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The human dimensions of water saving irrigation: lessons learned from Chinese smallholder farmers

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Abstract Water saving irrigation (WSI) is promoted as a strategy to mitigate future water stresses by the Chinese government and irrigation scientists. However, the dissemination of WSI in China has been slow and little is understood with respect to why farmers adopt WSI or how WSI interacts with the social and institutional contexts in which it is embedded. By analyzing qualitative data from 37 semi-structured and 56 unstructured interviews across 13 villages in northwest China, this paper examines smallholder farmers' knowledge and perceptions of WSI, and how WSI interacts with farmer livelihood decision-making and extant systems of land and water management. The results show that smallholders' willingness to adopt and continuously use WSI was dampened by (1) a lack of communal capital and measures for conflict resolution, (2) a disconnect between the temporal demands of practicing WSI and the ways farmers prioritize different livelihood strategies, (3) misconceptions about WSI systems and how they work, (4) market risks, and (5) landownership structure and economies of scale. These results suggest that programs for promoting WSI must be holistic in nature and address smallholders' day-to-day problems. Understanding why WSI did not succeed in some places will help formulate policy interventions that avoid reproducing conflicts, risks, and technological malfunctions responsible for previous failure.

Keywords Agricultural livelihoods · Drip irrigation · Risk perception · Technology adoption · Water conservation · China

Introduction

Water scarcity relative to human use has been acknowledged as one of the major problems facing humanity in the twenty-first century. The crystallization of the nexus concept has called attention to the interdependencies between energy, water, food, and the climate (Ringler et al. 2013). As such, it has been recognized that water is integral to maintaining food security, livelihoods, public health, environmental quality, energy production, and human well-being (Agnew and Woodhouse 2011). In China, water scarcity is of concern to many researchers and water policy analysts (Deng et al. 2006; Webber et al. 2008; Wong 2010). Irrigation water for food production is particularly important for meeting food demands and maintaining agricultural livelihoods in China (Lohmar et al. 2003). Irrigated agriculture accounts for about 80 % of food production and 62 % of total water use nationally (Yang et al. 2003; National Bureau of Statistics of China 2010). Despite its importance, irrigated agriculture tends to have high withdrawal rates and low level of efficiency, often making it a target for "solving" water scarcity problems.

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For example, irrigation practices used by Chinese farmers often apply one to two times the water requirements of crops (Lin and Zhao 1999), and agriculture in general has an average irrigation water use efficiency of 0.47, slightly over half the rate in developed countries (Cheng and Hu 2012; Zhu et al. 2013). Both globally and in China, these inefficiencies have led scholars and policy experts to argue that water scarcity may be addressed by reducing the amount of water delivered to agriculture (e.g., Postel 2000). This discourse often emphasizes modernizing irrigation systems through technological change, with small-scale water saving irrigation (WSI) technologies such as drip irrigation (DI) or sprinkler irrigation (SI) taking a leading role in proposed solutions (Van der Kooij et al. 2013). Specifically, DI uses a series of tubes through which water is emitted at regular intervals to apply water directly to the root zone of plants, increasing distribution uniformity. Fertilizer is often mixed with water, and DI often increases yields and reduces labor compared to conventional systems (Postel et al. 2001). SI uses sprinklers to spray water at regular intervals across a field's surface, improving watering speed and efficiency and distribution uniformity (Bernstein and Francois 1973). Those who support such technological solutions trumpet their economic development potential (Postel et al. 2001; Burney and Naylor 2012) and their ability to adapt agriculture to climate change (e.g., Zou et al. 2012), in addition to their water saving capabilities.

In China, WSI can be broadly categorized into two types: (1) household-based technologies that are highly divisible, have low fixed costs, and necessitate little to no collective action, such as plastic mulching and conservation tillage; and (2) community-based technologies that have high fixed costs and often require collective action for implementation and operation, such as DI and lined canals (Wang et al. 2009). In the 2011 Central No. 1 Document, the Chinese government laid out a plan to invest four trillion yuan ($600 billion) in rural water resource projects over the next 10 years, including improving irrigation efficiency through WSI (Yu 2011). China's National Plan for Coping with Climate Change also identified WSI as a solution to mitigate future water scarcity problems (State Council Information Office of China 2008). Recent research by Zou et al. (2012) showed that between 2007 and 2009 China saved 61.81–129.66 billion m^3 of water with the use of WSI and that WSI can potentially save more water than it already has. Yet some scholars have cautioned against an uncritical emphasis on irrigation projects as solutions to water scarcity and climate change because of their technocratic focus and frequently documented unintended consequences and failures (e.g., Nation 2010). For example, studies from Africa found that introducing irrigation or changing irrigation technologies had led to men asserting claims to land previously managed by women (Carney 1998; Nation 2010).

Generally speaking, the adoption of WSI among Chinese farmers has been slow, particularly when communal sharing or organization is required (Yang et al. 2003; Blanke et al. 2007). Relatively little is known about why or why not Chinese farmers choose to adopt WSI technologies or how WSI interacts with the social, political, economic, and technological contexts in which it is embedded. In this paper we focus on the human dimensions of WSI adoption and use in northwest China, paying particular attention to how WSI technologies interact with extant systems of land and water management, formal and informal social institutions, farmer livelihoods and agricultural decision-making, and localized social, political, and economic conditions.

Literature review: human dimensions of irrigation technologies

Most research investigating WSI technologies and advocating for their use belongs to a technology-centered epistemic culture that assumes technologies will perform similarly across the different sites where they are adopted. This thinking leads to comparisons across locations in terms of what is right or wrong with the engineered system, while ignoring how new technologies complement or contradict with the set of social norms, rules, rights, and social processes upon which many communities are built and water delivery is achieved (Mustafa and Qazi 2007; Boelens 2009). However, failure to consider issues such as men's and women's relative social status and work burdens, the local social relations of production, and gendered divisions of labor risks ignoring the variable effects that changes in irrigation practices may have on particular populations, thus marginalizing them and putting the long-term sustainability of irrigation projects at risk (Harris 2008).

Existing studies on the human dimensions of smallholder WSI practices are limited and are mostly focused on DI and the factors determining its adoption. Burney and Naylor (2012) reviewed the literature on smallholder DI adoption in Asia and Africa and found that successful introductions have the following in common: reliable access to and efficient delivery of water; technical success where excessive emitter clogging is avoided; and the adoption of high-value market crops that provide good returns on investment and allow multiple markets to be accessed. Studies from Africa and Asia showed that many smallholders have discontinued the use of DI because of technical problems with the system, including blockage, system wear, and lack of access to spare parts to fix the system (Haile et al. 2003; Kulecho and Weatherhead 2005; Moyo et al. 2006; Friedlander et al. 2013). Lack of technical assistance and marketing support have also inhibited DI adoption (Kulecho and Weatherhead 2006; Moyo et al. 2006; Belder et al. 2007). Urban, peri-urban, and wealthier farmers have shown higher rates of successful adoption because of their proximity to technical support, higher economic status, better access to credit, and higher levels of education (Namara et al. 2007; Woltering et al. 2011). In contrast, subsistence farmers have been less successful at adoption because they are less able to absorb risk and are reluctant to try new technologies for a long period of time (Kulecho and Weatherhead 2005; Belder et al. 2007).

In China, a number of constraints to WSI adoption have been identified, including underpriced water, limited smallholder access to extension services, high cost, lack of an incentive structure that encourages saving water, and various off-farm responsibilities (Blanke et al. 2007; Zhou et al. 2008; Wang et al. 2009; Cheng and Hu 2012). Specific to northern China, Pedersen et al. (2013) found that the low cost of hiring labor to help with on-farm tasks, coupled with low water prices and no volumetric restrictions on water demand, provided farmers with little incentive to adopt DI. Further, many researchers in China have worked to identify technical solutions to improve WSI adoption (e.g., Wang et al. 2000; Liu and Huang 2009; Wu et al. 2010), with most assuming easier-to-use or problem-free technology will automatically attract users. Others have simply attributed the failure of WSI technology dissemination to the lack of awareness among farmers about the need for water conservation, positing that with proper education farmers will choose to adopt (e.g., Wang et al. 2000). These researchers ignore previous research suggesting that the process of technology adoption is affected by a combination of endogenous and exogenous factors, including characteristics of both the potential adopter and technology, and the social, political, and economic systems within which the potential adopter operates (Morris et al. 2000; Rogers 2003; Kulecho and Weatherhead 2006). In particular, researchers have noted that interactions between technology design and institutional context, defined as "formal and informal modes of conduct (rules and laws, norms, and conventions)" that govern social interactions, are important for determining WSI project outcomes (Burney and Naylor 2012). When WSI projects are able to build on existing social structures and institutions such as farmer groups, they have higher success rates because such groups enable farmers to share risk and knowledge, and reduce per-capita equipment costs (Woltering et al. 2011; Burney and Naylor 2012).

Few studies within the WSI literature have examined the role of institutional context in determining WSI adoption and project success. However, the unintended consequences, risks, and failures related to the institutional context of technology adoption have been well-documented in the broader literature on the introduction of irrigation and irrigation technologies into smallholder communities. Previous studies have demonstrated that in addition to providing water, irrigation and irrigation technologies often create new institutions and transform production practices (Birkenholtz 2009). Further, they are taken up by not only farmers but also actors such as government entities and agricultural companies, engendering new social relations of production, often in the form of contract labor or other new production arrangements. For example, Mustafa and Qazi (2007) documented how the introduction of tubewells in Pakistan caused the decline of the traditionally used karez system and the complex social relations it supported. Nation (2010) found that switching from flood recession irrigation and rainfed agriculture to pump irrigation in Senegal led to men asserting claims to land that has been previously managed by women, removing the relative autonomy women had with respect to their own plots. The switch also increased labor intensity through the need for field leveling, fertilizer application, and system maintenance. In addition, irrigation projects can embed smallholders in market-driven agriculture and create new vulnerabilities. For example, Eakin (2003, 2005) showed that the introduction of irrigation in several communities in Mexico enabled smallholders to grow crops sold in regional and national vegetable markets, exposing them to volatile markets for which they lacked historical, present, or future data.

In this paper we add to the WSI literature by examining the human dimensions of WSI adoption and use in northwest China. We focus on two specific questions: (1) what factors affect smallholders' decisions to adopt WSI technologies and enable them to continuously use WSI? And, (2) how does WSI intersect with current agricultural production practices and livelihood strategies? We provide a preliminary analysis of the outcomes of implementing WSI in two villages, and a discussion of farmer perceptions of WSI technologies in the Loess Plateau region of northwest China. We argue that WSI technologies will diffuse with fewer unintended consequences if smallholders are drawn into the conversation and a better understanding is developed of why they do or do not adopt and what they want from it.

Methods and study site description

Our research was conducted in 13 villages across eight townships in three provinces in the Loess Plateau region of northwest China (Fig. 1; Table 1). Much of the region is dependent on agriculture for livelihood production and daily food needs. Smallholder farmers primarily grow corn,

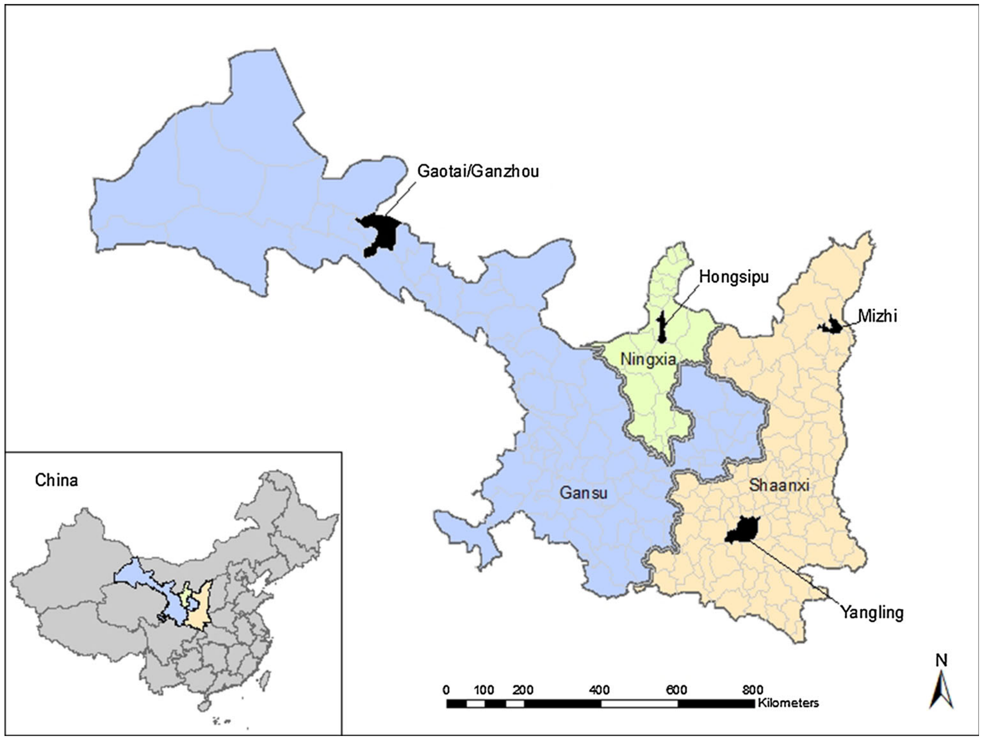

Fig. 1 Map of study area

Table 1 Study sites, annual rainfall, and irrigation method used at the village level

Province	County	Township	# of villages interviewed	# of interviews	Average annual rainfall (mm)	Irrigation method used at the village level
Ningxia[a]	Hongsipu (county-level district)	Hongsipu; Nanchuan	2	16	~260	Flood irrigation
Shaanxi	Mizhi	Shilipu; Yinzhou	4	29	~450	Flood irrigation
	Yangling (county-level district)	Dazhai; Yangcun	3	21	~635	Flood irrigation
Gansu	Gaotai	Luotuo-cheng	2	11	~103	Flood irrigation (note: Drip irrigation was adopted in one village but abandoned later.)
	Ganzhou (county-level district)	Dangzhai	2	16	~115	Drip irrigation in one village, flood irrigation in the other

[a] Ningxia is technically an autonomous region, not a province

though wheat is planted where temperatures permit double cropping. Increasingly, fruits and vegetables are grown for market purposes, including kiwi and tomatoes in Yangling, Goji in Hongsipu, and watermelon in Mizhi.

The data used in this study come from 37 semi-structured and 56 unstructured face-to-face qualitative interviews conducted with smallholders in the summer of 2011. Qualitative research provides a mechanism for eliciting information not likely to surface in a blanket survey approach like those thus far employed in many WSI studies in China (e.g., Blanke et al. 2007; Zhou et al. 2008). It also provides study participants with the opportunity to explain their responses in detail, which facilitates a more fine-grained understanding of the research topic at hand. This study also employed grounded theory (Glaser and Strauss 1967), which is an inductive research approach that allows researchers to conduct interviews, make observations, and analyze data in a way that identifies patterns and ensures that the "unexpected" is taken into account (Babbie 2013).

To select villages for our interviews, we had a number of discussions with the local agricultural bureau in each county to identify an initial two to three villages where agriculture was an important component of household livelihood strategies. To include a range of socioeconomic and geographic conditions in our sample, villages were also chosen so that a variety of crop types and village distances to the local population center were represented. Once initial villages were chosen, snowball sampling was used to identify the remaining interviewed villages. In snowball sampling, respondents introduce researchers to other potential informants who are then interviewed, thus building the interviewed sample in an accumulative fashion (Noy 2008). Within villages, snowball sampling was also used to identify potential smallholder interviewees. While snowball sampling is effective for identifying respondents in a target community and building rapport and trust between the researcher and informants, it has several limitations. Snowball sampling is non-random and individuals are selected for their involvement in a certain social network. This may lead to a homogenous sample in which all respondents belong to the same socioeconomic categories (Browne 2005). To minimize this potential effect, we asked our interviewees to recommend particular households types and individuals (e.g., women led; Hui ethnicity in Hongsipu) for additional interviews.

Our interview questions were designed to draw out farmers' knowledge and perceptions of WSI, the challenges and risks they face, changes made to their farming practices over the last 30 years, their social and professional networks and socioeconomic status, and information about general village and farming life. Interviews were coded and analyzed to identify major themes related to WSI use and adoption following the three-step process outlined in Neuman (2011). The following major themes were identified and will be discussed in detail in the next section: (1) conflict and cooperation; (2) livelihood prioritization and labor allocation; (3) knowledge and misconceptions; (4) market access and associated risks; and (5) economies of scale. Although the findings may not be fully extrapolated to villages outside of the study region because a random sampling approach was not used, the consistency of responses across villages suggests that many of the factors limiting successful WSI adoption and use are not contingent on locality.

Results and discussion

Profile of smallholder interviewees

Descriptive statistics and information about demographic, socioeconomic, and farm characteristics of interviewed smallholders are presented in Table 2. Smallholders in the interviewed villages relied on surface or groundwater for irrigation and primarily used flood irrigation (FI) for crop production. Household incomes were derived from agriculture, local wage labor, and remittances from family members. Most households grew crops for market purposes, particularly on their irrigated land, though many grew vegetables for household consumption in small gardens outside of their homes.

Of the 13 villages we interviewed, two (A and B[1]) in Gansu had experience with DI. None of the remaining 11 villages had experience using any type of WSI. However, local and provincial officials have expressed interest in promoting WSI in these villages, and many of the farmers we interviewed were familiar with both DI and SI. In village A, DI was installed by the local government in 2010, and was still in use at the time of our interviews. In village B, DI was installed in 2002 by a private agricultural company and was used for 8 years before being abandoned in 2010. Prior to installation in both villages, smallholders used water from the Hei River to flood irrigate their crops. Accompanying the switch to DI in both villages was a shift from using the Hei River as their water source to using groundwater drawn from wells dug within villages. In both villages, the initial cost of installation was covered by either an agricultural company or the local government, and farmers operated under contracts in which they were expected to hand their harvests over to a company at a price set at the beginning of the growing season. In village A, each household was paid 2,400 Yuan (~\$387) for each mu (~0.165 acre) of land they had planted in corn. Finally, while the initial cost of the DI system was covered in both villages, it was expected that after 4 years of use the farmers would assume any new costs associated with DI, including purchasing needed replacement parts and paying for maintenance. The parts that would need to be replaced most often were drip lines, made of durable material that requires replacing every 2–3 years.

Conflict and cooperation

In both villages (A and B) where DI had been introduced, conflicts among system users were the most often reported barrier to successful WSI usage. These conflicts generally arose from two sources. The first was that DI was not suitable for existing field layouts in the villages and the ways that individual households managed their land. This is a function of the way that the Chinese Household Contract Responsibility System has allocated land in each village, with most farmers having several small, non-contiguous plots scattered in and around the village where they reside. In both villages, each household had an average of 12–15 μm (~2–2.5 acres) of land divided across three to four plots. Prior to the introduction of DI, individual

[1] Village names are omitted to protect their identity.

Table 2 Demographic, socioeconomic and farm characteristics of interviewed smallholders

County	Age (years)	Gender (female)	Education (years)	Annual household income (Yuan[a])	% of income from agriculture	% employing market-oriented strategy	% employing mixed subsistence/market-oriented strategy	% engaged in off-farm labor	Most common off-farm jobs	Total land (ha)	Total plots	Primary crops
Hongsipu	45	47	8	40,189	38	45	55	81	Construction; commercial farm	12	3	Corn; goji
Mizhi	50	41	7	26,525	53	36[b]	40[b]	59	Construction; truck driver; coal mines	5	5	Corn; watermelon; vegetables
Yangling	55	57	7	12,485	40	15	85	57	Construction; factory worker	5	5	Corn; tomatoes; kiwi; wheat
Gaotai	54	57	5	31,938	61	47	53	63	Construction; commercial farm	12	4	Corn; vegetables
Ganzhou	52	44	5	28,645	63	32	68	63	Construction; commercial farm	15	3	Corn; vegetables

Data were derived as averages from a subset of the total sample as not all interviewed smallholders provided this information

[a] 1 Chinese yuan = 0.16 US dollar

[b] The remaining 24 % of interviewed smallholders employed subsistence-oriented strategy

households were able to apply water to their crops independently of other households. Water was delivered via a canal system to the village according to a schedule established by the local water resources bureau, usually about five times per growing season. Water from the main canal was directed to a particular plot by manipulating a series of gates that caused the water to flow through the subcanals that ran through the village's agricultural fields, eventually directing it to a household's plots. To irrigate, a household would need to send as many people to the field as there were gates that needed to be opened to direct the water to their own plot, usually between two and three. In contrast, to establish DI, each small, individually managed plot was connected to a communal well using a drip line. Each drip line had to cross over the fields of multiple farmers and be shared, meaning that households had to make a collective decision about when to irrigate and cooperation was necessary each time someone wanted to do so. In village A, each drip line was shared by six families, while in village B, each line was shared by five families. In both villages, this led to conflicts among households about who should have decision-making priority and no mechanism had been set up to either determine when to irrigate or to mediate user conflicts. In village B, the problem was exacerbated because each of the five families' plots was often planted with different crops and thus required different irrigation schedules.[2]

In both villages, smallholders were required to contribute money at the beginning of each season towards the cost of communally used fertilizer. This fertilizer was added to the irrigation water by the village well-manager, who was responsible for turning on the DI system when farmers wanted to irrigate. Having to share fertilizer added to the conflicts. The well manager in village B explained the role fertilizer played in the conflicts in his village:

> The drip irrigation itself had no [technical] problems. The emitters on the drip lines had no problems with uniformity in outflow. Starting in 2009, the disputes over fees, especially for fertilizer, started to grow. Every household had to send a bag of fertilizer [to the well-manager] for use during irrigation. But when we irrigated [some peopled claimed that] not every family's field got the same amount of flow from the system. [They said] fields close to the well get a lot [of fertilizer], and fields far from the well get less.

He went on to explain that this led to fights about some households having to pay for fertilizer being used by other households, while receiving no benefit from it. It is important to note that these conflicts led many smallholders in village A to state that they would not use WSI during the next cropping season. In village B, these conflicts were responsible for the abandonment of the system.

The second source of conflict was villagers manipulating the irrigation infrastructure to benefit their own crops. Specifically, some farmers were reported to have cut holes in the drip lines in order to deliver more water to their crops, while others disconnected the drip lines and irrigated their fields in the middle of the night in similar fashion to FI. In both villages, inadequate measures were taken to either prevent the problems or to deal with the subsequent fallout. A monetary fine was in place to prevent this type of behavior, but interviewees from both villages reported that the fine amount was too low to be a deterrent and fines were rarely levied in the first place. When asked why farmers cut holes in the drip lines, interviewees proffered that it was because they did not think their crops were getting enough water. While there may have been technological problems that resulted in uneven water delivery across drip lines, farmers' perceptions of insufficient water for their crops were related to their knowledge of crop-water interactions, which had been largely influenced by their past experience with FI, as will be discussed below.

As Birkenholtz (2009) has suggested, irrigation technologies become enmeshed in previous social relations and agricultural management practices, often simultaneously contradicting them and demanding them to change. In China, land tenure reform in the late 1970s shifted agricultural landholdings from a collectivized system to one where individual households hold 30-year guaranteed contracts to their plots of land, which are owned by the village administration. When decollectivization occurred, individual plots were distributed in an egalitarian way in most villages under investigation, meaning that households received several non-contiguous plots of land of differing qualities. This has led to households managing their land independently of their neighbors, including irrigating and applying inputs at different times. Thus, the implementation of DI contradicts the existing social relations in these villages by asking farmers to work collectively to manage the act of applying water and fertilizer to their crops. Our research shows this is problematic for several reasons. First, as in village B, households may prefer to grow different crops from each other, meaning that their irrigation timing is different. Second, our research suggests that labor migration and reliance on off-farm work leads to difficulties in coordination among households. Temporary and semi-permanent migration has become a major component of smallholder livelihood strategies in developing nations (Brookfield 2008), especially in China where the government has relaxed mobility restrictions and it has been increasingly difficult for smallholders to obtain enough

[2] An employee of the company that paid for and installed the DI system explained that the company recommended each farmer plant the same crop but that villagers refused.

income from farming alone (Murphy 2002). In China, nearly one-third of the peasantry engages in labor migration (Ye et al. 2013), with important implications for how agricultural management decisions are made and how household labor is allocated. In our study, more than 50 % of the interviewed households across the four counties derived income from some form of off-farm labor (Table 2). Many of the interviewed households prioritize wage work over agricultural labor, as will be shown below, meaning that usually one or two members are responsible for day-to-day agricultural activities in addition to any other work needed to be done around the home. In part, it is this constraint on available labor that leads to difficulties in coordination across households.

Finally, most of our interviewees indicated a strong preference for individual agricultural management systems where labor does not need to be coordinated with other households and technologies do not need to be shared. A common refrain that highlights the strength of this preference in the interviews with Gansu smallholders was the opinion of many participants that they would be successful if they had total control over the DI system and did not have to share it with others. The well manager in village B reported that "if only one [family] was doing the farming [in the plots associated with a single drip line] there would have been no problems." A farmer in village A who was planning to abandon the DI system echoed this sentiment: "If I had my own well, my own pump, my own water, and I could manage the water myself, I would choose to use drip irrigation and use it all the time." As Birkenholtz (2009) has shown with tubewell partnerships in India, the introduction of new forms of irrigation "enroll" farmers into partnerships that reconfigure social relations. Our findings corroborate this. In the Loess Plateau region of China, the implementation of DI requires partnerships among smallholders, and most smallholders we interviewed viewed such partnerships as burdensome for intertwined social and agroecological reasons.

Within China, Muldavin (1996) has argued that the breakup of collective farming has made it difficult for village leaders to build up communal capital—the coming together of social capital, labor availability, and other social factors needed to produce physical capital—and collective institutions are needed to undertake cooperative projects such as WSI. Our findings underscore this argument and point to a lack of communal capital and preexisting social institutions that facilitate social cooperation as one reason for the failures of DI system in two villages. As one woman in village A posited, "In my village people cannot unite and cooperate with each other." Her statement reflects a common sentiment held across all of the 13 villages. When we asked potential adopters in the 11 villages without experience with DI what problems they would anticipate facing with DI, several responded that conflict with neighbors would be frequent. As one woman familiar with DI in Mizhi told us, "If our family bought a drip irrigation system it would have to cross other families' plots and this will probably cause conflicts. Sometimes families can work together, but normally there is too much conflict and not enough benefit."

It should be noted that conflicts and eventual system abandonment are not always the outcome of technology adoption where cooperation is necessary. Water scarcity and subsequent mitigative technology adoption can lead to the development of new social institutions in which cooperation becomes the norm (Birkenholtz 2009). Outside of China, smallholders are frequently required to cooperate when WSI projects are implemented in their communities, and numerous examples of their ability to do so exist (e.g., Woltering et al. 2011). These examples open up the question of why this cooperation is not present in the villages we conducted our study. Given the history of collective agriculture in China, the prevalence of the actual or perceived inability to cooperate on the part of smallholders is somewhat surprising. Smallholders' interpretation of the reason for their inability to cooperate was best summed up by an interviewee in Mizhi who quoted the early 20th century Chinese leader Sun Yat-sen: "farmers here are *yi pan san sha*" (a plate of loose sand). The metaphor connotes a state of disunity among villagers caused by a shift in values away from an emphasis on community and modesty towards a focus on individual material accumulation and monetary gain (Gamble 2003). Our research suggests that a lack of social institutions in the villages that facilitate agricultural cooperation may also be responsible for the actual and perceived conflict among farmers.

Livelihood prioritization and labor allocation

WSI may create opportunities for the production of new crop types and for entering into contract farming, the latter of which many interviewees preferred over the regularly practiced market-oriented agriculture. However, WSI also shifts labor demands and can act as a constraint on households, leading to social differentiation and uneven gendered relations of agricultural production. When asked about what features they most desired in an irrigation system, interviewees answered it should save time and be easy to use. In villages where FI was used, interviewees reported that its biggest problems were that it was time consuming and labor intensive, with wasting water a secondary concern. This is particularly important given the reliance on labor migration and local wage labor in our study region.

In general, interviewees explained to us that many of the farm management decisions they made were based on freeing up time to perform wage work. Further, it was frequently explained that off-farm work is preferred to agriculture for making a living. For example, one farmer in Mizhi explained that he planted corn "because it takes so little time you can go out and earn money, usually 60–70 Yuan (~$9–11) per day." Another made clear that he chose to work off farm because it was more lucrative and they planted corn because it required less labor:

> I work in Mizhi in construction, so we do not always have time to do farming. You can earn a lot more money. [We plant corn because] my wife does not have enough energy to plant vegetables and take care of them [because of her other household responsibilities].

As smallholders are dedicating less and less time to working on their farm, it is instructive to examine how the switch from FI to DI shifted labor burdens in the two Gansu villages. In both, smallholders reported that with FI they would irrigate about five times per growing season, with the process taking approximately 40 min per mu (1 mu = 0.165 acres) of land. One or two household members, usually women, would go to their fields and open the canal gates to direct the water to their various plots, remaining in the fields until the process was over, a period of 5.5–7 h. With DI, however, smallholders reported that they would irrigate ten times per growing season, with the process taking three to 4 h each time. Additionally, using DI requires not only the labor time to complete the process, but also coordination among households to achieve enough pressure to use the system, as well as coordination with the well-manager who is in charge of turning on and off the pump. While DI does not necessarily require smallholders to remain in the fields as their crops are being irrigated, most reported they did so, mostly to prevent other users from manipulating the system to their advantage. It is important to note that DI indeed saves time and physical labor compared to FI, a benefit some smallholders appreciated, but it also shifts the way that time needs to be allocated to agriculture by a household or individual. Even though less time needs to be spent in the fields irrigating with DI overall, an individual needs to go to their fields more often when using DI, which many interviewees did not like as it interfered with off-farm labor. Finally, as previously noted in the literature, it was often women who performed irrigation labor, meaning DI conflicts with and adds to their other domestic responsibilities.

In brief, our research shows that the adoption and implementation of WSI systems intersect both directly and indirectly with the various activities undertaken within a household to maintain livelihoods, including unpaid domestic labor, wage work, and labor migration. This challenge is not unique to northwest China. Similar observations have been made in other developing countries (Eakin 2005; Nation 2010). As such, it is imperative to develop a better understanding of how smallholders construct their livelihoods, how they allocate time and labor as resources, how they prioritize the different income-generating components, and how each component will interact with the temporal/labor demands of installation and continuous use and maintenance of different WSI systems.

Knowledge and misconceptions

Interviewees from all 13 villages were asked what they know about two different WSI systems (DI and SI) and why they thought each system would be suitable or unsuitable for their land and operation. Overall, many interviewees had an incomplete understanding of or misconceptions about WSI, including those in the two Gansu villages with experience using DI. In particular, they did not fully understand how each system works, what crops each is best for, and how each system interacts with the water requirements of particular crops. In the case of DI, one major source of misperceptions was that smallholders could not see their crops being irrigated the way they could with FI. This resulted in many interviewees claiming that FI is superior to DI because it keeps soil wet for extended periods of time, whereas with DI the soil is not kept visibly wet. This observation was primarily espoused in the two villages where DI had been used, though interviewees in other villages repeated the claim. As noted above, the second major reason for much of the conflict in the two Gansu villages was smallholders' belief that their crops were not getting enough water with DI. Research done in Zimbabwe (Belder et al. 2007) noted similar concerns among smallholders, with many reporting that their crops were not receiving enough water with DI, prompting them to add extra water by hand. The authors argued that this points towards farmer misunderstanding of the water requirements of crops and that education should be directed towards correcting understandings of crop water needs. Our results confirm this but also add nuance by showing that farmer understanding of the water needs of their crops arise from experience with their former method of irrigation. We suggest that education programs will need to focus on more than just the water needs of crops if they are to successfully convince farmers that their crops are adequately irrigated with DI.

Relatedly, some interviewees thought that with DI water evaporation rates are high while water uptake rates by plants are low. Thus, many believed that crops would not grow as well with DI as they would with FI. Another major concern was that WSI, especially DI, cannot be used with polluted water as it would be more likely to kill the plants than would using polluted water to flood their fields.

Although the rationale for this concern was not immediately apparent from the interviews or subsequent data analysis, it is likely related to the fact that two of the four villages in Mizhi where interviews were conducted were downstream from a PVC plant. In addition, interviewees tended to think DI is only good for watering trees and that SI is only good for flower and grass production. These ideas are likely the result of many interviewees having heard about DI being used on large jujube (*jujube zizyphus*) farms near their villages, particularly in Mizhi, and of their familiarity with sprinklers primarily coming from seeing them used to water flowers and grass in local parks. Overall, there was little awareness of the utility of WSI for vegetable production, which many interviewees were either engaged in or were interested in pursuing. Moreover, interviewees were largely unaware that DI not only has the potential to save water, but also may increase crop production because it is more efficient than FI at delivering water and fertilizers directly to the root zone of crops (Postel et al. 2001). Finally, interviewees tended to think that WSI could get in the way of other farming practices, technologies, and equipment they use (e.g., combine harvester), and cited this as a reason they would not implement WSI on their land.

These findings seem to point to the potential for better smallholder education to facilitate the successful adoption of WSI, as argued by many researchers (e.g., Wang et al. 2000; Deng et al. 2006; Zhou et al. 2008). However, many interviewees reported that existing education and extension programs were inadequate. Frequently, when interviewees were asked where or from whom they learned about new technology and agricultural innovations, they responded that either they had nowhere to learn or extension specialists would come to their village and extol the virtues of some new technology or crop variety, but never explain how it works or how they could troubleshoot problems once the technology was implemented. This was well summarized by a farmer in Gansu:

> When the government told us about tractors they just gave it to us with a short explanation of how useful it is. It was free, but they did not teach us how to drive or how to use it. It is the same with the drip irrigation. The government made a huge investment, but the farmers do not know how to make use of it. They told us you can mix fertilizer with the water, but not what kind to use or what kinds cannot be used or what the ratio of water to fertilizer should be. They also did not tell us when to irrigate or for how long to irrigate. When the experts come they need to tell us how to use the irrigation, not just about why it is better… They need to connect the lectures to reality and real life problems with the system.

Trust between farmers and extension agents was also cited as a major issue. Many smallholders told us that they did not trust the advice given by the technical experts who came to their village, stating that if they wanted to learn new management techniques or the best ways to plant a new crop that it would be better to learn from another farmer who has experience with it. A common sentiment that highlights this was expressed by a village leader in Mizhi who told us, “[extension agents] come to our village twice [each year], once to eat and once to collect money.” Therefore, before education can contribute to promoting WSI in northwest China, effort is needed to better understand how smallholder education and extension programs are conducted, the culture of interaction between agricultural specialists and smallholders in the region, and what communication strategies and program attributes appeal to smallholders with respect to agricultural innovation adoption in general and WSI in particular. Until then, it is probably unwise to invest in status-quo education and extension programs as a strategy for promoting WSI among smallholders in the region and beyond.

Finally, interviewees from the two Gansu villages experienced with DI reported that the system itself had minimal problems when in use. For the most part interviewees found that it operated efficiently and met their expectations. When technological problems occurred, they were rather predictable—mostly clogged emitters. However, interviewees from both villages reported that it was difficult to find replacements for broken parts. Furthermore, none of the interviewees had been trained to repair the system and the people they worked with to install the system (i.e., government paid day laborers or technicians from private agricultural companies) were unavailable to come and help when problems arose. This suggests a need for identifying appropriate venues to provide technical training to smallholders and easier access for smallholders to troubleshoot problems so that they can repair WSI systems on their own. Future efforts to promote WSI need to include not only incentives for initial installation, but also assistance to address any subsequent technological issues related to system operation.

Market access and associated risks

When asked about the greatest challenges faced in agricultural production, a frequent interviewee response was that inputs cost more than what could be made from selling crops. Thus, it is understandable that many interviewees were reluctant to increase input costs by investing in new agricultural practices or technologies as it would only increase their losses. In particular, interviewees showed resistance to increasing crop production or venturing into new crop varieties as they feared a swing to low prices for the crops they were growing, they were not confident that they would have reliable access to markets to sell new or additional crops, and they did not know where and how to find markets that can absorb their product. Lack of advertising venues and networking opportunities were also mentioned in relation to this problem. Interviewees were concerned that if they greatly increase production without ways to communicate this information to potential buyers, the upfront costs of purchasing new technologies or adopting new practices would be at risk of never being recovered. As one woman in Mizhi explained, “There is risk in our selling network. I don’t have any problems with management, but I need a network to sell. If the market for what I want to sell has not been formed I am very worried about it.” In fact, several interviewees mentioned that they had considered larger-scale improvements to their farms, such as greenhouses, but that they decided not to invest, despite possessing the requisite technical and managerial expertise, as they lacked market access and were not confident they could recoup their investment. Given that a major incentive of WSI adoption is that it may increase crop production, one can infer from these findings that concerns regarding market access and unpredictable price fluctuations may prevent smallholders from investing in WSI. In addition, the findings of this study demonstrate that widespread WSI adoption will likely not occur organically; instead, some form of government intervention will be needed to promote WSI. These findings are in line with the work of others, who have found that adoption of community-based technologies will likely be outside the financial reach of farmers and that adoption is responsive to government-led initiatives, including subsidies (Blanke et al. 2007). Even with subsidies to cover the initial investment costs, it will not be sufficient to just hand over ready-to-use WSI technology or already built WSI infrastructure to smallholders. Rather, the technology and infrastructure will need to be coupled with market solutions if they are to be desirable, and, ultimately, continuously valued and used. A statement from a smallholder in Zhangye illustrates this point: “If you want to establish [WSI] on a large scale you need to set up a network that includes planting, sales, and management. You have to make finished products like vinegar [from the fruits or vegetables being grown].”

Market access is not just a challenge for WSI adoption in rural China. Investigating a rainwater harvesting project in Gansu province, Cook and Wei (2002) found that focusing on solving the often overlooked problems faced by villagers in everyday life can help facilitate the successful dissemination of agricultural technologies throughout rural China. Other village-level case studies have highlighted the need for agricultural policies to holistically address farmer needs and concerns with pragmatic interventions that couple technological fixes with improved access to markets and loans (Liu et al. 2008). Introducing technological innovations into a village without the market infrastructure in place to support the new forms of agricultural production will likely lead to failure (Lee 2005). Attention needs to be given to the new vulnerabilities and risks that shifts in irrigation and the accompanied new types of crop production and market integration may cause for smallholders (Eakin 2003). The findings from our study highlight this point and further suggest that interventions to promote WSI need to be multifaceted, taking into account not only the initial cost of technology and infrastructure investment but also the extension and creation of reliable market access to address the subsequent changes in agricultural production.

Economies of scale

With respect to barriers to WSI adoption, another recurring theme that arose from interviews across villages currently using FI was small plot size and associated concerns about economies of scale. Many interviewees mentioned that they did not have enough land to adopt DI or SI. They were concerned that WSI technologies are too expensive for them to adopt as individuals, and as each of them only had a small amount of land, they felt they could not produce enough crops to make up for the initial cost of investment. A second concern was that WSI technologies would not fit on small plots of land. Although these are valid concerns, research has shown that it is possible for DI to be an economically viable option for small farms in Nepal (Shah and Keller 2002; Westarp et al. 2004). Thus, there is a need for better communication between irrigation engineers, extension specialists, and smallholder farmers about the cost of installing each type of WSI technology on a per mu (1 mu = 0.165 acres) basis, the average yield per mu for different crop varieties commonly grown with WSI, and the minimum land requirement for WSI to be profitable with each crop type. Extension specialists may need to provide further assistance to help farmers calculate what their initial investment would be; how long it would take to recoup their initial investment; how much yield, and thus profit, they could expect; and if additional financial resources (e.g., bank loans) need to be obtained for the investment. Such information and assistance would enable smallholders to evaluate the actual investment risk and make informed decisions about whether or not to adopt WSI technologies and may reduce the likelihood of abandonment once the technology is adopted. Further, most of our interviewees believed that it should be the responsibility of the government to provide, at a minimum, subsidies to assist them with WSI installation. Many declared that the government should develop irrigation infrastructure and set up WSI for free. Only one interviewee mentioned that he would consider WSI if he could get help to secure loans for adoption. These preferences do not bode well for the autonomous dissemination of WSI, and point to the need for WSI to be implemented at a scale larger than an individual village so that more resources may be pulled together and made available to address smallholder needs and concerns.

Conclusion

Institutional context, extant agricultural production practices, and the ways that smallholders structure and prioritize different components of their livelihoods all play key roles in determining if irrigation technologies will be adopted and successfully used in the Global South. Recent studies of WSI adoption and usage by smallholders have called attention to the importance of local formal and informal institutions in determining patterns of farmer behavior and outcomes of WSI introductions (Burney and Naylor 2012). However, little attention has been explicitly directed at understanding how the set of social norms, values, and other institutions that regularize farmer behavior impact WSI adoption and patterns of use. In this study we investigated how the introduction of DI in two villages in Gansu, China intersected with local social relations, agricultural production practices, livelihood strategies, and the institutional context that underlies them. We also examined smallholder perceptions of WSI technologies and the factors that influence their decisions to adopt them in the broader Loess Plateau region. Our results demonstrate that the introduction of DI contradicted many of the local institutions that govern agricultural and water management, as well as livelihood decision-making, leading to either actual or a stated intent of system abandonment. Our results also highlight a range of factors influencing WSI adoption and continuous usage beyond saving water, increasing yields, monetary benefits, and avoiding technological problems as previously discussed in the literature.

First, we observed a disconnect between the temporal demands of practicing DI and the ways that farmers prioritize giving time to labor migration and off-farm wage work, which led to difficulties in coordination among households, women being burdened with more work, and a general dislike of DI. This result demonstrates that in addition to understanding how WSI impacts labor availability in aggregate, it is also necessary to investigate how WSI changes the way that farm labor is distributed across time. Such understanding is crucial for developing interventions to promote WSI technology diffusion that minimize unequal or unmanageable labor burdens and do not restrict smallholders' ability to diversify their income sources. This result is particularly important given that temporary and semi-permanent migration and off-farm wage work has become a major component of smallholder livelihood strategies in the developing world (Brookfield 2008). Second, we identified smallholder conflicts and unwillingness to cooperate with other households as major barriers to WSI adoption and usage. This result suggests that current land management practices and the set of social norms and values that underlie them, particularly those that govern communal behavior, are important determinants of WSI project outcomes. Failure to take into account local social and behavioral institutions that either facilitate or impede cooperation across households may lead to unsuccessful WSI adoption or abandonment, despite any water saving or pecuniary benefits its use would entail. Finally, our study highlights that smallholder knowledge of crop water interactions, their reluctance to increase production or diversify the crops they grow because of unstable and uncertain markets, and inadequate training on how to properly use and implement new agricultural technologies all play a role in inhibiting WSI adoption and continuous usage. From a policy perspective, efforts to disseminate WSI technologies to smallholders must go beyond educating farmers about water scarcity, setting the right water pricing mechanism, distributing WSI equipment, and building WSI infrastructure. Instead, WSI interventions should be multifaceted and conserve water; address smallholder concerns about the initial investment cost of WSI systems, time and labor requirements for maintenance and usage, and market access to absorb additional and new crop production resulting from changes in agricultural practices; and contribute to building communal capital and develop mechanisms for mediating conflict. Future research looking at the role of institutional context in WSI adoption and use should not only examine the factors that lead to successful outcomes, but also determine how the adoption of WSI technologies may exacerbate existing risks or create new vulnerabilities for farmers. This understanding would enable the development of holistic WSI interventions that address the day-to-day problems that smallholders face, thus reducing the likelihood of creating unintended consequences and disadoption.

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