Investigating the Impact of the Irrigation Method on Profitability of Smallholder Gardening: Incorporating HYDRUS-1D into a Decision Support System

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Abstract

Dry-season irrigation in tropical developing regions provides many households with both nutritional and monetary supplements. Optimizing production from these small-scale gardens is complicated by the unpredictability of water amounts available throughout the season, as well as the time, labor, and capital constraints common to subsistence livelihoods. Drip irrigation, known mostly for its high water use efficiency, holds additional benefits of time savings in comparison to a conventional hand-watering of smallholder gardens. The HYDRUS-1D software was incorporated into the Microsoft® Excel-based Decision Support System (DSS) to model and compare the economic performance of these two irrigation methods under a holistic range of agronomic, labor, and water parameter values. Results of this investigation suggest that, due to the tradeoff between capital costs and time-savings, drip irrigation does not always result in optimal net revenue as compared to hand-watering. We identified a linear relationship between the rate of revenue earned and the ratio between water and time availability for both irrigation methods. While these relationships are nearly identical, they reach a unique threshold value after which water becomes a limiting factor. The value of this threshold is lower for hand watering because the amount of water applied per unit of working time is less, thus labor becomes a limiting constraint at lower water supply levels. Drip irrigation allows labor to earn higher revenue at sufficient water supplies. Thus, it should be promoted where labor is relatively limiting.

1. Introduction

Dry-season irrigation in remote areas of tropical developing regions provides many households with both nutritional and monetary supplements. Often, smallholders depend on traditional (unimproved) water sources for meeting their irrigation needs, which are highly seasonal and many times unreliable throughout the length of the season: dams, ponds, ephemeral streams, or hand-dug shallow wells. Optimizing profits from these small-scale gardens is complicated by the unpredictability of water amounts available through the season as well as the time, labor, and capital constraints common to subsistence livelihoods. In resource-poor communities, labor commitments may replace cash payments for critical investments, such as water supplies, when coupled to income generating activities, such as irrigation (Abramson et al., 2011). Millions of smallholder farmers face the above challenges daily.

Low-cost drip irrigation has emerged as a means to address these challenges through increased water use efficiency, labor savings, and higher economic returns (Ngigi et al., 2005; Polak et al.,
A recent study quantified the time savings and economic gains associated with drip irrigation for smallholders (Woltering et al., 2011). However, no studies have investigated the economic advantages of drip irrigation against traditional hand-watering while holistically considering all relevant constraints within a sufficiently robust modeling environment. These include agronomic factors as well as labor and water availability. This study’s aim is to outline, through a representative scenario under a range of parameter values, the strategic niche of drip irrigation against hand-watering in smallholder gardens.

2. Materials and Methods

Figure 1 presents a comparison of the time and capital costs of hand-watering and drip irrigation.

![Figure 1. Relationship between work requirements, capital costs and irrigation method. Drip irrigation saves time, but requires more initial capital than hand watering. Work requirement data are adapted from Woltering (2011).](image)

The HYDRUS-1D modeling environment (Šimůnek et al., 2008) was incorporated into a Microsoft® Excel-based Decision Support System (DSS) for investigating the economics of rural water development (Abramson, 2013). Modeled transpiration levels for field-grown tomato under a range of irrigation rates (mm day⁻¹) were obtained through a VBA-coded automation mechanism of the HYDRUS-1D software within Excel. These transpiration results were then translated into actual crop yields according to the yield-transpiration relationship investigated by Ben-Gal et al. (2003) for field-grown tomato. Various measures of time availability in the garden were input into the DSS. For 100 irrigation levels discretized between 10% and 150% of PET, total agricultural costs, comprised of capital and operation costs ($ m⁻²), were calculated along with modeled yields (kg m⁻²) and benefits ($ m⁻²).
In the DSS optimization scheme, two main constraints exist for determining the revenue generated from irrigation: availability of labor (the time constraint) and the amount of available water for irrigation (the water constraint). Optimal net benefit occurs at the maximum of:

\[
\text{Net Benefit, } \left[ \min \left( \text{Time, Water Constraint} \right) \right]
\]

where \( i \) is irrigation level (mm day\(^{-1} \)).

3. Results

In order to demonstrate the general trends of these factors, a single scenario was defined and imputed (Fig. 2).

As expected, both total yield and net benefit increase linearly with irrigation application until roughly 100% of PET. Due to the tradeoffs illustrated in Figure 1, with increasing irrigation applications, work requirements also increase, resulting in less area that can be cultivated. The optimal revenue is achieved in light of these two opposing factors.

Figure 3 demonstrates that where the time constraint is the limiting factor (i.e., allows less irrigated area than available water), drip irrigation strongly outperforms hand watering. This is because of the time savings, which translates into higher irrigated areas and higher project revenues. Figure 4 presents a generalized representation of these trends.
Figure 3. The relationship between irrigation application, labor availability, irrigation method, and project revenue for three scenarios: a) low (20 hr wk⁻¹); b) intermediate (100 hr wk⁻¹); and c) high (1,000 hr wk⁻¹) labor availability. Dotted lines represent the peak revenue achieved.
Figure 4. The relationship between available water and labor against revenue earned, expressed by the variation of the revenue rate by the ratio of available water-to-labor. Linear regression of the first (increasing) section of each line supports a constant, and nearly identical slope, which represents the revenue earned per daily water supply available ($ (m^3 \text{ day}^{-1}))$. The area to the right of the vertical dotted line represents scenarios where drip irrigation is advantageous to hand watering, and vice versa. The nearly identical slopes of the two regression lines and the unitary values of $R^2$ indicate that these trends are explained entirely by the factors investigated.

As the available water-to-labor ratio increases, the revenue rate reaches a threshold. The value of this threshold is lower for hand watering because the amount of water applied per unit of time working is less, thus labor becomes a limiting constraint at lower water supply levels. Drip irrigation allows labor to earn higher revenue where water supplies are sufficiently high in relation to time commitments. Thus, it should be promoted where labor is relatively limiting. The exact values of these figures will change according to the scenario investigated, but these trends will remain.

4. Conclusions

These results demonstrate the following:

1) While drip irrigation certainly does demonstrate applicability in low resource smallholder economies, this may be limited to very water and/or labor scarce conditions. Given the time-capital tradeoffs associated with the transition from subsistence to ‘developed’ economic status, drip irrigation finds its niche in the latter stages of this transition. Other non-market benefits, however, such as increased water use efficiency, should be included in development strategies.

2) The HYDRUS-1D software can be effectively automated for conducting Excel-based analyses through simple algorithms.
References