On-farm labour allocation and water use in smallholder irrigation systems: lessons from Africa and Arabia

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Abstract

Using experience and specific case studies from sub-Saharan Africa and South-eastern Arabia, this paper addresses fundamental issues of labour allocation for on-farm water management. Farming practices within smallholder irrigation systems are reviewed, with particular reference to the trade-off between farm labour and water. Factors which affect farming decision-making for labour allocation and the qualitative and quantitative effects of these allocations are examined in detail. Based on these findings, the paper concludes by encouraging a better understanding of labour allocation practices for water management, and summarizes considerations for more effective planning, design and management of smallholder systems.
Keywords: irrigation, water management, labour, on-farm, water use, water costs, smallholder systems, planning, design, decision-making.

1 Introduction

In the world's arid regions, many countries with developing economies continue to look to agricultural intensification through efficient irrigation technologies and methods as an important part of achieving national economic and nutritional sustainability. Over the years, significant political and financial investments have been made to develop sophisticated, large-scale systems in these regions, although most irrigated production today remains within smallholder systems where surface irrigation is generally employed. More recently there have been enhanced efforts to rehabilitate old systems and to employ more appropriate and efficient technologies and management practices; and the FAO has renewed its call to increase support for smallholder farming with special attention to water management. (FAO [1], Giri [2] and Alam [3].)

Yet, in spite of these efforts, comparatively little is understood about farmer practices relating to water management to date – notably that of factors, both internal and external to the farm, which influence how farmers choose to allocate available resources for the management of water within the farm parcel. This paper attempts to fill this void, at least in part, by examining on-farm water management and related labour allocation practices. Factors which affect such labour use are multiple, and often interconnected and complex. A review of both quantitative and qualitative data, taken from a number of separate case studies conducted in smallholder systems in West Africa and South-eastern Arabia, provides the opportunity to examine some of these determinants more closely and to characterize some aspects of on-farm water use.

2 Methods

2.1 Systems typology

The practices that farmers employ within their farm parcels are greatly influenced by the type of system in which they work. For this reason, it is useful to group smallholder systems into one of two general categories. *Single-source/single-user* systems (henceforth referred to as "individual" systems) are those having a single source of water (such as a well, a spring or a surface water body) that is exploited and managed exclusively by the individual or his household. These systems are usually privately-owned and farmers generally exert full control over the volume and frequency of irrigations – only being limited by water availability and the costs of extraction and/or conveyance to the farm parcel. Typically, in arid regions of Africa, the majority of traditional/indigenous irrigation systems fall into this category. *Single-source/multiple-user* systems (henceforth referred to as "shared" systems) are those in which a single water source (such as a reservoir or large river pumping station) is shared by a community of water users. These systems are often government-sponsored and both system-wide and on-farm (parcel) water management are generally influenced by an irrigation bureaucracy or water user's association. While some traditional systems fall into this category, most newly developed and/or public systems constructed over the last 50 years in developing regions would be in this category. (Norman [4]).

2.2 Case studies

All case studies, whether individual or shared, are of systems that employ gravity-fed water distribution through canals and/or field channels. For each case study, daily farm parcel flow rates and farmer parcel water distribution times were monitored within selected sites throughout several growing seasons. Mean seasonal flow rates to the parcel (Q_p) were then determined, along with mean seasonal labour times for water distribution within the parcel (L). Crop water demand was estimated – for each crop type and parcel area – from climatic data taken directly in the field or from locally published sources. Volumetric water costs (C_w) were developed from land tax or rent figures, associated investment and depreciation costs for irrigation equipment or infrastructure, and through direct field monitoring and/or surveys of energy or labour costs (to bring water from its source to the farm parcel). (It should be added that cost related figures are taken from field studies and other data sources established at varying periods from the mid 1980's to the present, and no attempt is made to develop present-day values for these figures. However, emphasis in this paper is placed on non time-bound trends – or characterizations – yielded by the data, and not on comparison of individual figures across time periods.)

Case studies from the African Sahel region include individual *manual systems* (water hand-drawn from a shallow, open well and distributed through earthen channels among basins, usually onion cultivation, typically 0.1 ha) and individual small *pumpset systems* (similar to manual systems but where portable, fuel-powered pumps are employed, typically 0.12 ha). Shared systems include small *reservoir systems* (barrage with downstream lined-canal delivery network among parcel holders, wet season sorghum and cotton cultivated in short 10-15 m furrows, dry season onions and wheat in small 2-10 m^2 basins, usually 50-250 ha. serving 110-850 farmer parcel holders); a *tubewell system* (drawing from a network of 43 shallow tubewells, similar crops to reservoir system, 260 ha serving 525 farmer parcel holders); and a *river pumping system* (with lined canal delivery network, rice cultivation, 380 ha divided among small parcels of approximately 0.16 ha each). Detailed descriptions of these systems are provided in Norman and Walter [5], and Norman et al. [6].

Case studies from south-eastern Arabia include individual *pump systems* (water pumped from wells of 10-30 m, usually with a diesel- or electric-powered pump, alfalfa production, typically 3.5 ha) and indigenous shared systems, better known as a*flaj* (ancient systems where water is accessed by gravity flow from underground galleries or surface springs and distributed to individual farm parcels through a canal network; wheat, alfalfa and date production, 5-20 ha.). Detailed descriptions of these systems are provided in Norman et al. [7], Norman et al. [8] and Al-Ghafri [9].

2.3 Performance variables

Performance variables used to describe and characterize irrigation practices among case studies are described below. Units for each variable may vary, depending on the case study and/or time period from which they were drawn.

Labour, L: Represents the amount of labour allocated by farmers to water distribution *within* their farm parcels during the crop growing season. Units used within this paper are hours per unit volume of water distributed, L_v (hrs/m^3); hours per unit area of the farm parcel, L_a (hrs/ha); and labour costs per unit volume of water distributed, L_c (RO/m^3 or CFA/m^3), with costs given in Omani

Rials (RO) or West African francs (CFA). Labour costs are generally obtained by applying monitored seasonal labour allocation (hrs) to local hourly wage labour rates observed during the growing season.

Parcel Flow Rate, Q_p: Generally described as "mean parcel flow rate", that is, the irrigation delivery rate to the farm parcel. These are mean seasonal values given in unit volume over time (l/s or m^3/hr).

Water Costs, C_w: This variable describes the actual cost the farmer incurs for water delivered to the parcel during the growing season, as a function of observed irrigation supply. Units used are RO or CFA per unit volume of water (CFA/m^3, RO/m^3).

Irrigation Efficiency, EFF: A standard irrigation engineering variable relating crop water demand to the actual amount of water supplied (Burman et al., [10]), and is obtained from the ratio of estimated crop water demand to observed irrigation supply at the parcel level; given in percent (%). In general, an EFF of 60% is often used in the design of surface systems to accommodate crop water needs and anticipated operational losses. Values below this level would normally be considered unacceptable while values above 100% may indicate that maximum potential crop yields are not obtained.

3 Results and discussion

3.1 Determinants of parcel flow rates

Most smallholder systems employ surface irrigation methods for farm parcel water distribution, usually a system of flooded basins (or short level-impoundment furrows) served by small earthen channels. These require manual opening and closing with each water application – a very labour intensive activity. Among shared, government-sponsored systems in the Sahel, farmers generally allocate about 350 hrs/ha for on-farm water distribution. Private individual systems employing gasoline-powered pumpsets may require three to four times this amount, while labour for both water lifting and simultaneous field distribution in manual systems may be as high as 3,000 hrs/ha. (Norman and Walter [5], Norman and Walter [11]).

A number of complex and interdependent factors influence how labour may be allocated for farm parcel water distribution. These may include: soil type and methods of land preparation (levelling, basin or furrow preparation, etc.), control over volume and timing of irrigations delivered to the parcel (i.e., individual-, community- or bureaucracy-controlled), competing demands on household labour which are external to the irrigated farm parcel, and irrigation water costs, Norman and Walter [11]. Studies in south-eastern Arabia and the Sahel have shown that of these factors, the direct or indirect cost to the farmer for water exerts an influence on farmer decision-making that often supersedes others, Norman and Walter [5], Norman et al. [7]. These studies demonstrate that as water costs increase, farmers will often respond by using lower farm parcel irrigation flow rates and investing more labour in parcel water distribution. When water costs are low farmers will, in contrast, very quickly trade high-value labour time (normally allocated to parcel water distribution) for low-cost water by using higher irrigation rates. Data from field studies in pump systems of Arabia have shown that as volumetric costs, C_w (and corresponding water table depths) increase, farmers tend to use lower pumping rates (Q_p) during irrigation. This relationship is demonstrated in Figure 1. In this case study, the individual farmer exercises full control over both the volume and timing of irrigations, and Q_p appears to be primarily a function of water costs. Often, in larger shared systems, individual farmers exercise far less control over both volume and timing of irrigation water delivered to the parcel level. In some cases, depending on parcel location in the system (e.g., at the "tail" end of a distribution canal), farmers may encounter problems of water scarcity. In such cases, the relative "cost" of water may change significantly. Operational Q_p rates delivered to the parcel level can often be low and irregular, and as a result labour input for effective parcel water distribution may be increased dramatically.

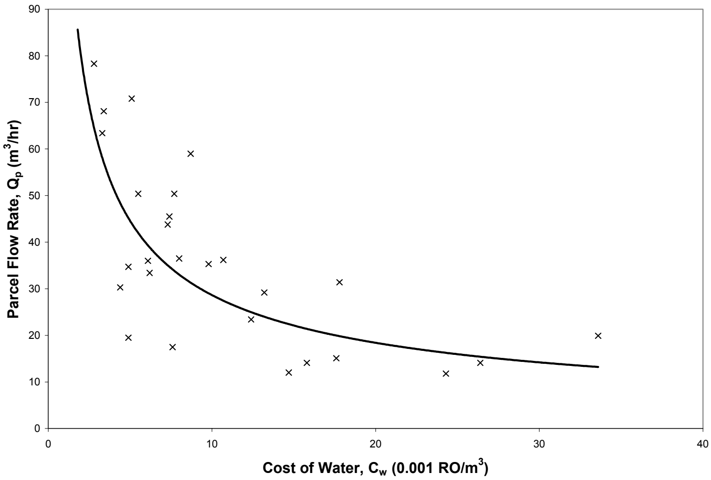

Figure 1: Farm parcel flow rates and cost of water, from a study of 26 private pumping systems in south-eastern Arabia. Source: Norman et al. [7].

3.2 Relationship between labour and parcel flow rates

Once water is delivered to the parcel and parcel delivery flow rate, Q_p, is established – either by farmer choice or by other aspects of system management or design – the farmer then decides how much labour he will allocate to on-farm water distribution. The above-mentioned exchange (or "trade-off") between labour use and parcel flow rate is demonstrated in Figure 2, for the same case study in south-eastern Arabia (Figure 1), and in Figure 3 for a group of varying system types in the Sahel. As a general rule, where there is unrestricted access to low-cost water, farmers will exchange more valuable labour, with higher operational flow rates (Q_p). The usual result is that greater volumes of water are applied in the field over a shorter time span, resulting in increased on-farm losses – primarily in the form of excess water loss below the effective crop root zone. (Norman [4], Young [12]). The relationship between water distribution labour and parcel flow rates for basin and row crops among monitored parcels within shared systems of the Sahel is demonstrated in Figures 4 and 5, respectively. In general, use of flooded basins occurs during the dry season when water tends to be scarce and higher value cash crops are grown. The use of row crop cultivation is generally restricted to the wet season when water is not a limiting factor and a greater percentage of staple (non-cash) crops are produced.

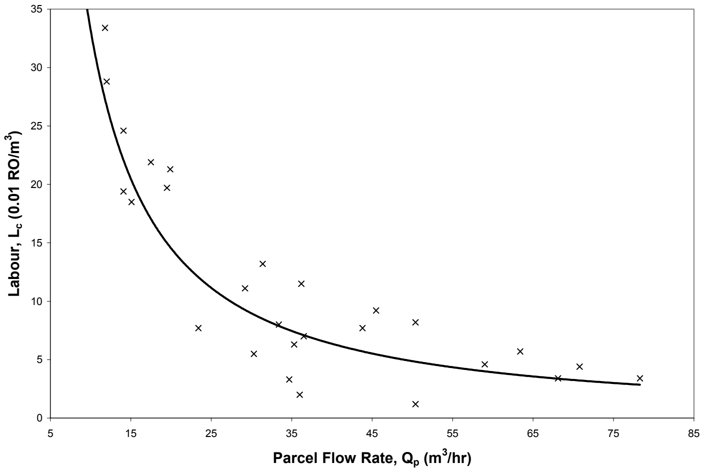

Figure 2: On-farm water distribution labour cost and farm parcel flow rates among 26 smallholder farms in south-eastern Arabia. Source: Norman et al. [7].

3.3 On-farm water use performance

In a study conducted among 18 smallholder parcels of the shared system depicted in Figure 5, mean parcel flow rates over the growing season, Q_p, ranged from 3 l/s (10.8 m^3/hr) to 15 l/s (54 m^3/hr). It was found that within this range of flow rates, on-farm water distribution labour was *reduced* by about 2 hrs/ha (for the season) for every cubic meter per hour *increase* in mean parcel flow, Q_p. There were six irrigation applications (supplemental to normal rainfall) in the course of the crop season. The farmer using the highest Q_p (15 l/s) experienced ¼ hr/ha savings in irrigation labour time on each irrigation day, as compared to the farmer operating with the lowest Q_p (3 l/s). However, labour input for various crops correlates well with the evenness of water distribution within the parcel. In the same system, it was also found that as labour for on-farm water distribution was *increased* the even distribution of water within the parcel *increased*, and vice versa. Mean L_v values (hrs/m^3) were derived from monitored parcels and found to be 0.33, 0.41 and 1.33 for cotton, maize and onion parcels, respectively (cotton and maize in furrows, onions in basins). The corresponding coefficients of variation (in %) for grid soil moisture samples taken across selected parcels 24 hours following irrigation were 33, 15 and 12, respectively. (Norman [13]).

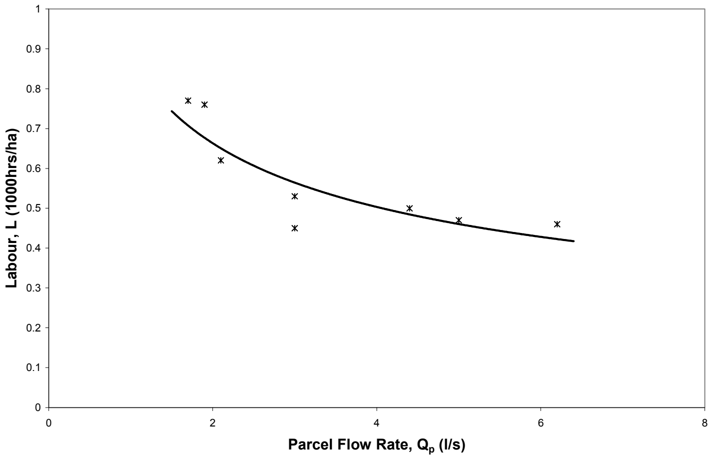

Figure 3: On-farm water distribution labour costs for basin irrigation and farm parcel flow rates among both shared and individual systems in the Sahel. Sources: Norman and Walter [5], Norman and Walter [11].

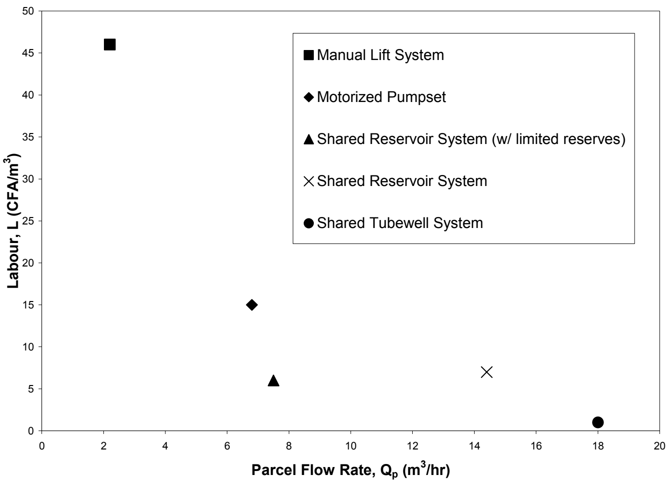

Figure 4: Seasonal water distribution labour versus flow rate for dry season *basin* crops within shared reservoir systems in the Sahel. Source: Norman [13].

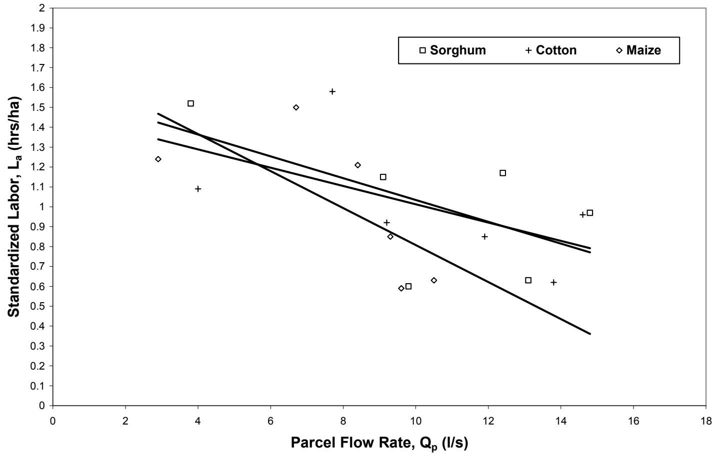

Figure 5: Seasonal water distribution labour versus flow rate for wet season row crops among shared reservoir systems in the Sahel. Labour standardized by dividing by the mean for each crop. Source: Norman [13].

As one moves from the larger shared systems, to individual pump systems, to even smaller individual manual systems, data from the Sahel indicate that irrigation water becomes more costly and time given to field water distribution (L_v) increases correspondingly, Norman and Walter [5]. While Figure 1 illustrates that lower Q_p rates are used as water costs, C_w, increase, Figure 6 (from the same case study used in Figure 1) illustrates the corresponding tendency for water to be managed more efficiently within the parcel (achieved through increased labour input) as it becomes more costly and/or scarce. This tendency, or its inverse (the tendency to use water in excess when access to it is unrestricted and/or without direct cost), has been observed elsewhere (Schram and Gonzales [14], Small and Carruthers [15], Norman et al. [6]).

3.4 Labour use changes and farmer adaptations to irrigation technologies

Households having farm parcels in smallholder irrigation systems are often engaged in a variety of other year-round or seasonal activities which demand various levels of household labour allocation. Furthermore, some household labour may be drawn outside the local community in search of better returns to investment and labour. Because of these competing demands, irrigation-related activities in the smallholder parcel may not always rank high in terms of priority labour allocation – a simple, and very common, issue in rural communities that is often not given adequate consideration in the planning and design of smallholder irrigation systems. Among shared systems in the Sahel, there is often major competition during the wet season between the household's smaller irrigated parcel and the much larger, off-system rain-fed holdings where most staple crop production occurs. At certain critical periods during this cropping season, such as planting or weeding, system parcels may actually be neglected in some measure. Among the traditional a*flaj* systems in south-eastern Arabia, increasingly more youth are forgoing the option of continuing the maintenance of the family *falaj* holdings for increased returns to labour found in urban centres. As is now found among many pumping system farms, increasing numbers of *falaj* holdings are managed by hired, low-cost expatriate labour – a luxury most economies in Sahelian Africa cannot afford. (Norman et al. [16]).

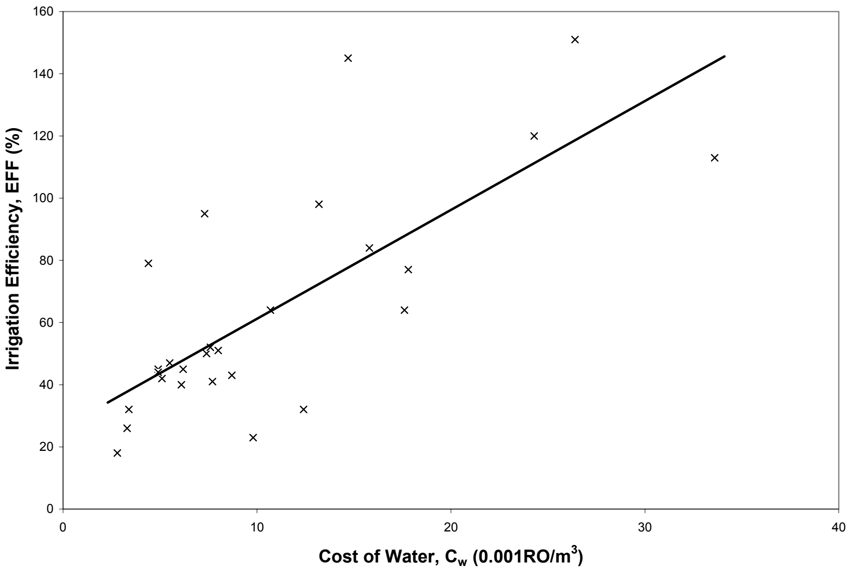

Figure 6: Irrigation efficiency and water cost from a study of 26 private pumping systems in south-eastern Arabia. Source: Norman et al. [7].

Among newly developed smallholder systems in the Sahel it is often found that farmers will gradually circumvent original design plans established at system implementation so as to better accommodate their labour constraints. In one shared reservoir system in the Sahel, original plans for row crop cultivation called for 100 m furrows and a parcel turnout delivery, Q_p, of 6 l/s – whereby an average parcel of 0.5 ha would require two, 8-hour days to fully irrigate. Turnouts to parcels from lined tertiary canals were designed to deliver this flow rate. Farmers, however, did not have the means or available labour to meticulously develop long furrows capable of delivering water at expected application efficiencies. Farmers were also unwilling (and/or unable) to invest the labour time required for prescribed parcel irrigations (2 full days). Following initially poor production levels in the first years, farmers responded by reducing furrow lengths to 10-15 m (essentially level impoundment furrows) and doubling operational flow rates to parcels – usually by placing rocks or other items in the tertiary canal to raise the delivery head to the turnout. This resulted in a 50% reduction in labour requirements for applying water to row crops in both the wet and dry seasons. The total required time to irrigate the entire systems remained the same (4 days), but was completed with less individual time on behalf of the irrigator. Similar changes were made in basin sizing during land preparation for dry season basin crops. Before these farmer-initiated adaptations, system crop yields were 80% lower than yields are today. (Norman et al. [6]).

According to local farmer perception, the value of saved labour from these adaptations far exceeded the value of marginally increased on-farm water losses. This tenable circumvention of design plans was also facilitated by the relatively low unit volume cost of system water. In shared systems, the level of beneficiary satisfaction (and thus productivity) often decreases quickly following system implementation, and can result in a high rate of parcel abandonment within the first years – a common problem among many newly-developed systems in the Sahel. This is especially true when operation rules are more rigidly maintained and such rules conflict with local labour allocation preferences of beneficiary households. These lessons imply that planned irrigation development should be well coordinated to accommodate both constant and periodic labour constraints. In these instances, system operation needs to be well synchronized with non-irrigation-related household activities.

4 Conclusions

Among the many factors which influence farmers' use of irrigation water within smallholder systems, the availability and allocation of on-farm labour is perhaps one of the least understood and appreciated by engineers and planners. This failure has resulted in many failed or under-performing systems. When irrigation water costs are relatively low and access is unrestricted, farmers will often increase irrigation application rates so as to reduce labour input required for field water distribution. This often results in losses and low water use efficiencies. Conversely, when the costs of getting water to the farm parcel are high or water is scarce, farmers will often apply field water at lower rates and with increased labour input to assure better field water distribution and more efficient use of the resource. These characteristics of farmer practice, and the associated decision-making processes, need to be incorporated into the planning and design of new or improved systems. Design prescriptions for both infrastructure and operations need to take into account varying household labour demands. Planning needs to include a careful, pre-implementation assessment of farmers' willingness and ability to allocate labour to system activities. System operations need to be well coordinated to fit both constant and periodic (or seasonal) labour constraints – with irrigation timing well synchronized with off-system activities such as rain-fed production. Management of systems needs to be sufficiently flexible so as to accommodate farmer initiated changes or adaptations to system operations which serve to optimize household labour use. In summary, a better understanding of on-farm water management and labour allocation practices, along with incorporation of these considerations into design, planning and management processes, should serve to improve the productivity and sustainability of smallholder irrigation systems.

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