Productive Efficiency in Water Usage:
An Analysis of Differences among Farm Types and Sizes in Georgia

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ABSTRACT

In Georgia, the price of irrigation water is equal to the cost of extraction, including pumping and diversion, storage, treatment, and delivery costs. These water-pricing conditions are repeated in locales around the world. In lieu of established water markets, water use and its efficient use are driven more by farm-level characteristics and management strategies than by the resource price. The purpose of the research presented herein is to examine what factors guide Georgia farmers' water use decisions. Using data envelopment analysis (DEA) to calculate technical water use efficiency scores, a second step Tobit model is estimated to determine the effect of farm type and farm size. A farms' use of conservation tillage or organic farming positively affected their water use efficiency, while farms of smaller size or solely owned were more inefficient in water use.

1 INTRODUCTION

The United Nations predicts that the earth's population will increase by nearly 40 percent until reaching a peak in 2075 at a level of 9.22 billion, at which point population will slowly stabilize to a level of 8.97 billion by the year 2300 (United Nations. Dept. of Economic and Social Affairs. Population Division., 2004). While population is by no means the sole determinant of water consumption, it does serve as a good proxy in understanding the relationship between current and future water demand. It is generally agreed that regardless of population changes, water consumption, by means of food consumption, will continue to increase through economic development leading to increased affinity and subsequent demand for water intensive protein sources. It is projected that irrigated agriculture will account for 72 percent of total water withdrawals while accounting for 44 percent of total agricultural production in 2025 (Rosegrant, et al., 2002). These forces have resulted in increasing efforts to assess the water management potential in agriculture.

In developed nations gains from economic growth and a traditionally greater access to freshwater resources, has lead to a high per capita use of water. In the United States, 11.6 percent of cropland is under some form of irrigation with more than 60 percent of total water withdrawals being used for this purpose. In Georgia, between the 1997 and 2002 Census of Agriculture, there was a 10.5 percent increase in the amount of irrigated acreage equating to 18.1 percent of the 4.68 million acres of cropland (United States. National Agricultural Statistics Service., 2004). While this trend in increasing levels of irrigated lands is leveling off rapidly, it is certainly not decreasing. As a result, the water used for agriculture, will likely serve as a continued, and dominant, user of water in the United States and Georgia specifically. Until recently, water quantity has not been of much concern in the Southeastern United States, but in the midst of a recent drought induced water crunch, the vulnerability of the region's current water sources have been called into question. Agricultural, environmental, and urban stakeholders seek continued and reliable access to the water resources that have been historically available.

In the state of Georgia, it is estimated that roughly 10.74 million acres, or 29 percent of the total land area, are owned as farmland. Of this land, 3.25 million acres produced harvested cropland in 2002 with estimates of irrigated acreage ranging between 850 thousand and 1.5 million acres (Harrison, 2005, United States. National Agricultural Statistics Service., 2004). Georgia ranks first in the nation in the production of broilers (young chickens weighing less than two and a half pounds), peanuts, and pecans. Agriculture is the most economically important sector of the economy, with food, fiber, and related industries accounting for 16 percent (or $56 billion) of Georgia's total economic output (nearly $353 billion). Furthermore, one in seven residents (15 percent) of Georgia works in agriculture, forestry, or a related field (Flatt, 2004).

Agricultural water use in Georgia, and much of the southeast, is characterized by a multitude of distinguishing dimensions. The variable cost of irrigation water is a function of the extraction costs, the most significant of which, in most cases, is the fuel or electricity required to pump the water from a ground or surface water source. The nature of this irrigation is largely supplementary, because Georgia is characterized by a hot, moist growing season with an average rainfall of 40 inches, and the average amount applied is equivalent to one acre-foot of water, per acre, per growing season[1] (Cummings, et al., 2003, Evans, et al., 1998).

Much attention to water management has been directed to agriculture, though analysis of the factors affecting variability in water usage productive efficiency among farmers has been historically neglected. It is important that these factors be analyzed in order to evaluate the effectiveness of future implementation of various policies and extension assistance. Using a contingent behavior survey, differences in intra-agriculture water usage are analyzed along two dimensions specifically: farm type and farm size. It is hypothesized that additional productive efficiency with water is accounted for in alternative agricultural practices, such as organic and conservation tillage, compared to conventional agricultural practices, and that increasing farm size also yields improved productive efficiency with water.

Large and small farms often have different objectives and motivations when engaging in farming, and therefore their observance of water productivity is disparate when appropriate pricing and other policies are in place. In terms of water usage measured on the basis of average number of hours irrigated per acre, large farms are more efficient while small farms tend to be less efficient (Skaggs and Samani, 2005). In the same way, organic farms typically

[1] Cummings reports that irrigation withdraws in wet years (those years with above average precipitation) are as low as 4 inches per acre, or 1/3 acre-foot of water, 7 inches in average years, or .5833 acre-feet of water, and as high as 18 inches in years of severe drought, or 1.5 acre-feet of water.

are categorized within the small farm classification but emphasize a management methodology of sustainability. Comparatively, little is known on the degree to which water use on organic farms is efficient in practice. In turn, policy must respond to farm-level differences in objectives of farming and other identified farm characteristics.

2 *BACKGROUND*

2.1 Determinants of Water Use Efficiency

Water is an economically complex resource with increasing scarcity, and in many settings is a common property resource. That is to say, it is a resource owned by a common (a group of people enjoying similar rights) and managed according to the adopted social institutions of the common (Griffin, 2006). The term "tragedy of the commons" as expressed by Hardin refers to the problem of open access resources (those resources in which there is an absence of management rules) and has been restated by economists as a situation in which individual users seek to maximize self-interest (Hardin, 1968). The socially efficient solution is when individuals equate marginal benefits to marginal costs, and in an open access situation, marginal net benefits are driven to zero by the individual decisions. It is easy to imagine that if this behavior was fully realized by all individuals, decrement of the resource is a likely scenario.

Water used in Georgia agriculture currently has no cost and very limited restrictions (in the form of permitting) associated with its use. The only variable cost is that of extraction.

According to one study, water scarcity is not a factor when farmer's make decisions about irrigating and how much water to use (Gonzalez-Alvarez, et al., 2006). It is difficult for farmers to make socially optimal economic decisions concerning water allocation and conservation, when the current pricing of water does not make improving irrigation efficiency economically efficient in most situations. More precisely, water losses or inefficiencies are in fact optimally used unless the cost of preventing such losses is less than the value of the water saved (Griffin, 2006).

Norman et al. review that the factors which are external and internal to the farm, and influence farmers' practices relating to water management, are not well understood, particularly at the smallholder irrigation level within the context of agricultural development (Norman, et al., 2008).). In both developed and developing countries, it was found that farm level allocation of labor between agriculture and other economic pursuits is correlated with irrigation efficiency; there exists a negative relationship between off-farm income and irrigation efficiency (Abernethy, et al., 2000, Skaggs and Samani, 2005).

As stated earlier, few studies have directly assessed the determinants of productive efficiency of water. Most recently, Speelman et al. (2008) employed a two-stage date envelopment analysis (DEA) / Tobit model to review the determinants of water efficiency, concluding that farm size, land ownership, irrigation method, and crop choice were significant factors for smallholder farmers in South Africa. In one of the few studies conducted in developed countries, Skaggs and Samani (2005) assessed this concern over intra-agriculture water use variability, and found, through interviews and a comparison of hours irrigated per irrigation event, that the smallest farms lacked interest in improving their current, inefficient irrigation systems or methods in New Mexico. The findings were attributed to the prevailing characteristic of small farms--residential/lifestyle/retirement agriculture environment in which profit is not a discernable motivation for farming--such that irrigating is viewed as a cost of living/recreation as opposed to an operational business expense as realized by larger, commercial farms.

Table 1:
Potential irrigation water productivity rates

		Range (%)	Average (%)
Sprinkler	Solid Set	60 – 80	70
	Center Pivot	70 – 85	75
	Linear Move	60 – 70	65
	Big Gun	55 – 65	60
	Traveler	55 – 70	60
Drip/Trickle		80 – 98	90

On a purely functional level, different irrigation technologies have a variety of associated water application characteristics and efficiency potentials. Water productivity (also referred to as application efficiency in other studies), or the ratio of water reaching the root zone to total water applied, for the irrigation systems commonly installed in the Southeastern United States, are detailed in the preceding table, Table 1(Evans, 2006). A center pivot is the predominant irrigation system used for corn, cotton, peanuts, soybeans, sorghum, Vidalia onions, watermelons, and wheat. For tobacco, a traveler system is predominant, and for peaches, the systems are divided between drip/trickle and traveler. Application efficiency constraints exist with any particular irrigation technology but inefficiency of a particular system is also related to regular maintenance and monitoring. However, not all irrigation systems are feasible alternatives for the particular crop being grown. One possible conclusion to this information is that a transition to more efficient trickle systems, where applicable, could result in up to a 20 percent gain in water productivity when replacing center pivot sprinklers. In contrast, Mollá (Garrido, 2001) and others have shown that after transitioning to drip irrigation technologies, irrigators have not reduced application rates.

2.2 Organic Agriculture and Conservation Tillage

A large body of agronomic and soil science literature concludes that organic agriculture and conservation tillage can be effective management strategies for enhancing soil quality/health and thereby increasing soil water storage and water infiltration (Doran, 2002, Reeves, et al., 2005, Triplett, et al., 1968). These characteristics translate into less irrigation water needing to be applied in order to achieve the same desired results. In regard to production, on average, organic farms are more efficient relative to their own technology, but use a less productive technology than conventional farms (Oude Lansink, et al., 2002). As such, our a priori expectation is that farms practicing such management techniques will be more efficient users of water than conventional farming; however, agricultural practices less sensitive to soil management may necessitate increased irrigation to maintain productivity on degraded soils (Tillman, et al., 2002).

3 METHODS

3.1 Efficiency Measures and Farm Characteristics

This paper looks at two aspects of efficiently: technical efficiency and productive efficiency. More specifically our analysis seeks to determine farm-level, input-specific technical and productive efficiency measures for agricultural water use. In general, input-specific technical efficiency indicates the ratio of minimum potential input required to produce the given output, while productive efficiency is the product of technical efficiency and allocative efficiency (Lovell, 1993). Input-specific productive efficiency as addressed hereto is the ratio of actual output to potential output for a given level of water, ceteris paribus.

Data envelopment analysis (DEA) lends itself well to calculating input-specific, or sub-vector, technical efficiency measures and is more appropriate for smaller samples as opposed to econometric methods such as stochastic frontier analysis (Faïre, et al., 1994). Following a variable returns to scale, input-oriented specification in which weak disposability of the fixed input (land) and strong disposability of all other variable inputs (labor, water, fertilizer, insecticide, and compost) and output (farm revenue) is assumed.

Using DEA calculated measures, censored between 0 and 1, of technical water use efficiency as the dependent variable, a Tobit model is employed to determine the relationship between farm type, size, and other sample characteristics. The independent variables include farm-level characteristics and demographic information. The key farm-level characteristic is the type of farming method currently employed, coded as multiple dichotomous dummy variables equal to one for those practicing a particular agricultural technique and zero for those who farm without such method. Past research has not compared water usage between organic or conservation tillage and conventional farms. Production acreage is used as the primary measure of farm size's affect on water efficiency.

Additional farm-level traits include business structure of the farm, labor employed, time spent farming, irrigation acreage allocation decisions, cropping pattern, crops grown, acres under irrigation, type of irrigation equipment used, years of farming experience, and motivation for farming. In considering water usage, various crops have different water needs and are useful control variables. Similarly, variability in irrigation technology application rates requires a control for what kind of irrigation equipment is used. The variables of business structure and motivation for farming are particularly useful for analyzing the relationship between factors which are internal and endogenous to the farm with water usage.

3.2 Data

This study uses researcher collected survey data on organic farms, conventional farms, and other farms employing conservation/reduced tillage techniques in order to investigate differences in water use decisions between farmers with different agricultural methods. 769 total farms were surveyed in Georgia. Participants were mailed the survey with all responses being voluntary. After 7 days, non-respondents were followed sent a follow-up reminder postcard. Following another three weeks, the remaining non-respondents were sent a second copy of the survey[2]. Pre-survey, farm types were identified based on affiliation to regional growers' associations. Table 2 reflects the sample representation of the identified types of farms and response rates to date.

Table 2:
Survey sample and response rates

Farm type	Sample size (%)	Undeliverable	Received	Response Rate
Total	769	67	93	13.2 %
Conventional	435 (56.6)	50	26	6.8%
Conservation Tillage	173 (22.5)	11	35	21.6 %
Organic	161 (20.9)	6	32	20.6 %

Each survey participant was asked questions concerning farm demographics, production and water usage decisions. This information included farm acreage, acres irrigated by crop, labor, average acre-inches of water applied, chemical use, and the degree to which various management strategies were employed, such as conservation tillage, organic agriculture, cover cropping, green manure, etc. Table 3 shows the observed characteristics and their independent relationship to total irrigated water applied.

Table 3:
Pearson correlations between farm characteristics and total water use

Variable	Correlation
Age	-0.097
Full-time farmer	0.276*
Solely owned	-0.239*
Production acreage	0.583*
Percentage of land owned	-0.313*
Conservation tillage	0.297*
Organic agriculture	-0.224
Cover cropping	0.205
Green manure	-0.217

* indicates 95% significance level

[2] Second mailing underway as of 4/24/09

Spatial variables such as primary soil type, rainfall, and evapotranspiration measures will be verified using a Geographic Information Systems (GIS) based U.S. General Soil Map (STATSGO) soils database from the Natural Resources Conservation Service of the USDA and Oregon State's PRISM Group precipitation data sets. The precipitation data sets are compiled monthly and are available from the current calendar year back to 1895.

4 RESULTS AND DISCUSSION

According to initial results, the average overall technical efficiency and sub-vector water efficiency for the VRS DEA model were 0.67 and 0.43 respectively. This indicates that these farms could reduce the use of all inputs by 33 percent or water only by 57 percent without reducing output. These preliminary results are subject to further analysis after the survey delivery regimen is completed.

The Tobit model results suggest that farms employing conservation tillage and/or organic agriculture have greater technical water use efficiency relative to conventional farms; however, cover cropping is negatively related to efficiency. Additional inferences can be made regarding farm size: as production acreage increases, efficiency increases. If a farm is solely owned, they are more inefficient in water use than partnership/corporation business models.

The absorption and retention of water in the soil, due to good soil structure associated with abundant soil life and organic matter, will probably offer some of the most cost-effective approaches to mitigating water shortages for agriculture. Remedying low organic matter is a necessary but not sufficient condition for better crop performance (Doran, 2002). Reliance on plowing and agrochemical use has diminished soil capacities rather than augmenting them (Franzluebbers, 2002). From this lens, it is not a surprise that organic farms and/or those practicing conservation tillage techniques are more efficient users of water. Alternatively, one could imagine that those farmers who do engage in these practices are not doing so because of any improved input efficiency generated by soil capacity, but simply a mindset of sustainability that drives a motivation to reduce all inputs or to conserve resources. Further rationale for these initial results regarding increased technical water use efficiency with organic agricultural practices is the price premium of organically produced foodstuffs.

The slogan "more crop per drop" has been promoted globally in an effort to expand agricultural production with a finite water supply. This research adds to a growing understanding of what factors and management strategies affect technical water use efficiency at the farm-level.

5 REFERENCES

Abernethy, C. L., et al. (2000) Farmer-based financing of operations in the Niger Valley irrigation schemes, pp. v + 35 pp.

Cummings, R. G., C. A. Holt, and S. Laury. "Using Laboratory Experiments for Policy Making: An Example from the Georgia Irrigation Reduction Auction." Georgia State University, Andrew Young School of Policy Studies September 2003.

Doran, J. W. "Soil health and global sustainability: translating science into practice." *Agriculture, Ecosystems & Environment* 88, no. 2(2002): 119-127.

Evans, R. G. "Irrigation Technologies." USDA-ARS-NPARL.

Evans, R. O., et al. "Irrigation conservation practices appropriate for the Southeastern United States." Georgia Geologic Survey, Georgia Department Of Natural Resources, Environmental Protection Division, 1998.

Faïre, R., S. Grosskopf, and C. A. K. Lovell. *Production Frontiers*. New York, USA: Cambridge University Press, 1994.

Flatt, W. P. (2004) Agriculture in Georgia: Overview.

Franzluebbers, A. J. "Soil organic matter stratification ratio as an indicator of soil quality." *Soil and Tillage Research* 66, no. 2(2002): 95-106.

Garrido, A. "Transition to Full-cost Pricing of Irrigation Water for Agriculture in OECD Countries." Organisation for Economic Co-operation and Development, Environment Directorate and Directorate for Food, Agriculture and Fisheries, February 21, 2002.

Gonzalez-Alvarez, Y., A. G. Keeler, and J. D. Mullen. "Farm-level irrigation and the marginal cost of water use: Evidence from Georgia." *Journal of Environmental Management* 80, no. 4(2006): 311-317.

Griffin, R. C. *Water resource economics : the analysis of scarcity, policies, and projects*. Cambridge, Mass.: MIT Press, 2006.

Hardin, G. "The Tragedy of the Commons." *Science* 162, no. 3859(1968): 1243-1248.

Harrison, K. A. (2005) Irrigation Survey for Georgia, ed. K. J. Hatcher. Univ. of Georgia Institute of Ecology, Athens, Ga.

Lovell, C. A. K. (1993) Production frontiers and productive efficiency, ed. C. A. K. Lovell, H. O. Fried, and S. S. Schmidt. New York, NY, Oxford University Press, pp. 440.

Norman, W., I. McCann, and A. Al-Ghafri. "On-farm labour allocation and irrigation water use: case studies among smallholder systems in arid regions." *Irrigation and Drainage Systems* 22, no. 1(2008): 79-92.

Oude Lansink, A., K. Pietola, and S. Backman. "Efficiency and Productivity of Conventional and Organic Farms in Finland 1994-1997." *European Review of Agricultural Economics* 29 1(2002): 51-65.

Reeves, D. W., et al. (2005) Conservation Tillage in Georgia: Economics and Water Resources, ed. K. J. Hatcher. Univ. of Georgia Institute of Ecology, Athens, Ga.

Rosegrant, M. W., X. Cai, and S. A. Cline. "Global Water Outlook to 2025: Averting an Impending Crisis." International Food Policy Research Institute;

International Water Management Institute.

Skaggs, R. K., and Z. Samani. "Farm size, irrigation practices, and on-farm irrigation efficiency." *Irrigation and Drainage* 54, no. 1(2005): 43 -57.

Speelman, S., et al. "A measure for the efficiency of water use and its determinants, a case study of small-scale irrigation schemes in North-West Province, South Africa." *Agricultural Systems* 98, no. 1(2008): 31-39.

Tillman, D., et al. "Agricultural sustainability and intensive production practices." *Nature* 418, no. 6898(2002): 671-677.

Triplett, G. B., Jr., D. M. Van Doren, Jr., and B. L. Schmidt. "Effect of Corn (Zea mays L.) Stover Mulch on No-Tillage Corn Yield and Water Infiltration." *Agron J* 60, no. 2(1968): 236-239.

United Nations. Dept. of Economic and Social Affairs. Population Division. *World population to 2300*. New York: United Nations, 2004.

United States. National Agricultural Statistics Service. (2004) 2002 Census of Agriculture. Washington, D.C., U.S. Dept. of Agriculture, National Agricultural Statistics Service.