ethiopian National Metrological Agency (ENMA)</td>
</tr>
</tbody>
</table>

**Biophysical data:** Land preparation, mulch application date/amount (kg/m²), planting detail, plant density, irrigation, fertilizer/pesticides application, mulch application date/amount (kg/m²), harvesting dates, crop yield

**Economical data:** Labor hour; in planting, harvesting, tilling, mulching, weeding, water-tank fill, fertilizer/pesticide application

**Cost data:** seed, fertilizer, pesticide
Experiment: one-tailed paired ‘t’ test

- Water productivity: crop yield per cubic metric water consumption
- Hypothesis:
  \[ H_1: \mu_d > 0 \ (\text{water productivity}) \]
  \[ HO: \mu_d = 0 \]
- One-tailed paired-t test:
  \[ t = \frac{\mu_d - 0}{S_d/\sqrt{n}} \] follows \( t_{n-1} \) distribution
  \[ d_i = CA_i - CT_i \]
- Significance level: \( \alpha = 5\% \)
- \( t > t_{n-1,a} \) or \( p-value < \alpha \); Reject \( Ho \)
APEX modeling: hydrology (water management) and crop yield

- APEX hydrology and crop yield components were validated using field data (stream flow and crop yield)
Scaling-up CA with drip irrigation: APEX model, MCE-GIS based technique

MCE Technique

Land use → DEM → Population density → Road network → Soil → Weather data → Crop management → Groundwater recharge and depth to groundwater

Slope → Euclidian distance → Unique APEX model (soil texture * rainfall regime) → APEX model combination → Optimized suitability > 85%

Reclassify → Overlaying weighted factors → Constraints → Preliminary irrigation suitability → Potential irrigable land

Groundwater potential

Modeling

Constraints → Preliminary irrigation suitability → Optimized suitability > 85% → Potential irrigable land

Upscaling

Soil texture → rainfall regime
- Water productivity significantly increased ($\alpha = 0.05$) under CA in Dangishita
  - Garlic ~ 100% increase
  - Onion ~ 120% increase
- Water productivity significantly increased ($\alpha = 0.05$) under CA in Robit
  Tomato ~ 222% increase
  Cabbage ~ 33% increase
The degree of the impacts of CA varies based on crop type, weather, water input, etc.

Modeling Results: Impacts of CA on hydrology/water management

<table>
<thead>
<tr>
<th>Hydrology</th>
<th>Dangishita, Ethiopia (% change in CA)</th>
<th>Robit, Ethiopia (% change in CA)</th>
<th>Significance ($\alpha = 0.05$) $P(T&lt;=t)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evapotranspiration</td>
<td>-33 - 49</td>
<td>-28 - 44</td>
<td>0.0004</td>
</tr>
<tr>
<td>Runoff</td>
<td>-17 - 54</td>
<td>-34 - 62</td>
<td>0.039</td>
</tr>
<tr>
<td>Irrigation</td>
<td>-15 - 44</td>
<td>-18 - 34</td>
<td>0.0001</td>
</tr>
<tr>
<td>Percolation</td>
<td>+173 - 231</td>
<td>+52 - 312</td>
<td>0.009</td>
</tr>
<tr>
<td>Soil water content</td>
<td>+12 - 15</td>
<td>+12 - 28</td>
<td>0.0004</td>
</tr>
</tbody>
</table>

If the impacts of CA vary based on crop type, weather, water input, etc.
Modeling Results: Impacts of CA on hydrology/water management

- Significant crop yield increase; 8.3 – 12.9 tha\(^{-1}\) under CA with drip versus 7.9 tha\(^{-1}\) national average under CT
- Groundwater could supply 1.4 – 3.5 Mha under CA; 17% of the irrigable land (18.7 Mha) versus 0.6 Mha in CT
- Oromia and Amhara states constitute about 61% of the nation’s groundwater potential.

Note: Administrative regions (TG- Tigray, AM – Amhara, AF – Afar, BG- Benshangul Gumaz, AD- Addis Ababa, DD- Dire Dawa, GP-Gambela Peoples, SNNP- Southern Nations, Nationalities and Peoples, SM- Somali)
Conclusions/Lessons/

- **Crop yield** significantly improved under CA; garlic (+46 to 56%), onion (+44%), tomato (+184%), and cabbage (+9%); and **irrigation water** use reduced by 15 to 44%

- **Water productivity** significantly (α = 0.05) increased under CA when compared to CT; 33 to 222%

- **Agricultural water management** was substantially improved under CA; evapotranspiration (-28 to 49%), runoff (-17 to 62%), percolation (+52 to 312%), and soil moisture (+12 to 28%)

- **Groundwater** significantly improved; 1.4 to 3.5 Mha in the nation if CA with drip irrigation practiced (versus 0.6 Mha with tilled system); crop yield improved for instance cabbage, 8.3 – 12.9 tha⁻¹ versus 7.9 tha⁻¹

- **CA with drip irrigation** is found to be an ideal approach for sustainable intensification

- **Competitive use of mulch** is a limiting factor to expand CA practice
Research outputs/publications/


If you are a modeler, go to the field and feel the difference!!!

Thank You