RESEARCH ARTICLE

Agricultural water conservation in China: plastic mulch and traditional irrigation

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Abstract. Plastic mulch is commonly used with micro-irrigation in developed countries; however, Chinese farmers use plastic mulch on a vast scale independent of micro-irrigation. For the past three decades, China's land area in plastic mulch has exceeded the world's total land area in micro-irrigation. We report results from the water-scarce region of Minqin County, where 87% of Chinese farmers interviewed responded that they use plastic mulch to conserve water and 53% to increase yields. Survey results indicated the desire to conserve water through the use of plastic mulch to be statistically equivalent to the desire to increase yields. Responses to interviews and surveys indicate that farmers perceive water savings of 24–26% when plastic mulch is used. Interview and survey responses suggest farming families are shifting to purchasing wheat from outside the region; a potential import of "virtual water" into this water-scarce region.

Key words: *agriculture; cash cropping; China; irrigation; plastic mulch; virtual water; water conservation*.

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Introduction

As with other developing nations in Asia, Africa, and elsewhere, the severity of China's water shortage is arguably the nation's greatest social and environmental challenge of the 21st century. Irrigated agriculture comprises 70% of the world's annual freshwater withdrawals (United Nations 2012). In response to this challenge, the Chinese government has decided to invest 240 billion Chinese *yuan* (US$40 billion) to construct the South-to-North Water Transfer (SNWT) project: the largest ever built by any nation (Nickum 2006, Gu et al. 2012). Others have proposed a more integrated approach of managing water scarcity through the inclusion of small-scale agronomic water conservation measures, such as altered cropping patterns, altered tillage practices, and the use of plastic mulch (World Bank 2002). The tendency for agricultural communities who experience water scarcity to alter crop selection and grow high-value cash crops so as to purchase crops that have a higher water demand from outside their region is viewed as a type of "virtual water" trade (Yang and Zehnder 2001).

Plastic film mulch is called "mulch" even though its appearance as a thin sheet of plastic film does not resemble traditional types of organic mulch, such as straw or leaves. It is purchased in rolls and applied the length of field rows to seal the upper layers of the soil. Crops are allowed to grow up through holes that are cut into the plastic. There is a wide array of plastic mulch products varying in color, thickness, dimensions, plastic type, and intended purpose. Farmers in different parts of the world have different ways of installing the plastic film. The methods used range from fully mechanized installation to installation with hand tools. A partial list of desired outcomes from plastic mulch may include increased yield, conserving water, weed suppression, rain shedding, promoting earliness in ripening or compressed cropping cycles, enhanced germination, agrochemical fumigation, greater variety of crop types, reduced soil erosion, and others (Lamont 1993, Ingman 2012). Existing agronomic water conservation research primarily focuses on conservation resulting from technological advancements, such as overhead irrigation and micro-irrigation systems. These categories of irrigation systems commonly take the form of center-pivot and drip irrigation, respectively. There are three types of micro-irrigation that differ based on the type of emitter used: drip (the most common form of micro-irrigation), bubbler, and micro-sprinkler. Smallholders in the developing world often lack access to pressurized irrigation water. They also often lack the necessary capital to purchase the required micro-irrigation com-

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ponents, such as pumps, emitters, filters, and pressure reducers (Polak et al. 1997). The maintenance costs and technical knowledge required for installing, operating, and repairing micro-irrigation systems further limit their implementation in the developing world, although some advancements have been made in reducing costs and simplifying the design of advanced irrigation systems (Polak et al. 1997). In contrast, the development and use of specialized plastic products in agriculture, i.e., plasticulture, has become a valuable source of products used in large quantities by farmers all around the world (Wittwer 1993).

Plastic film mulch is one of the most extensively used forms of plasticulture, and it is currently used on a vast scale in China. While plastic mulch is used to enhance water savings of micro-irrigation in developed countries, its adoption in developing countries is often independent of micro-irrigation technology. China accounts for 40% of the world's plastic mulch use. On an annual basis, 20 million hectares of farmland are covered with plastic mulch (Kasirajan and Ngouajio 2012, Dai and Dong 2014), whereas only 3% of Chinese farmers use micro-irrigation (Deng et al. 2006, Kasirajan and Ngouajio 2012). Despite its prevalence in agriculture, the reasons farmers in developing countries increasingly choose to purchase and use plastic mulch are not well understood.

While plastic mulch use can provide many advantages to farmers, the most common finding from prior research is that plastic mulch is used by farmers to increase productivity, or crop yield. Wittwer (1993) summarizes this when he writes, "the initial driving forces for the use of plastic in horticulture were, first, to increase earliness and total crop productivity of high-value horticultural crops." Laboratory testing and field trials more often investigate how plastic mulch may increase crop yield rather than how it may conserve irrigation water (Ricotta and Masiunas 1991, Easson and Fearnehough 2000, Xie et al. 2005). Some studies have considered how the use of plastic mulch may conserve soil moisture; however, these studies most often involve the use of drip irrigation (Tiwari et al. 2003, Amayreh and Al-Abed 2005, McCann et al. 2007), instead of surface flood irrigation techniques most often applied in developing countries.

In some regions, the use of plastic mulch has been shown to conserve water through significantly reducing the evaporation of soil moisture in the upper layer of the soil (Mahrer et al. 1984, Li et al. 2003). Therefore, the total remaining soil moisture loss under plastic-mulched conditions is primarily through transpiration and percolation. To observe crop yield and water conservation concurrently in a field trial, a hole must be made in the plastic either through mechanically injecting a seed through the plastic and into the soil, through manual cutting of the plastic to allow for the seeds that were previously planted to emerge, or by cutting transplant holes into the plastic. These holes lessen the sealing effect of plastic mulch and the ability of plastic mulch to conserve soil moisture (Li et al. 2003). However, these holes may also provide a path for crop foliage to naturally collect and route precipitation into the soil (Haraguchi et al. 2003).

Few applied studies have attempted to estimate the total water savings afforded through plastic mulch use. A feasibility study for the use of plastic mulch in Nigeria found clear polyethylene mulch to increase soil moisture content by an average of 40% over bare soil for the duration of the growing season (Anikwe et al. 2007). However, because the study did not involve local farmers in the study design, the variability in practices used for application of irrigation water and plastic mulch by farmers was not considered, and further research is needed to better understand the moisture conservation that would be experienced in practice.

Not all aspects of plastic mulch use in agriculture are positive, however. Use of plastic mulch has increased worldwide every year for the past six decades. By 1999, over 12 million hectares of land globally were being cultivated with plastic mulch (Miles et al. 2005). The growth in agricultural plastic demand at the global scale contributes to an overall average increase of 10% in world plastic production per year (Scarascia-Mugnozza 2011). One consequence of this tremendous amount of plastic use, and plastic mulch use globally, is that there are few if any recycling options for farmers. Previous studies report that <5% of agricultural plastics are recycled (Levitan and Barros 2003).

The most common method of disposal for agricultural plastics, of which plastic mulch is arguably the dirtiest and least recyclable, is open burning on the farm. The burning of plastic mulch film releases carcinogenic dioxins at a rate of 40 times that of controlled high-temperature incineration (Levitan and Barros 2003). Furthermore, China commonly uses an extremely thin type of polyethylene plastic that is eight hundredths of a millimeter (0.08 mm) thick. Installing this plastic with hand tools or machinery requires as much as 30% of the plastic mulch to be buried in the soil in order to seal the edges of field rows. The buried plastic usually gets shredded through tillage and thus contributes to the phenomenon known in China as the *baise wuran*, the "white pollution" that litters their landscape, endangers livestock, and pollutes rivers and lakes. The detrimental effects of single-use plastic mulch waste present a tremendous disposal challenge not only for China, but for agricultural communities throughout the world.

A review of the literature on plastic mulch use in agriculture (Ingman 2012) found hundreds of articles in agronomic journals discussing the production advantages of plastic mulch in various experimental field trials, and one journal article that discussed its water conservation advantages. Furthermore, no published articles were found that provide insight into how and why farmers use plastic mulch so extensively, despite problems with disposal.

Much has changed in the world over the past 30 years concerning agricultural practices and the status of water resources. Our study sought to reduce a gap in applied social science research by exploring from farmers' perspectives how and why plastic mulch is used through a case study of agricultural practices including application of plastic mulch and water use in an agricultural community in China. Farmer practices in aggregate are believed to have a potentially large influence upon the status and availability of water resources. Therefore, why farmers use a particular agricultural practice can provide critically important information relevant to promoting efficient water use and crop production under conditions of water scarcity.

Our study attempted to directly measure farmer practices relating to water and plastic mulch use. In addition, we sought to gain information about the reasons behind the increasing use of plastic mulch in agriculture and the attributes farmers require of a mulch product through systematically collecting information from farmers and directly observing their practices at the local level. The research questions that motivate this study are as follows: (1) What is the relative spatial extent of plastic mulch use in China and drip irrigation use in the world? (2) What are the reasons why farmers choose to use plastic mulch? (3) How much water may be saved through using plastic mulch?

To a certain extent, this case study is exploratory and descriptive in nature. Through literature review and analysis of technical reports on plasticulture, as well as surveys and interviews with farmers in our study region, we hoped to gain insights into the extent to which plastic mulch is used in various regions as well as at a global scale, and the reasons for its use. In addition, we hoped to gain information about the water conservation potential of this practice. By understanding the nature of the practice of plastic mulch application and the attributes that farmers find desirable or necessary in a mulch product, we hope to also inform development of biodegradable mulch alternatives that could provide the same utility needed by farmers without the current problems associated with lack of options for mulch disposal.

Methods

The methodological approach used in this study is analogous to the creel census methodology used by fisheries biologists to understand the status of fisheries and the impacts of various fishing practices. For nearly a century, biologists and fisheries managers have relied upon creel census interview and survey methods to collect large amounts of information (Eschmeyer 1939, Mottley 1949, Moyle and Franklin 1957). Creel census is a methodology using surveys and informal interviews to collect data relating to fish counts, fish species, harvest methods, duration of fishing effort, and other useful information. This method collects information directly from fishermen, the people who use the natural resource that is under investigation, and has been a cost-effective method for providing high-quality data. In more recent years, fisheries experts have used creel census data as a baseline for validating new technologies, such as sonar (Yule 2000, Frear 2002). The field methods employed in our study are analogous to creel census in that they also employ survey, interview, and scientific observation methods to directly investigate how the use of plastic mulch by farmers may be influencing their use of irrigation water.

Methods for fieldwork

The fieldwork portion of this study occurred in Minqin County of Gansu Province, China, in the summer of 2011 (Fig. 1). The study's sample population was equally distributed across the county's 16 townships that are situated along the Shiyang River. These sites are located along irrigation canals and the terminal reaches of this northeasterly flowing river, although today the flow of the Shiyang River ends prior to reaching Qingtu Lake, which has been dry since the 1960s.

Of the 136 households sampled, there were 30 interviews conducted, and 96 face-to-face surveys conducted. In addition, at the start of the project, an additional 10 pilot interviews and surveys were conducted. The interview and survey instruments collected demographic information, perceptions of ecological risk, plastic mulch use, water use practices, and questions relating to standard of living (Ingman 2012). Participants were selected upon the criteria that they were over the age of 18 and that they had first-hand knowledge of farming practices. Interviews were conducted by a team of three, including the first author and two native Chinese students.

Interviews were semi-structured, a format in which some questions were open-ended so as to allow participants to provide additional information they judged to be relevant. After all revisions were made based upon the pilot interviews, two interviews were conducted in each of the 15 townships for a total of 30 interviews.

The interview transcripts were translated directly by our local Minqin County translator into standard Mandarin Chinese in Microsoft Word. These transcripts were then translated into English while still retaining the original Chinese responses in the transcript. The transcripts were then imported into NVivo 9 software (QSR International, Melbourne, Australia) in their multilingual format. The English portions of the transcripts were coded into themes for each question such that all responses to a question could be readily

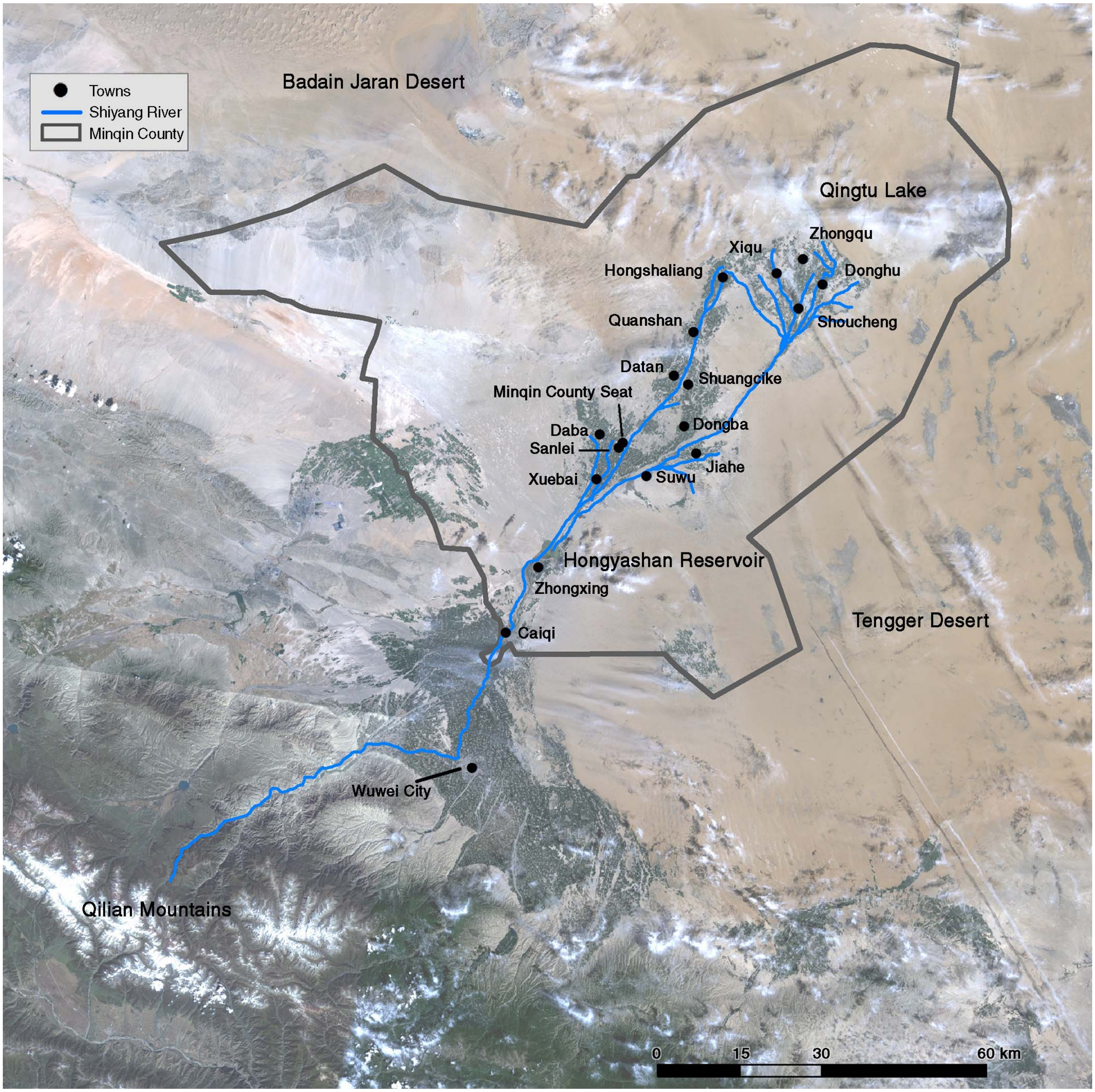

Fig. 1. Map of Minqin County, China. Imagery source is Landsat 5 Thematic Mapper 2010.

evaluated and placed into sub-themes (Gibbs 2002). Themes can be seen as "tags or labels for assigning units of meaning to the descriptive or inferential information compiled during a study" (Miles and Hubermann 1994, Patton 2002). This process allowed us to understand the issue of plastic mulch use from the perspective of local study participants.

Each survey requested the respondent to rate their level of agreement with a provided statement on a five-point Likert index (Likert 1932). The questions involved the following content areas: perception of plastic mulch use, water scarcity and water quality, and the local standard of living. These data were later assessed with descriptive statistics. Additional questions were asked that were not on a five-point scale. Pilot surveys were conducted to improve the survey questionnaire and also to ensure all team members were trained and capable of conducting surveys independently and uniformly. After this training and the improvement to the survey questionnaire was completed, the second phase of the project began, consisting of the household survey. Two surveys were conducted by each of the three team members for a total of six surveys in each of the 16 townships to include Zhongqu Township. Paired sample Wilcoxon signed-ranks tests were used to compare the means of the two sets of responses for our survey participants. This nonparametric test was chosen in order to compare two sets of responses from the same group of participants where a normal distribution was not assumed.

Ethnographic methods

Participant observation was used in conjunction with interviews and surveys to better understand the perspectives of individual farmers. Participant-observation is a useful method for triangulating the interview and survey data and increasing the validity of our results (Hammersley and Atkinson 1995, Bernard 2006). The first author spent seven weeks in Minqin County observing and sometimes participating in farming activities. The research team traveled by bus and by foot throughout the county to administer the interview and survey instruments. In the final week of the fieldwork, the first author lived with a Minqin farming family to increase his familiarity with local farming practices, to better understand the routine events of their daily lives, and to further investigate the research questions. Gaining this perspective at the local level provided a window into the ways Minqin farmers have adapted their practices to ameliorate the effects of severe water scarcity. Practices observed include plastic mulch use, cash cropping, use of salt-resistant crops, and retaining the structure of work units and communes from the Collectivization Period to pool and use labor more effectively.

Meta-analysis

All available estimates of the total agricultural land area Chinese farmers cultivated through the use of plastic mulch were collected and compiled in order to compare the spatial extent of this practice to the spatial extent of other forms of water conservation involving plasticulture or new irrigation technology, such as micro-irrigation. Data were compiled from nine independent sources (Wittwer et al. 1987, Ma 1988, Jensen and Malter 1995, Postel et al. 2001, Rosato 2004, Kulkarni et al. 2006, Chen et al. 2013, Worldwatch Institute 2013, Dai and Dong 2014), which provided 23 different estimates for spatial extent of given water conservation practices worldwide (including use of plastic sheeting as a mulch). In addition, data were collected on the spatial extent and proportion of the total amount of plastic used in agriculture by practices also intended to conserve water, notably micro-irrigation.

Results

Spatial extent of plastic mulch use in China

Information from nine independent sources was collected and compiled to document the land area in China that has been cultivated through using plastic mulch since its introduction to China in the late 1970s. Since prior studies suggest that plastic mulch may be used in China as a water conservation strategy, we used data on the spatial extent of micro-irrigation (also known as drip irrigation) as a context for comparison with the spatial extent of plastic mulch use in China. The results of this analysis are presented in Fig. 2.

These results suggest that for over three decades China has cultivated more agricultural land with plastic mulch than all nations have cultivated through the use of micro-irrigation. Less than four percent of China's agricultural land uses micro-irrigation; therefore, the comparison presented in Fig. 2 includes a minimal amount of overlapping data (Jin and Young 2001, Deng et al. 2006, World Bank 2006).

Reasons for plastic mulch use

A major focus of the interviews and surveys was to investigate the reasons why farmers choose to use plastic mulch. Six major themes emerged from the interview transcripts, indicating that water conservation was the primary motive behind mulch use, supplemented by the desire for productivity and profitability. Allied with the theme of water conservation were the themes that mulch use is an imperative and that the semiarid climate of the region influenced plastic mulch use. Allied with the theme of productivity and profitability were the themes relating to crop germination and earliness and efficiency in fertilizer use. Table 1 provides the compiled themes and the percentage of participants citing each theme.

The results of Table 1 indicate that nearly 90% of farmers use plastic mulch for the purpose of conserving irrigation water. By contrast, a little over 50% of participants expressed the intention of using plastic mulch to increase the productivity of crops. When asked why plastic mulch is used one farmer replied, "The most important reason is for maintaining water content. Today Minqin is very water scarce." Statements such as this were the most common theme of our interviews.

The two leading reasons identified in the interviews as to why farmers use plastic mulch were then included in the survey questionnaire to provide a quantitative comparison. Prior research predicts plastic mulch is used by farmers predominantly for crop productivity, or increased yields (Wittwer 1993). This would suggest the mean response value for productivity would be higher than the mean value for water conservation. We also used paired sample Wilcoxon signed-ranks tests to investigate if income or education influenced participant

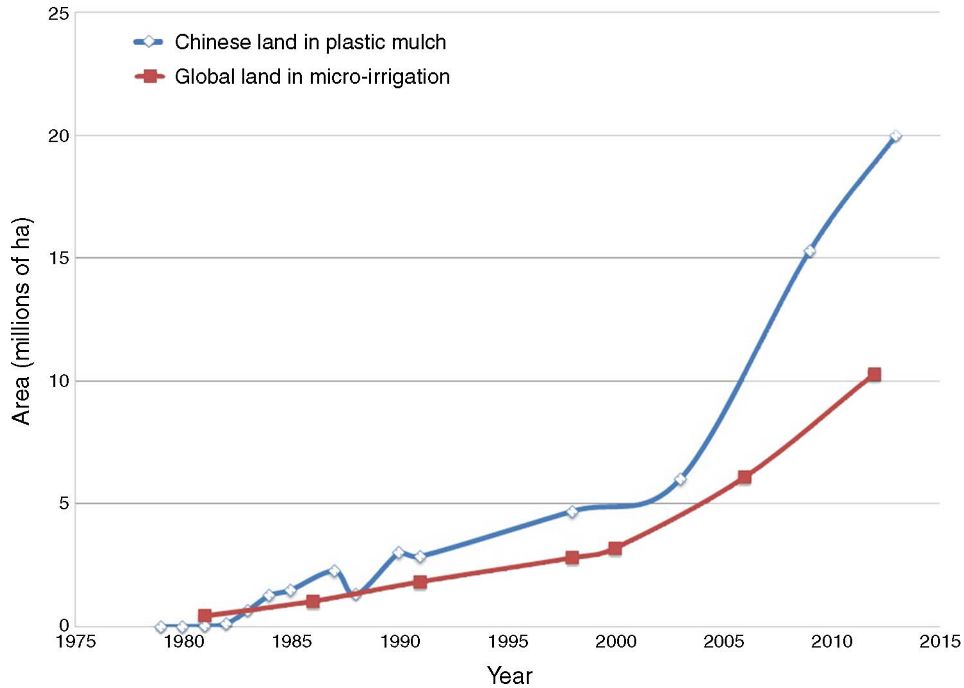

Fig. 2. Total area of agricultural land in micro-irrigation globally as compared to the total area of agricultural land in China employing the use of plastic mulch (Wittwer et al. 1987, Ma 1988, Jensen and Malter 1995, Postel et al. 2001, Rosato 2004, Kulkarni et al. 2006, Chen et al. 2013, Worldwatch Institute 2013, Dai and Dong 2014).

responses. Table 2 presents the results.

The difference between the mean value for increased yield (4.71) and water conservation (4.61) is not statistically significant ($n = 96$, $P = 0.177$) and the effect size is categorically considered to be small ($r = 0.14$; Cohen 1988, Vaske 2008). The analyses of income and education levels indicate relatively similar mean values between the purposes of increased yield and water conservation. The income and education categories indicate no statistical significance in the means ($n = 96$, $P > 0.05$), and all effect sizes are considered to be small ($r \sim 0.1$). In contrast to prior research, our results indicate farmers may use plastic mulch as much for conserving water as they use it for crop productivity.

Water savings

Plastic mulch conserves irrigation water by reducing evaporation in the upper layers of the soil (Mahrer et al. 1984, Li et al. 2003). When farmers were asked to estimate the amount of water savings that may be afforded through plastic mulch they estimated this amount based upon the total water budget for their crops. This includes not only evaporation, but also uptake and transpiration by the plant, percolation down into the soil, and even losses in water delivery prior to

Table 1. Reasons for plastic mulch use as expressed by farmers (interview sample size $n = 30$).

Use theme	Expressed (%)	Participants (n)	Description
Theme 1: water conservation	86.7	26	The use of plastic mulch conserves irrigation water and retains soil moisture.
Theme 2: productivity and profitability	53.3	16	Plastic mulch use promotes the growth of healthy crops and dependable yields for farmers.
Theme 3: use is an “imperative”	46.7	14	Crops can only be planted with plastic mulch due to water scarcity, climate conditions, and other reasons, thus making its use a “requirement.”
Theme 4: germination and earliness	43.3	13	Plastic mulch use leads to faster germination, soil moisture retention for sprouts, and compressed cropping cycles.
Theme 5: semiarid climate	26.7	8	With plastic mulch use, the arid conditions and high temperatures can be overcome.
Theme 6: fertilizer conservation	20.0	6	Plastic mulch use leads to fertilizer conservation and fertilizer use efficiency.

Table 2. Purposes for using plastic mulch.

	Mulch purpose†				
Independent variable	Increase yield	Conserve water	*Z*	*P*	Effect size *r*
Overall evaluation	4.71	4.61	−1.35	0.177	0.14
Income‡					
≤¥10,599	4.65	4.46	−1.34	0.10	0.19
≥¥10,600	4.77	4.77	0.000	1.00	0.00
Education§					
≤Eighth grade	4.78	4.73	−0.88	0.378	0.13
≥Ninth grade	4.64	4.50	−1.09	0.28	0.15

† Variables were coded on a five-point scale: 1, completely disagree; 2, mostly disagree; 3, neutral; 4, mostly agree; and 5, completely agree.
‡ Income category was based upon median split where 48 participants were below and 48 above the median (1 U.S. dollar was equal to ~6.5 Chinese *yuan* [¥] in 2011).
§ Education category was based upon 45 respondents at or below the median of eighth grade education and 51 respondents with nine or more years of education.

reaching the crop. In all studies to date, including our own, the accuracy of estimates of water savings afforded through plastic mulch are limited by the significant confounding of factors such as crop type, climate, soil type, methods of installing plastic mulch, transplant holes, irrigation system type, plastic mulch thickness and color, perforations or cuts made in plastic film, irrigation scheduling patterns, and others. For these reasons, estimates of the water savings afforded through plastic mulch are site-specific and highly dependent on the variability of farmer practices. However, because of the location-specific nature of the processes involved and the many factors that influence water conservation, farmers provide one of the best sources of information for estimating water savings through plastic mulch use.

Another way we were able to understand the water use practices of our sample population was to consider recent water policy reforms for Minqin County. In 2009, Minqin government officials implemented the Well Closure and Land Restriction policy (*guanjing yatian*), and they set a firm cap on irrigation water use of 415 m^3 per Chinese *mu* (one hectare is 15 Chinese *mu*). This irrigation quota effectively restricts most farmers in the county to five annual inundations of their fields. The mechanism used to restrict farmers from using water in excess of this quota was through the installation of a computerized card-swipe system that was installed on the head of each irrigation well. The team leader within the village keeps track of water use so as to avoid exceeding the water budget for the team of households. Fig. 3 shows a computerized card-swipe system installed at one of the townships.

During his stay in China, the first author took part in helping farmers dig and move soil to align irrigation ditches prior to an irrigation event. This process of working together in the traditional team units, or *dui* in Chinese, requires a minimum of 50 collective hours of hard manual labor prior to each irrigation event. For this reason our study's participants knew the exact number of irrigation events not only on the basis of the government water quota, but also through their own expenditure of heavy labor to align their fields for receiving irrigation water. We therefore have a high level of confidence in the interview responses that indicate after plastic mulch was used, the number of irrigation events per year decreased from an average of 7 events to their present average of 5.3. This decrease in annual irrigation events represents a water savings of 24%. To illustrate this finding, one of the interview participants

Fig. 3. The card-swipe water allocation system in Minqin County.

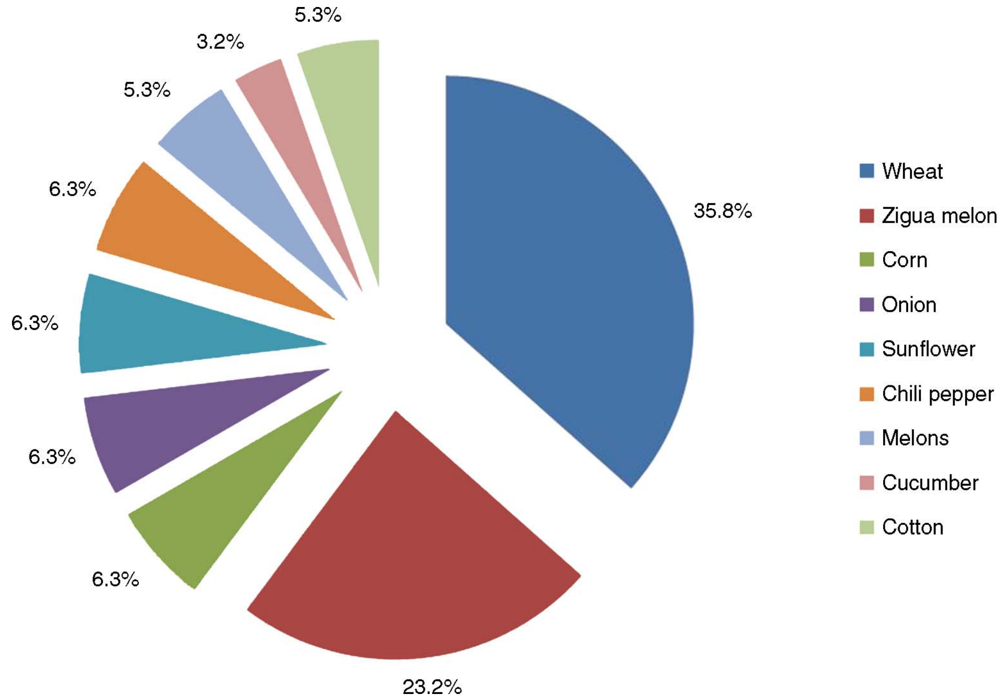

Fig. 4. Responses from farmers to the survey question "Which crops do you plant less of each year?" (Survey sample size $n = 96$.)

stated, "Using plastic mulch can save about 30% in water use." These results caused us to ask our survey participants to quantify the change in water use as a result of using plastic mulch. One farmer in the survey indicated an increase in water use, while the remaining 95 farmers (99% of sample population) responded that it conserved water. These survey participants reported an average water savings of 26% when using plastic mulch. This figure is relatively consistent with the estimate of a 24% reduction in water use based upon irrigation events. Taken together, best estimates indicate that plastic mulch use may provide the farmers of Minqin County with an average water savings of 25% under current conditions.

Shift in cropping patterns

Interview responses also indicated a potentially large shift in cropping patterns for Minqin County, a shift that provides further insight into the second and third research questions. For centuries, households in rural China have relied upon subsistence farming of staple grains to provide for the nutritional needs of their families. Hand-pulled wheat noodles (*la mian*) are the expected lunch or evening meal anywhere throughout Minqin County. In past years, the wheat in these noodles was grown by the household who consumed them. However, most of the households encountered by members of our research team now purchase wheat from the market, or less often, they are eating the last remaining wheat they grew in previous years. For all 136 households in the study we observed, every household used plastic mulch in their fields. When we asked interview participants which crops use plastic mulch one farmer responded, "Except for wheat, all of them use it. For example: cotton, sunflower, corn, and melons." When asked what is the least amount of subsistence grains the household cultivates a farmer explained, "We don't plant grains," and later added, "Wheat requires a truly large amount of water to be grown." This statement suggests some households have entirely shifted their household's source of staple grains from subsistence farming to relying entirely on the market through purchasing wheat. A second farmer reiterated this trend: "Now we don't have any [of our own] grains. For many years we have not planted wheat." For these reasons our team asked survey participants which crops they planted less of each year. The responses to this question are included in Fig. 4.

This figure indicates a significant decline in wheat production, followed second by the Zigua melon. Farmers indicated the price the market returned for the Zigua melon seeds had declined considerably in recent years; therefore, most farmers have discontinued its cultivation. For wheat production, interview results indicate that 43% of farmers do not cultivate wheat at all, 33% cultivate wheat sparingly, and 23% provided no response. Our team did not observe wheat grown in any of the 136 household that participated in the study. A total of 63% of interview participants indicated that wheat was not cultivated either because it could not be cultivated with plastic mulch or because it otherwise required too much water to be cultivated. These results suggest the significant decline in wheat cultivation for Minqin County relates to the overall high irrigation demands of wheat. Furthermore, the comparatively high water demand of wheat as compared to cash crops relates to its inability to be able to have its water footprint reduced through plastic mulch use.

Discussion

Our meta-analysis of plastic mulch use suggests that China has been applying plastic mulch on a vast scale, largely without the use of micro-irrigation, since the early 1980s. The results indicate that for three decades China has cultivated more land area with plastic mulch than all nations in the world have cultivated through the use of micro-irrigation. The focus of past and current water conservation research on the use of plastic mulch in conjunction with micro-irrigation would suggest that, because plastic mulch is most often used in China without micro-irrigation, it may not be used as a water conservation technology. The field components of the project were critically important in elucidating both why plastic mulch use is so prevalent in China and to confirm whether or not is being used for the purpose of water conservation.

The results of our fieldwork indicate that water conservation is a leading reason why Chinese farmers use plastic mulch. Prior research indicated that crop productivity is the leading reason why farmers use the product. However, our interview results indicated water conservation ranked ahead of crop productivity (ranked as important in 87% and 53% of responses, respectively). Furthermore, there was no statistically significant difference in the way our sample of participants responded to the purpose of using plastic mulch for water conservation vs. the purpose of using it for increasing productivity. It is important to note Theme 4 of Table 1, described by one participant as "faster germination and soil moisture retention for sprouts" indicates plastic mulch may provide a sort of "germination safeguard." We did not anticipate this reason for plastic mulch use prior to conducting the fieldwork because it was not found anywhere in our review of previous research. This unexpected finding is further evidence that the research community has something to learn from farmers whose knowledge is supported by years of firsthand observation.

Our results suggest that the use of plastic mulch provides farmers with water savings. Owing to the complexity of the many combinations of cropping practices and environmental conditions, it would be impractical to attempt to simulate the water conservation outcome of plastic mulch use for every site and every individual farmer's practices. Social science research methods such as those employed here can provide direct access to region-specific estimates of water savings through interviews, surveys, and direct observation of farmer practices at relatively low cost. According to interview results, farmers have reduced their annual water irrigation events from 7 to 5.3 by using plastic mulch; a savings of 24%, consistent with farmer estimates of conserved water in our surveys (water savings of 26%). Based on these data, we estimate water savings of ~25% for farmers of Minqin County when plastic mulch is used with traditional flood irrigation methods to grow cash crops, such as cotton, corn, and melons.

A study in Nigeria estimated that plastic mulch conserves 40% of soil volumetric water content (Anikwe et al. 2007). Since transpiration and percolation comprise the rest of the water budget, our estimate of 25% in total irrigation water savings through plastic mulch use may be comparable to those reported for the Nigerian study, though we recognize there are methodological differences between the studies.

The use of plastic mulch plays an important role in what appears to be a recent and dynamic shift in crop selection for the region. Most households have discontinued traditional cultivation of wheat in favor of cash crops. This trend is closely related to both plastic mulch use and water conservation. Responses to interview and survey questions indicate that the decision by farmers to discontinue wheat cultivation is related both to stricter government-mandated water allocation and to the incompatibility of using plastic mulch to cultivate wheat. This shift in cropping patterns from grains to cash crops can be viewed as a regional trend to conserve water through a type of virtual water trade in this water-scarce region (Yang and Zehnder 2001). The conditions of severe water shortage for Minqin County, when combined with the incompatibility of using plastic mulch to cultivate wheat, indicate that the use of plastic mulch and cash cropping may be coupled practices for the region.

Conclusions

Our meta-analysis of plastic mulch use in China provides a context for comparison of these estimates to the global prevalence of micro-irrigation. We expected that both plastic mulch and micro-irrigation would share a rising trend with the global increase of plasticulture. While it is widely recognized that China uses more plastic mulch than any other country, the great disparity in spatial extent of plastic mulch use in China relative to the spatial extent of the use of micro-irrigation at a global scale was unexpected. This finding highlights the need for more research to better understand recent trends in how these and other technologies may be influencing the status of water resources for developed and developing countries.

Minqin County is one of the most water-scarce regions in China; however, water scarcity is common in much of northern and western China and in many other regions of the world. The extent to which farmers in our study identified water conservation to be of a similar order of importance as enhancement of crop productivity in their use of plastic mulch may not appear surprising for this semiarid region of China. However, these are the first results in any study to indicate that crop productivity is not necessarily the first consideration for farmers when choosing to purchase and use plastic mulch. Our farmer interviews provide new insights into additional benefits of plastic use, such as providing a "germination safeguard" for seedlings.

There are very few comparable data from other studies to compare to our estimates of water conservation through plastic mulch use. The 25% total water savings afforded through plastic mulch use estimated from our study is fairly consistent with the 40% savings in soil moisture observed through plastic mulch use by Anikwe et al. (2007). Much more applied research is needed to better understand the potential for water conservation through mulch use across different crop types, mulch types, and in various regions.

Investigation into the significant decline of wheat cultivation in Minqin County provided considerable insight into reasons behind use of plastic mulch. Plastic mulch use is strongly connected to both crop selection and agricultural water use, selecting for the growth of cash crops and against continued cultivation of wheat. This shift in the region to cash cropping represents a sharp break with the past, when subsistence staple crops were traditionally grown by households in this region. Thus, in Minqin County, use of plastic mulch appears to be a water conservation strategy that allows farmers to grow cash crops in order to purchase grains from outside the region, in a type of virtual water trade.

While plastic mulch provides important benefits of increasing crop productivity and water conservation, its disposal presents a serious challenge for farmers. Most plastic mulch is used only once and is too thin and dirty to be transported and recycled. As a result, farmers in both developed and developing countries have few options other than to bury or burn plastic mulch waste on their farms. More research and innovation is needed to provide farmers with sustainable disposal alternatives as well as suitable biodegradable alternatives to plastic mulch.

This study is merely a beginning, highlighting the need to investigate the extent to which plastic mulch is being used as a water conservation practice in other regions of the world. As plasticulture plays an increasingly important role in providing both water conservation and crop productivity, the disposal of agricultural plastic waste will likewise become an increasing challenge for farmers. This study found that Chinese farmers are using plastic mulch in innovative ways to conserve water without the use of micro-irrigation. More research is needed to understand how farmers, as the primary stewards of 70% of the world's annual freshwater withdrawals (United Nations 2012) may be adapting new products and practices to conserve water. In aggregate, these practices may have a profound effect on the future status and availability of water resources.

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