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Authors: Guy Jobbins[1], Jack Kalpakian[2], Abdelouahid Chriyaa[3], Ahmed Legrouri[4] and El Houssine El Mzouri[5]

Authors' full correspondence details

Guy Jobbins (Corresponding Author), Overseas Development Institute, 203 Blackfriars Road, London, SE18 6FF, United Kingdom. Tel: +44 2079228240. Email: g.jobbins@odi.org.uk

Jack Kalpakian, Al Akhawayn University in Ifrane, Hassan II Avenue, Ifrane, 53000, Morocco. Tel: +212535862000. Email: j.Kalpakian@aui.ma

Abdelouahid Chriyaa, Institut National de la Recherche Agronomique, Route 1406, Settat, Morocco. Tel: +212 523729300. Email: chriyaaa@yahoo.fr

Ahmed Legrouri, Al Akhawayn University in Ifrane, Hassan II Avenue, Ifrane, 53000, Morocco. Tel: +212535862000. Email: legrouri@aui.ma

El Houssine El Mzouri, Institut National de la Recherche Agronomique, Route 1406, Settat, Morocco. Tel: +212 523729300. Email: e.elmzouri@gmail.com

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Authors: Guy Jobbins[1], Jack Kalpakian[2], Abdelouahid Chriyaa[3], Ahmed Legrouri[2] and El Houssine El Mzouri[3]

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Water-energy-food nexus, Morocco, drip irrigation, poverty

Abstract

This paper draws on three case studies of drip irrigation adoption in Morocco to consider the Water-Energy-Food (WEF) nexus concept from a bottom-up perspective. Findings indicate that small farmers' adoption of drip irrigation is conditional, that water and energy efficiency does not necessarily reduce overall consumption, and that policies supporting, and adoption of, drip irrigation can create winners and losers. The paper concludes that, although the WEF nexus concept may offer useful insights, its use in policy formulation should be tempered with caution. Technical options that appear beneficial at the conceptual level can have unintended consequences in practice, and policies focused on issues of scarcity and efficiency may exacerbate other dimensions of poverty and inequality.

[1] Corresponding Author. Guy Jobbins, Overseas Development Institute, London, United Kingdom. Email: g.jobbins@odi.org.uk

[2] Al Akhawayn University in Ifrane, Ifrane, Morocco.

[3] Institut National de la Recherche Agronomique, Settat, Morocco.

Introduction: The Water-Energy-Food nexus

It has long been recognised that water, energy and food are interdependent. The interconnections between these resources in planning and policy have been a longstanding issue explored in the literature (see, e.g. Keeney & Wood, 1977; Batliwala, 1982; Sachs, 1984; Greeley, 1987; Allan 1997). The WEF nexus has also been promoted by the international community: in 2011, the World Economic Forum and a conference held in Bonn both recognised the interdependence of water, energy and food securities (Hoff 2011; Waughray 2011). Both argued that these should not be treated in separate silos by policy and planners, concluding that although problems are systemic, it is the world's poor who are those most at risk from the scarcity and mismanagement of water, energy, and food.

Central to the arguments of the Water-Energy-Food (WEF) nexus is that increasing demand due to demographic and economic growth, coupled with stresses on supply resulting from factors such as climate change, are leading to shortfalls in availability of, and access to, food, energy and water (Waughray 2011). Resource scarcity necessarily implies trade-offs between uses, such as choosing between allocating water to irrigation or hydropower in times of drought. Conversely, investments to address one aspect of insecurity can exacerbate other insecurities: for example, increasing water supply through desalination or groundwater pumping is highly energy intensive (Trieb & Müller-Steinhagen, 2008; Siddiqi & Anadon, 2011). Similarly, exposure to risks in one dimension can exacerbate insecurities in the other dimensions, as demonstrated by the potential for increased energy prices to result in higher food prices (*see* e.g. Zhu, Ringler, & Cai, 2007). The interactions between these three sets of securities mean that attempting to address insecurities in a piecemeal fashion can result in a zero-sum game (Bizikova, Roy, Swanson, Venema, & McCandless, 2013).

WEF nexus approaches are therefore advocated as means of optimising resource allocation decisions and addressing unsustainable growth (Hoff, 2011; Waughray, 2011). A review of WEF nexus conceptual frameworks by Bizikova et al. (2013) concluded that their common goal is to promote action by identifying policy entry points to reduce trade-offs between securities, improve all three securities simultaneously, and exploit synergies. There are also concerns with, and connections to, other dimensions of human security and development, including international trade and investment (Allan, 2003; Allan, Keulertz, & Sojamo, 2012), ecosystem services (Rasul, 2014), and transitions to new economic systems such as the green economy (Hoff, 2011).

Despite this common goal noted by Bizikova et al. (2013), there are some differences in focus between these frameworks. For example, the World Economic Forum report emphases broad public policy areas such as trade, national security, finance, and business. It concentrates principally on macro-scale considerations of optimal resource allocation to avoid conflict and ensure economic growth (Waughray, 2011). By contrast, the Bonn2011 conference report is more aspirational, and identifies a series of options for economic transitions to promote inclusive and sustainable social and economic development (Hoff 2011).

In the context of these different frameworks, the WEF Nexus Conference[1] held in Rabat during June 2014 challenged participants to consider new ideas, and how the WEF nexus might be moved from concept to application, and how it might benefit small farmers in global drylands. The authors have responded to this challenge by drawing on three case studies from their research in Morocco that focus on the uptake of drip irrigation. We start by demonstrating that drip irrigation is an example of a nexus idea, and propose a simple framework to assess whether small farmers benefit from it. The paper then outlines the key issues of water, energy and agriculture in Morocco and policies supporting the adoption of drip irrigation, before turning to the three case studies and, finally, a discussion based on the analytic framework, and conclusions.

Drip irrigation as a nexus idea for small farmers in drylands

Drip irrigation – also known as micro-, localised, or trickle irrigation – uses networks of pipes and tubes to apply water directly to the soil surface or root zone of plants. As a water efficient technology, it has been promoted as a demand side management option for reducing water consumption while maintaining yields, particularly through minimising non-productive evaporative losses (see e.g. Narayanamoorthy, 2004; Rijsberman, 2006). However, one review of the literature on drip irrigation has found that there are no common definitions of efficiency in use, and that measured efficiency gains can depend on specific boundary assumptions and operational conditions, including time and spatial scales (van der Kooij, Zwarteveen, Boesveld, & Kuper, 2013).

The pressurisation of waters used in drip irrigation has led to research on water-energy linkages. That the rapid expansion of groundwater irrigation has been underwritten by energy subsidies, which has in turn contributed to depletion of aquifers and placed strains on energy supply, is well documented (*see* Scott & Shah, 2004; Shah, Scott, Kishore, & Sharma, 2004). For example, research in Spain suggested that drip irrigation can be more energy efficient than other technical options (Hardy, Garrido, & Juana, 2012); while research in China found that conversion from groundwater flood irrigation to drip irrigation can reduce both energy consumption and carbon emissions (Wang et al., 2012). An examination of trade-offs between water and energy in Australian irrigation concluded that the use of drip irrigation is appropriate for reducing energy consumption in pumping groundwater, while surface waters should be used as flood irrigation so as to avoid the energy costs of pressurisation (Jackson, Khan, & Hafeez, 2010).

Drip irrigation therefore connects food production with water and energy use efficiency. Drip irrigation technology predates the WEF nexus concept, and the food-water, energy-water, and energy-food dimensions have generally been considered separately rather than as a trilateral nexus. Nonetheless, the potential combined benefits of drip irrigation for these dimensions is well recognised, although questions remain on the necessary boundary conditions for them to be realised (see e.g. Jackson et al., 2010; van der Kooij et al., 2013). Experiences with adoption of drip irrigation in drylands can therefore serve as a model for understanding how nexus ideas might have positive or negative impacts on dryland farmers.

[1] International Conference on Water-Food-Energy Nexus in Drylands: Bridging Science and Policy, Rabat, Morocco, 11-13 June 2014

We propose a simple analytic framework with three components to assess whether drip irrigation has improved water, energy and food securities and benefited small farmers in Morocco. The first component asks whether small farmers have been able to adopt drip irrigation. The second component considers whether adoption of drip irrigation has improved water, energy and food securities, how, and for who. The third component asks whether drip irrigation adoption has affected other markers of poverty such as employment. In the discussion at the end of the paper, this framework is used to consider what lessons can be drawn to help small farmers benefit from nexus ideas.

The Development of Drip Irrigation in Morocco

Morocco is a water scarce country, with unmet energy needs, an economy based on agriculture, and over recent decades has experienced increasingly frequent and intense droughts. It therefore provides a useful case to consider interconnected issues of water, energy and food in a context of climatic variability and change.

Population growth and socioeconomic development have increased demands for water and energy in Morocco. The national water potential, estimated at 22 $x10^9$ m^3 per year is above current demand estimates of 15.7$x10^9$ m^3 per year (Departement de l'Environnement, 2009; Droogers et al., 2012). However, demand and supply are not distributed evenly in time or space. Precipitation is highly seasonal with high intra- and inter-annual variability, and a large proportion of irrigation, industry and domestic demand is in areas with little rainfall, such as Casablanca. To better match supply and demand the government is developing water infrastructure for the mobilisation, storage, and transfer of water, but the investment costs are high as the majority of easy gains have already been made. For example, the 130 large dams constructed before 2009 had a combined storage of 17.5$x10^9$ m^3, yet the 60 dams planned by 2030 will add only a further 1.7 $x10^9$ m^3 combined (Departement de l'Environnement, 2009). Further population and economic growth will place further stresses on water resources, and expectations are that water deficits will increase markedly in the future, particularly if impacts of climate change are taken into account (Droogers et al., 2012).

Energy supply and demand have risen steadily, although demand has grown faster. To meet energy demand, Morocco needs to invest approximately 1 billion Euro per year for the next ten years in new generation capacity (Vagliasindi, 2013). Growth of electricity demand has been particularly large, both from an increasing industrial base and due to a highly successful rural programme that increased electrification rates from 18% to 97% between 1995 and 2011. Around 96% of national energy needs are met through imports, which has created huge financial pressures on the state to reduce energy subsidies (Vagliasindi, 2013). Since 2009 the government has been phasing out fuel and energy subsidies that have reduced public spending and increased consumer prices, although some support for diesel remains ("Morocco Ends Gasoline, Fuel Oil Subsidies," 2014).

Morocco is therefore a country in which both water and energy are scarce, and require considerable investment to meet demand. Both water and energy are also significant resource inputs to Morocco’s chief economic activity, agriculture.

Since the 1980s the mobilisation and supply of both energy and water to agriculture has become a critical question. A series of intense droughts, unprecedented in the last

500 years, have struck the country since 1981, including the three successive dry years of 1999-2001 (Chbouki, Stockton, & Myers, 1995; Touchan et al., 2008). Relatively low use of irrigation meant that agriculture was highly sensitive to drought. Morocco also did not have extensive rural government services, subsidies, safety nets or markets: consequently, the social and economic impacts of drought were severe, and helped precipitate a national economic crisis in the 1980s (Doukkali, 2005).

Officially, around 90% of Moroccan agriculture was rainfed, with the majority of irrigation schemes state-managed and based on surface water gravity and flood irrigation. However, in response to this onset of droughts, and the increasing access to and affordability of rural electricity, diesel pumps and fuel, many farmers dug private tube wells and started pumping groundwater, often without the required permits. As a result, aquifers across Morocco have been rapidly depleted. For example, the Souss aquifer, a strategic reserve in southern Morocco, has been falling an average of 2m per year for the last 30 years (Bouchaou et al., 2008). Groundwater pumping has also added strain to the energy sector and state energy subsidies, although that is rarely mentioned by comparison to the issue of water.

This is creating a dilemma for the State. On the one hand, there is a need to manage strategic water reserves and energy demand. On the other, agriculture is an engine of the economy and a social safety net, and it is difficult to enforce procedures and permits. The problem is complex, and linked to issues of social development, poverty alleviation, institutional reform and international trade, and not only to issues of water and energy scarcity and agricultural production and productivity.

Among other approaches such as institutional reforms, drip irrigation has been promoted by the state as a technical solution. Increasingly large subsidies to support adoption of drip irrigation have been offered: there is currently a standard subsidy of 80%, rising to 100% for farms smaller than 5ha. New forms of organisation and coordination have also arisen for the management of irrigation and delivery of services. This has included community based schemes, the empowerment of private companies to provide technical assistance alongside infrastructure sales, and also the world's first public-private partnership in irrigation – the Guerdane scheme in Taroudant Province in the Souss Massa (Errahj, Kuper, Faysse, & Djebbara, 2009; Houdret, 2012).

There has, then, been a large effort towards achieving the apparently obvious benefits of drip irrigation in terms of reducing water and energy consumption, boosting agricultural productivity, and increasing drought tolerance. However, the case studies in the next section of this paper suggest that it is not clear that drip irrigation is fulfilling its potential in Morocco as a technical adaptation to water stress and drought. This appears to be largely due to issues of institutions, policies, and administration, resulting in barriers to the uptake of drip irrigation and unintended consequences of drip irrigation uptake.

The Case Studies

Bitit and Ain Chegag, Sebou

The 2,200 km^2 Saiss sub-basin in the upper Sebou accounts for 11% of Morocco's annual water endowment. The mountainous Saiss sub-basin holds around 8,000 commercial and subsistence farms, 37,000 ha of which are irrigated. Commercial farms oriented to international exports include the cultivation of water-intensive

crops, with 4,500 ha of apple orchards and hundreds of hectares of wine vineyards, particularly in the fertile valley floor (Pers. Comm., Director of Sefrou and el Hajeb Provincial Department of Agriculture, 23 February 2009). Of the irrigated land, 32% is flood irrigated from surface waters, 45% is flood irrigated from groundwater, and about 22% is drip irrigated from different sources, mainly groundwater (Rhaouti, 2007).

Since the 1980s, the onset of more frequent drought and increasing access to international export markets has driven groundwater abstraction for agriculture. The number of wells has risen from less than a dozen to over 9,000 in the last 40 years while the annual precipitation in the area has fallen by 33%, and the resulting imbalance has led to a water deficit of 100 $Mm^3\ yr^{-1}$ (Kalpakian et al., 2014). This has reduced flows in springs, and some sources and wells have dried up completely, particularly in the uplands. According to the Sebou River Basin Agency (ABHS), the Saiss aquifer has fallen 70m over 27 years to 2008, and on current trajectories could be exhausted within 20 years (Rhaouti, 2007). Against this background, ABHS has prioritised the promotion of drip irrigation among other policies to reduce water demand in the basin.

A Knowledge, Attitudes and Practice (KAP) survey of 519 farmers in the Ain Chegag and Bitit communities found that 83% of farmers identified drip irrigation as the best means of conserving water resources (Kalpakian et al., 2014). Farmers identified the key benefits as savings in water, energy, and labour inputs.

However, despite recognising the potential benefits of drip irrigation, only 10% of farmers had adopted it. The KAP survey identified a complex set of institutional barriers to financing arising from issues of land tenure, the subsidy and credit system, and administrative requirements. For example, 48% of farmers identified a lack of money as the primary obstacle to adoption, 16% cited the administrative complexity of accessing the subsidy system, while 5% were impeded by land fragmentation or being tenant farmers. Other farmers preferred flood irrigation due to their proximity to reliable sources (*see* Kalpakian et al., 2014).

At the root of several of these barriers is the diversity of land tenure systems in Morocco. Common forms of ownership include *Melk* (private property), '*Urfi* (informal, unregistered but communally recognised), *Sulaliya* (tribal or communal title), *Habous* (a religious endowment), *Guich* (formerly used as compensation for military service) and *Domain* (state land). In the past, possessors of communally owned lands, such as *'Urfi* or *Sulaliya*, were disqualified from obtaining mortgages as their properties were ultimately owned by the community. Even with large subsidies provided by the state, poor farmers would need access to credit to finance the remaining investment cost of drip irrigation. In Ain Chegag and Bitit, poor farmers were disproportionately holders of *'Urfi* or *Sulaliya* lands, and therefore without access to mortgages and credit. The laws have, however, recently changed, allowing mortgages for land for which legitimate use rights have been officially documented.

The KAP survey also indicated that education was a major factor in being able to register land, with literate and illiterate farmers having very different levels of success in managing required paperwork and being able to access the bureaucracy. Similarly, although a 100% subsidy is available for small farmers (<5ha) to install drip irrigation, considerable paperwork and knowledge is required to access it. Private firms that sell drip irrigation systems generally offer farmers help with the paperwork

and administration for credit and subsidies. However, they charge for the service and many farmers distrust their motives.

Institutional fragmentation was also a challenge. The ABHS was charged with planning and allocating water at a basin level, and tightly controlled permits to dig wells out of concern with declining aquifer levels (also requiring evidence of land ownership). According to procedure, the Provincial Department of Agricultural (DPA) required evidence of a well permit to before providing farmers with subsidies for drip irrigation investments. However, the two agencies had only limited interactions and did not have harmonised practices, with the DPA promoting irrigation and the ABHS attempting to restrict the number of wells. As well as education, physical distance from and between the location of the two offices was also a significant impediment to farmers attempting to access these state services.

One clear implication of this case study is that the uptake of drip irrigation by small farmers was conditioned by administrative processes and regulations. Improved coordination in planning and operations between the involved agencies at a local level could conceivably have harmonised policies and developed a strategic plan to promote drip irrigation within sustainable limits of groundwater abstraction.

However, it is also clear that there are important issues that go beyond policy and administrative coordination. In Ain Chegag and Bitit, the ability of farmers to access subsidies and take up drip irrigation depended on a wide range of factors, including the source of water being used, education level, the form of property ownership, level of land fragmentation, and physical distance to administrative centres. Other social barriers found to be significant by the researchers included customary law, levels of social capital, and the specific obstacles faced by women farmers from some communities in inheritance law and accessing state services and subsidies[1]. These barriers to small farmers accessing the policy instruments (subsidies and credit) supporting drip irrigation are markers of social exclusion and poverty, and are much broader issues of development than a concern with resource use efficiency.

Lamzoudia, Tensift

The rural commune of Lamzoudia covers a plain of 77,000 ha southwest of Marrakech in Tensift Basin. It consists of 55 *douar* (small villages) totalling approximately 22,000 people. Traditional livelihoods in this area are based on sedentary agro-pastoralism, with pasture and rainfed winter barley being used to support sheep. The rangelands are predominantly state-owned land, although the area also includes 1725 ha of communally owned property managed through usufruct rights.

The climate is semi-arid, with irregular rainfall, concentrated in the winter months from October to March, and high evapotranspiration. Prior to the 1980s average annual rainfall was 250mm yr^{-1}, but over the last three decades this shifted to a regime averaging 150mm yr^{-1} which has remained stable since. Furthermore, whereas rain used to fall in regular, small quantities, it now falls in less frequent and more intense bursts that are less beneficial to barley production. These intense rains are prone to flood, and are thought to be less effective at recharging groundwater.

[1] These social factors varied markedly between communities in a relatively small geographic area, reflecting Morocco's social and cultural diversity.

With greatly reduced productivity of barley and rangelands, the traditional rainfed agriculture-livestock system has been significantly negatively impacted. It has been partially replaced by agriculture irrigated from groundwater using the pumps and energy that became increasingly accessible during the 1980s.

This conversion to groundwater could have been used as an important buffer for farmers, granting time to adapt to new, drier conditions. However, in the absence of appropriate advice, and acting individually and tactically rather than strategically, the farmers of Lamzoudia made unsustainable choices. With improved access to groundwater and to markets for cash crops, many farmers converted to horticulture. Water intensive crops, including watermelons and orchard fruits, are now key products of this area. Groundwater levels have fallen over 180m in the last 40 years, and in 2010, the authors found that communities in the area were increasingly reporting dry or salinized wells.

Drip irrigation was particularly adopted by new commercial farmers, many of whom purchased land from destitute agro-pastoralists. For them, drip irrigation offered a means to reduce the energy costs of groundwater pumping. However, they also saw it as means of managing costs, and for converting efficiency savings in water and energy into larger irrigated areas. The uptake of drip irrigation has therefore had no discernable impact on overall water conservation, although it has benefited users' agricultural productivity.

By contrast, smaller farmers tended to view the returns on drip irrigation as insufficient to justify costly investment. This was largely due to their difficulties in accessing subsidies due to their land status similar to those in the case study from Sebou. Their incentives for investment were further lowered due to the unbounded nature of groundwater: any water efficiency savings resulting from their investment in drip irrigation could be used by others without restriction.

The incentives on both commercial farmers and small traditional farmers have therefore been to convert water into cash as quickly as possible rather than using water efficiently, a classic tragedy of the commons scenario. Following the work of Elinor Ostrom and others, co-management or community based management is a common prescription for common property resources (Ostrom 1990). However, in Lamzoudia the community lacked the social capital and local institutions necessary to develop an agreement to regulate private abstractions from the common property aquifer within sustainable levels (that in any case would be hard to define). The presence of outside investors and commercial farmers made agreement even more unlikely.

The experience of Lamzoudia offers an example of Jevon's Paradox (Alcott, 2005), suggesting that, very simply, the adoption of technology offering water (and energy) use efficiency is not necessarily sufficient by itself to resolve scarcity. By comparison to flood irrigation from groundwater, drip irrigation offered greater water and energy efficiency. However, water users and farmers operated under incentives that did not encourage conservation, and they lacked access to the capital and institutions necessary to change those incentives.

Guerdane and Issen, Souss Massa

The Souss Massa basin covers 27,000 km^2 in the south of Morocco. Producing more than 50% of Morocco's vegetable and citrus exports, it is one of the most important

agricultural regions in the country. This export-based agriculture has grown rapidly since economic liberalisation in the 1980s.

Since the 1980s, average annual precipitation has fallen to 80% of the long-term mean, and variability has also markedly increased. Traditionally around 80% of the area was rainfed, and focused on olive and cereal production. However, increasing water variability and scarcity, and demand for water intensive crops for export, has driven demand for irrigation waters (Keith & Ouattar, 2004; Van Cauwenbergh & Idllalene, 2012). Around 93% of water in the Souss Massa is now used in agriculture.

Surface waters have been mobilised for irrigation through the construction of eight medium to large dams. However, agricultural water demand has continued to grow in areas unsupplied by these irrigation schemes, with farmers turning to pumped groundwater. Within areas supplied by irrigation schemes, groundwater is also used for supplementary irrigation. In total, almost 70% of the water used in irrigation is drawn from groundwater, and the Souss aquifer has a deficit of 360 $x10^6$ m^3 yr^{-1}. The aquifer has fallen at a rate of 1.5m to 2m per year, and in some places tubewells are now at over 200m (Houdret, 2012).

As elsewhere in Morocco, the State has responded with a variety of measures that have included the promotion of drip irrigation. This has included the provision of pressurised surface waters, as well as measures to promote drip irrigation for reducing groundwater abstraction. One of these schemes is the Guerdane perimeter, a public-private partnership (PPP) managed by the Amensous company. This scheme delivers water to an area which is prioritised for the production of citrus for export. Previously, the farms in this area were using 10,000m^3 ha^{-1} yr^{-1} for citrus production, all abstracted from groundwater for flood irrigation. The new irrigation scheme requires drip irrigation, for which 6,000 m^3 ha^{-1} yr^{-1} is sufficient for the same yield of citrus. Of this 6,000 m^3, two thirds is provided from surface waters delivered by Amensous, while one third is expected to be pumped from groundwater. This represents a potential saving of ~ 8,000 m^3 ha^{-1} yr^{-1} in terms of groundwater abstraction, and concomitant energy savings[1] (Amensous officials, pers. comm., 21 May 2014).

Unusually for Morocco, where approximately 70% of farms are smaller than 2ha, the Guerdane scheme serves an area where 67% of farms are larger than 20ha. The owners of these larger farms are generally wealthy, and for many agriculture is either a secondary income, or the land is rented to a foreign company. In addition to other benefits for property owners, the values of land in the PPP perimeter have risen in value from 25 000 Dirham (2 800 US$) to 250 000 Dirham (28 000 US$) per hectare since the scheme's inception in 2009 (Amensouss and Ministry of Agriculture officials, pers. comm., 21 & 22 May, 2014). The Guerdane PPP scheme has therefore been criticised for subsidising the infrastructure, productivity, and capital gains of larger, wealthy farmers at the taxpayer's expense (Houdret, 2012; Van Cauwenbergh & Idllalene, 2012). Other criticisms have focused on the impact on the traditional water rights of – relatively poor - upstream communities affected by the mobilisation of surface waters for the Guerdane scheme (Houdret, 2012). There are also questions about the cultivation of citrus for export, as orchard crops fix water demand for years

[1] The energy cost of pressurised delivery of surface water to the scheme was not available, but is assumed to be substantially less than the cost of pumping groundwater from the deep aquifer.

or even decades rather than being able to respond flexibly to annual variation in supply.

At the nearby Issen Traditional scheme, several farmers reported that they viewed reduced labour costs as the main benefit of converting from flood to drip irrigation, rather than increased water and energy efficiency. Rather than needing to employ part-time labourers to channel irrigation waters, the drip irrigation system allowed small farmers to irrigate alone and with minimal effort. Other farmers increased their irrigated area, resulting in smaller than expected or no net water savings. Some farmers have both increased the irrigated area and reduced their labour force. Others have converted to water intense crops such as fruit and vegetables, with further consequences for water demand.

Discussion

Have small farmers been able to adopt drip irrigation?

In each case study, wealthier farmers were better able to adopt drip irrigation than small farmers. Although the State offers subsidies of up to 100% to offset high initial investment costs, many small farmers experienced significant barriers to accessing this support.

One of the most significant issues was land tenure status. Small farmers on private property (*melk*) in Souss Massa were better able to access subsidies than farmers on other forms of land tenure, such as *'Urfi* or *Sulaliya*, in Tensift and Sebou. Other identified barriers to accessing subsidies and services involved literacy and ability to work through administrative processes, geographic remoteness from administrative offices, gender, and ability to procure a well permit from water management authorities. While offering a subsidy of 80% or 100% was an effective means of supporting small farmers on private property, it did not reduce access barriers for all small farmers, particularly the most marginalised groups.

Other small farmers did not see sufficient economic reasons to invest in drip irrigation. Upstream farmers in Sebou and the Issen perimeter in Souss Massa, with more assured surface water supply, had few incentives to conserve water to benefit downstream users. Similarly, some small holders in Tensift saw little value in water conservation efforts that would be open to abuse from free riders in a common pool resource. Another economic barrier for some farmers in Sebou and Tensift were farms that were too small, or too fragmented, to realise benefits from drip irrigation, particularly where they were not able to develop cooperative agreements with their neighbours.

These findings suggest that policies supporting the adoption of technical options may not be successful without careful anticipation of institutional barriers. Many of these issues – land tenure, education, and gender – are fundamental to dimensions of poverty, are complex and diverse, and are frequently highly political and difficult to resolve. Technical options inspired by nexus ideas, and the policies supporting them, are highly unlikely to initiate transformative changes that resolve these issues. However, policy formulation processes could potentially map what barriers there might be to adoption by small farmers, and how they might be lessened, and ensure policies are framed appropriately.

Has drip irrigation improved water, energy & food securities?

The three cases demonstrate that the efficiency savings offered by drip irrigation do not necessarily reduce on-farm consumption of water and energy, and have not had a clear positive impact on water, energy and food securities. Rather, the positive and negative impacts of drip irrigation on water, energy and food securities appear to be distributed among different groups and at different scales.

Whether drip irrigation generates significant water savings in any real sense at the hydrological scale has been challenged by many authors (see e.g. Perry 2007; van der Kooij et al., 2013). Efficiency savings can be generated by reducing non-beneficial evapotranspiration, losses to sinks such as the sea or the desert, and improved irrigation management. However, aside from these potential savings, excess irrigation water not used in beneficial evapotranspiration (contributing to plant growth) returns to the aquifer, where it becomes available for use by others. By contrast to flood irrigation, drip irrigation could, in principle, actually decrease the water security of other users by reducing environmental return flows.

Large reductions in excess irrigation waters by adoption of drip systems, therefore, do not necessarily translate into real savings. To restore aquifer levels, water efficiency savings need to be translated into permanent reductions in abstractions. However, there is always a pressure to use water for economic activities rather than to use it for environmental flows or for non-economic uses such as subsistence agriculture by the poor. Indeed, the Souss Massa and Tensift cases found that the incentives operating on farmers encouraged many of them to expand irrigated areas and cultivate water-intensive crops rather than reduce groundwater abstractions. In the Sebou case, the majority of farmers were aware of the potential benefits to water and energy conservation. However, it appeared that at least some of the minority who had adopted drip irrigation were, like those in Tensift and Souss Massa, adopting water intensive crops.

Energy efficiency can also be improved by drip irrigation (see e.g. Hardy et al., 2012; Wang et al., 2012). That might be of more significant value to the State where energy is heavily subsidised, or more significant value to the farmer where energy costs are high. However, energy consumption does not decline unless the total quantity of water pumped is also reduced. So long as water efficiency gains from drip irrigation are used to extend irrigation areas and increase water-intensity, total energy consumption will not decline. Replacing flood irrigation from surface water with drip irrigation does introduce energy costs for pressurisation to the farmer, but here too these can also be offset – and profit margins increased - by growing water intensive, commercial crops.

In these case studies, the farmers adopting drip irrigation have enlarged their incomes by maximising the profitability of their water use. From their perspective, water and energy costs are less significant than profit margins. Gains have instead been made in agricultural productivity and income generation, and benefits have tended to accrue directly to the farmer rather than society in general.

Has drip irrigation impacted on other aspects of poverty?

The case studies indicated that small farmers who had adopted drip irrigation had increased agricultural productivity, often due to switching to new crops. For these farmers, adopting drip irrigation appeared to have positive impacts on incomes and other markers of poverty.

Drip irrigation requires lower labour inputs than flood irrigation. Several small farmers reported that this had increased their personal quality of life by reducing work hours. Both large farmers and small farmers had been able to reduce their costs of employing agricultural labour. While this increased the profit margins of farmers, it necessarily means a reduction in employment for agricultural labourers. This implies that adoption of drip irrigation can contribute towards concentrating the economic benefits of agriculture in the hands of property owners, increasing poverty among agricultural labourers, and making the rural economy less inclusive. This finding may be context dependent, however: there was some evidence that expansion of drip irrigation on new commercial farms in formerly rainfed areas of Tensift has provided employment opportunities, particularly for women.

Aside from employment issues, the use of surface water resources for the Guerdane scheme also has reportedly resulted in distributional impacts, with upstream communities in the upstream area losing access to water sources (Houdret 2012).

There are, therefore, questions to be asked about who has benefited and who has lost from adoption drip irrigation and the associated public subsidy. There is some evidence that, at least in some cases, drip irrigation technology and subsidies have contributed to exacerbate social and economic inequalities. Individual farmers, particularly those already wealthy, have been the largest beneficiaries, while the impact on agricultural labourers has been negative in some instances. In particular, questions can be asked about the public subsidy of 80% available to large commercial farmers for adopting drip irrigation. They are more likely to have the capital necessary for investment, and are more likely to respond to respond to market signals and reduce energy and water costs to maximise profits.

This does not mean that drip irrigation and the associated public subsidies are entirely negative. However, those developing policies to support technical options need to be aware that creating winners and losers is more likely than creating "win-wins", and that technical options can exacerbate social and economic inequalities.

Can nexus ideas be made to work for poor drylands farmers?

Reflecting on these cases of drip irrigation adoption, how it has affected water, energy and food securities, and some of the impacts it has had on of poverty provides two important lessons for understanding how nexus ideas might benefit small dryland farmers.

The first lesson is that, while drip irrigation has clearly benefited some, the realisation of benefits depends on a number of contextual factors. The ability of farmers to access drip irrigation depends on their available capital, perceived returns on investment, and ability to access subsidies. In turn these depend on markers of poverty and social marginalisation such as farm size and land tenure. Similarly, drip irrigation does not necessarily result in greater water and energy security at the basin level due to the incentives acting on individual farmers. This suggests that the conditions for successful application of nexus ideas require careful assessment, and that supporting policies should be targeted at specific user groups in specific contexts.

The second lesson is that drip irrigation has the potential to create winners and losers between societal groups and at different scales, and that this is more likely than creating positive outcomes for all. This lesson implies that, if the WEF nexus is to benefit small farmers, it should purposefully integrate *ex ante* evaluation of distributional impacts and engage with pro-poor development agendas.

More fundamentally, we would ask to what end WEF nexus approaches are oriented. Is the reduction of tradeoffs between water, energy, and food securities considered an end in itself, or does it support higher-level social goals such as the reduction of poverty? The most significant water, energy and food security challenges faced by poor dryland farmers are to do with availability, access and stability of those resources, not efficiencies of use or optimisation of tradeoffs between them. In large areas of rural Morocco, food production and income generation depend on scarce and variable water supplies. Pressurising surface waters for drip irrigation in Sebou and Issen might not be an efficient use of energy resources (e.g. Jackson et al., 2010), but does deliver crucial water supplies that help alleviate rural poverty and strengthen resilience to drought. By contrast, pressurisation of surface waters for drip irrigation in Guerdane might be less energy intensive than pumping groundwater resources, but has reportedly impacted the water rights of marginalised upstream communities. The fundamental issues in these cases are about poverty and marginalisation, not efficient energy use.

Addressing basic insecurities in water, energy and food, and other dimensions of poverty such as rights, income, employment, health, and education, are the focus of international development efforts. Where opportunities can be identified to reduce tradeoffs between these securities, that is all to the good. However, we are not convinced that this is a beneficial starting point for analysis if it might lead to situations in which poor farmers are expected to prioritise efficiency over fundamental securities and poverty reduction.

Conclusions

This paper has presented findings from three sets of case studies on the uptake of drip irrigation in Morocco. Although drip irrigation predates the current formulation of the WEF nexus concept, it has long been recognised that it offers water and energy efficiency savings while maintaining, or even increasing, agricultural production and productivity.

The case studies suggest that making nexus solutions and technologies work for small farmers in drylands is complicated. Institutional barriers to access can be complex and diverse, and incentives may not always be sufficient to encourage users to save water or energy. The boundary conditions for achieving desired outcomes might be highly specific. By contrast, the prioritisation of technical and policy options for resource use efficiency has, in some cases, the potential for unintended consequences that include the creation of winners and losers at different scales and between different groups.

Based on these case studies, we suggest that those interested in developing WEF nexus ideas to benefit small farmers in drylands ensure that boundary conditions for success are well understood, that supporting policies are carefully targeted, that *ex ante* evaluations consider potential distributional impacts, and that technical, institutional and policy options proposed are supportive of pro-poor agendas of inclusive social and economic development.

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