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The Impact of Green Water Management Strategies on Household-Level Agricultural Water Productivity in a Semi-Arid Region: A Survey-based Assessment

Afton Clarke-Sather [1,2,*], Xia Tang [3], Yonglan Xiong [2] and Jiansheng Qu [2]

1 Department of Geography, Urban, Environmental and Sustainability Studies, University of Minnesota Duluth, Duluth, MN 55412, USA
2 Lanzhou Information Center, Chinese Academy of Sciences, Lanzhou 730000, China; xiongyl@llas.ac.cn (Y.X.); jsqu@lzb.ac.cn (J.Q.)
3 Key Laboratory of Ecohydrology of Inland River Basin, Northwest Institute of Eco-Environment and Resources, Chinese Academy of Science, Lanzhou 730000, China; tangxia@llas.ac.cn
* Correspondence: afton@d.umn.edu; Tel.: +01-218-726-7875

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Abstract: This study evaluates the effect of policies that encourage farmers to shift to crops with higher water productivity (CWP) on the farm-level CWP of agricultural systems in a semi-arid region of western China. We combine survey results of farmers' historical cropping decisions from a 2010 survey with estimates of CWP from agronomic experiments analogous to actual cultivation practices in the region to model CWP at the farm level and understand changes driven by shifting crops. Policies designed to replace subsistence agricultural systems with two cash crops; potatoes and maize; resulted in an increase in the CWP of semi-arid agricultural systems of approximately 30% between the years 1990–2010. This change was driven by shifting to crops that have a peak water demand that occurs in the portions of the growing season with the highest rainfall. The results of this article illustrate the potential of shifts in cropping patterns to increase the CWP of agricultural systems in semi-arid regions.

Keywords: agriculture; green water; vaporshift; crop water productivity; China; subsistence agriculture

1. Introduction

Improving the crop water productivity (CWP) of the global agricultural system is a key concern in the face of the combined impacts of a growing population, the rising protein demand by increasingly affluent populations, water overexploitation in many river basins, and increasingly variable hydroclimatological conditions due to climate change [1–3]. Crop water productivity (CWP) represents the "crop per drop" or yield per unit of water evapotranspired. These concerns are particularly acute in rain-fed agricultural systems, which often have lower and more variable CWP [4]. Over the past decade, green water has been recognized as a central component of water use in the global agricultural system. Green water, characterized as precipitation that is evapotranspired by plants without leaving the vadose zone, is contrasted with blue water, which enters surface or ground water flows. Green water is the sole water source for rain-fed agriculture. Historically, blue water has been the focus of agricultural water policy and management, but additional gains in the water productivity of the global food systems during the 21st century are likely to arise from improvements in green water management [5]. Although improving green water policies and management has become a focus for increasing the CWP of the global food system, identifying what green water management and policy interventions look like in practice remains challenging.

This study investigates agricultural policies that have collectively altered green water use in a semi-arid region of north-western China, and provides one view of what green water policy and management in arid and semi-arid regions looks like in practice, as well as what impacts it may have on agricultural water productivity. We use a novel approach to analyzing green water management, in which we combine survey data of household agricultural production with existing agronomic estimates of the CWP of individual crops drawn from peer-reviewed published studies, using this to estimate the CWP of agricultural systems at the farm level in five villages. This study also presents evidence from actual farms on how farmers in arid and semi-arid environments might close the yield gap between potential and actual CWP through the decisions that they make in practice. Such a meso-scale approach derived from survey data at the village level is particularly important because information on changes in some agricultural practices, such as use of mulches and fertilizer applications, may be difficult to assess under heterogeneous conditions through remote sensing or modeling approaches. As we consider green water management, scholars will have to look beyond the traditional disciplinary boundaries of agricultural water management to examine broader socio-economic processes that impact green water use. This paper continues with a brief description of the problem of green water management, followed by a description of the research site and green water management policies that have been employed at the site. We then describe our research methods and data, followed by our results and a discussion of our findings.

1.1. Green Water Policies for the Water–Food Nexus

Green water has been recognized as a critical component of the global food–water–climate nexus, yet our understanding of green water policies remains underdeveloped. Hoestra and Mekonnen [6] estimate that although green water accounted for 78% of global agricultural water use, agriculture still accounted for a full 87% of global blue water use. Improved blue water management, particularly irrigation, played a major role in expanding food production in the 20th century. In the 21st century, the global potential for the areal extension of irrigation is nearing its limit, as relatively few developable locations remain for additional large-scale irrigation projects [7]. In the absence of further large-scale expansion of blue water use for agriculture, it is important to focus on improving the productivity of green water used in agriculture, particularly in rain-fed agricultural systems in semi-arid regions of the developing world, where water productivity may be low [4]. Hoff et al. [2] have identified several improvements that can be made in green water management, including: the use of supplemental irrigation; improved nutrient management; virtual water trade; and vaporshift, defined as shifting non-productive evaporation to productive transpiration. In this study, we focus on vaporshift by examining two forms of vaporshift: the use of mulches that physically limit evaporation, and temporal vaporshift—shifting to crops whose water demands are attuned to seasonal cycles in precipitation, allowing more evapotranspiration to take place as transpiration by crops during periods of peak rainfall, rather than as unproductive evaporation outside of the growing season. The use of seasonal vaporshift has the potential to increase CWP in semi-arid regions of the world, which often feature high seasonality of precipitation [4]. Unlike irrigation projects, from a policy and management standpoint, vaporshift and other green water management policies are likely to be implemented through numerous small-scale projects, many of which may not be visible to traditional water resource agencies [4,8]. Instead, green water management may often be undertaken by agricultural or local development agencies.

A number of models have shown the potential of green water management to significantly improve green water use at global [1] and watershed [9] scales. Yet these studies are limited by the large spatial extent of analysis, which makes it difficult to examine what specific interventions farmers may employ to improve CWP. Simultaneously, field-level studies have illustrated the potential of individual interventions in crop growing conditions to improve CWP in agronomic experiments [10,11]. However, from these studies it remains unclear how often such approaches will be adopted by farmers outside of controlled experimental settings. This study adds to our understanding of green water management by examining how farmers in one county in north-western China have implemented crop shifts in practice, and what impact their decisions have had on CWP.

Research on how green water policies are implemented in practice is particularly important to our future understanding of green water in the global food system because both hydrologic models and crop-level experiments fail to capture the realities of how farmers make decisions in practice. Approaches that appear economically rational may not be adopted for a variety of reasons. While water researchers focus on the importance of maximizing the water efficiency of an agricultural system, farmers must balance considerations of water against input costs, capital requirements, and labor costs [12]. For example, as explained below, farmers in the study area have often planted maize instead of potatoes because maize requires less labor, thus freeing up household members to sell their labor. Thus, studies focused solely on maximizing water productivity may not fully explain why shifts towards crops with higher water productivity have been slow to happen.

1.2. Green Water Management in Anding District

Anding district lies in a semi-arid region of China's Loess Plateau, receiving approximately 380mm of precipitation annually, the lowest rainfall possible for rain-fed agriculture in China. Due to the influence of the East Asian Monsoon, 60% of annual precipitation is concentrated in July, August, and September [13,14]. As a result, the region is vulnerable to droughts early in the growing season in May and June. The region is among China's poorest, and historically agriculture in the region has been dominated by subsistence crops, particularly in small grains. Wheat, historically the principal small grain in the area, has its greatest water demand in the early growing season (May and June) when the risk of water shortage is greatest [13].

Anding district has been a test bed for green water and water-efficient agricultural management strategies in China over the past 25 years. Several irrigation schemes have been developed with mixed success. A basin-scale irrigation program promoted in the 1980s proved unsustainable, while groundwater irrigation has improved crop security in some villages at the cost of declining water tables [15]. Anding district was also at the center of a program seeking to improve rainwater harvesting to support supplemental irrigation [16,17], but after approximately 20 years such systems have not been sustained for agriculture, though they remain widely used for domestic water supplies [16,18–20]. Since the late 1990s, in light of the limitations of these blue water agricultural strategies, local government actors have pursued two approaches to improve the CWP of the agricultural system, both based on promoting cash crops: potatoes, and drought-resistant maize planted with plastic-film mulches. Potatoes were long grown as part of a mixed subsistence agricultural system, but since the mid-1990s have been encouraged as a cash crop with state support. Potatoes take advantage of having higher water demand during the periods of greatest rainfall in July and August [14]. Maize, which historically has not been grown in the region, has been introduced with the use of both drought-resistant cultivars and plastic-film mulches since the mid-2000s. Both crops improve CWP through the use of vaporshift, and both have been actively supported through agricultural extension efforts.

Both of these policy interventions can be conceptualized as supporting vaporshift [1], though of two distinct types. In the case of maize, the use of film mulches reduces evaporation, shifting unproductive evaporation to productive transpiration [21]. This physical form of vaporshift was found by Rost et al. [1] to have the potential to improve global agricultural productivity between 2.3% and 24.7%. The second form of vaporshift, which has not previously been discussed in the literature, is temporal vaporshift and has been exhibited by both potatoes and maize. Temporal vaporshift involves planting crops whose greatest water demand occurs at the time of greatest water availability, thereby reducing annual losses to transpiration outside of the growing season. In the case of potatoes and maize, peak water demand occurs in July and August [22], which are the times of greatest rainfall. Early-season crops, including wheat and peas, have peak water demands during the months of May and June, which experience relatively limited rainfall on average. Since their water demands fell late in the year, potatoes were treated as a fallback crop in the case of the failure of early-season crops.

Traditional subsistence agriculture in Anding District mixed crops that had water demands occurring both early and late in the growing season to adapt to the possibility of drought in either season. This is a useful adaptation because droughts in north-west China are highly seasonal. For example, during the years 1956–1985 there were only eight years during which drought (defined as rainfall at least 25% below average) did not occur in any of the three phases of the growing season: spring (March–May), June, and late summer (July and August). Yet during this 30-year period there were also only three years during which drought occurred in all three phases of the growing season [23]. During 20 of those years drought occurred in one or two phases of the growing season, but not all three.

Shifting crop production from wheat to potatoes and maize were deliberate policy interventions by the local government intended to change green water use in Anding District. Potatoes were identified in the late 1990s as a crop that would be a suitable cash crop for the region based on aligning water demand with rainfall [24]. The local government's efforts to increase potato cultivation focused on turning potatoes into an economically viable cash crop. Specific policies designed to encourage potato agriculture included the construction of marketing and warehousing facilities, the organization of transportation to markets in eastern China, and the development of a research and breeding center [15].

Policy interventions to promote maize agriculture are slightly different. Until the mid-2000s, maize was not grown in the region, and a high probability of success for the crop cannot be assured without use of both plastic-film mulches to retain soil moisture and drought-resistant cultivars [25]. Maize agriculture was promoted as the "double ridge and furrow technique" developed by agronomists through the mid-2000s [26], though in actual practice we observed that the only consistent features of how maize is grown is the application of plastic-film mulches, fertilizers, and drought-resistant cultivars. The local government provides subsidies for film mulches to encourage farmers to switch to growing maize. Subsidies were administered by township governments, and the exact subsidy mechanisms varied among villages, but based on survey results they generally covered most of the cost (60%–80%) of films. Such subsidies had been used previously to encourage the use of films with both wheat and potatoes [18], and such approaches increase yields for wheat and potatoes [10,27]. However, the use of films with crops other than maize has not been sustained in the region. Notably, many farmers purchased additional mulches even beyond those covered by subsidies to plant more area to maize than the subsidies allowed.

Both maize and potato agriculture have served as test cases of green water policies in Anding district. While neither appears to be directly linked to blue water management, in both cases state actors promoting these policies have focused on the potential of the improved use of rainfall to increase food supply and peasant incomes. In this case green water policy should be examined from perspectives not usually associated with water management. It should be emphasized that water is not the sole consideration the farmers use when making decisions about what to plant. In the case of potatoes and maize, the lower labor input associated with maize may have had the effect of encouraging farmers to plant more maize in recent years, particularly as migrant labor markets in construction have offered opportunities for wage labor.

2. Materials and Methods

This study estimates the CWP (measured in kg ha^{-1} mm^{-1}) of agricultural systems of five villages in Anding district, Gansu. Our analysis estimates the CWP of individual farms by combining survey results of farmers' land allocation to different crops with agronomic studies that included CWP estimates selected as analogues for the conditions under which those crops were grown. Data estimating how much land farmers dedicated to individual crops were derived from a survey conducted in 2010. Estimates of CWP for each crop were obtained by averaging CWP estimates for crops from nearby controlled agronomic experiments published in peer-reviewed sources.

2.1. Surveys

A 2010 survey of five villages in Anding District, Gansu asked farmers how much land they dedicated to each crop that year, five years in the past, and 20 years in the past. In each village 10% of households were randomly surveyed. In person surveys were conducted by the lead author and two research assistants. Identifying information was not collected, and all data were anonymized. Village names have also been anonymized in this study. Table 1 lists the villages, the number of surveys completed, the mountain/valley status of the land, and the percentage of each village's area covered by the crops used in this analysis (explained below). Five villages were purposefully selected to examine how water management had changed in both mountainous areas and valley bottomland. Anding district lies in China's incised Loess Plateau, and farmers classify land as being either mountain or valley land. Mountainous villages were expected to have a slower adoption of green water policies because: (1) the film mulches used with maize cannot be used on sloping mountain land and; (2) because of their more remote location, mountainous villages have fewer extension services, and their cash crops have higher transportation costs than valley villages. The survey was designed by the research team and asked questions about agricultural practices, water saving agriculture, and household conditions and income. While data on household conditions and income were collected, analysis of the relationship between these variables and CWP is beyond the scope of this study. Open-ended survey questions asked farmers how much of their cropland they planted to different crops in the years 2010, 2005, and 1990, with those time intervals chosen to reflect periods of major change in agriculture in the region in consultation with experts in the area's agriculture. We acknowledge that surveys dependent on memory from previous years may introduce recall bias [28], however there is no other available source of data on cropland allocation at the household level. Responses were coded during data entry into the categories: wheat, potatoes, maize, millet, legumes, flaxseed, grass (forage), vegetables, and 'other'. 'Other' constituted less than 1% of the crop area and was removed. For the analysis we removed vegetables and grass because these crops were too heterogeneous to estimate CWP, leaving six categories of crops: wheat, potatoes, maize, millet, legumes, and flaxseed. The average portion of total cropland for each village planted to these six categories of crops is shown in the columns labeled "% of cropland covered" in Table 1. For the year 2010 there was a decrease in total land planted to the crops included in this study, driven primarily by a rise in the planting of forage crops. Each household's area measurements (measured in the Chinese unit *mu*) were then standardized into the portion of land dedicated to each crop by each farmer to control for variation in plot size both between and within villages, and to account for changes in individual farm size over the 20-year period (due primarily to the division of land between children). These portions represent the area planted to each crop divided by the total area dedicated to the six crops included in this study. The portions of land dedicated to each crop can then be understood as an indication of how farmers deployed their limited land resources to manage water through crop choice.

Table 1. Villages including sample and percentage of coverage by crops listed.

Village	Sample Size	Mountain/Valley	Cropland Covered 1990 (%)	Cropland Covered 2005 (%)	Cropland Covered 2010 (%)
1	36	Valley	97.3%	92.6%	88.1%
2	20	Mountain	89.7%	92.0%	88.5%
3	37	Valley	96.8%	94.3%	89.8%
4	26	Valley	98.4%	99.9%	78.0%
5	30	Mountain	93.3%	89.5%	87.2%
Total	149		95.5%	93.6%	86.5%

2.2. Crop Water Productivity Estimates

CWP estimates for each crop (Table 2) were derived by averaging the CWP estimates of individual crop trials from published studies from the region that were analogous to the actual growing conditions in Anding District. English language searches were conducted in Web of Science and Google Scholar, and Chinese language searches in China Academic Journals Database for agronomic studies of the six crops examined that included estimates of CWP. In many cases multiple articles used the same study datasets, and in those cases data were only included once. Studies were examined carefully to identify practices that were analogous to practices actually employed by farmers in the region. All crop trials were not irrigated. Estimates for maize were only derived from those treatments identified in a study that included the use of plastic-film mulches, as no farmers surveyed planted maize without plastic-film mulches. Similarly, treatments that included the use of plastic-film mulches for either potatoes or wheat were not included because farmers did not report using such mulches during the survey period. Trials were included that used varying amounts of fertilizer, and for maize varying arrangements of plastic films, because farmers' actual practices vary considerably in both cases. Studies were selected based on sites that were relatively close to the survey area of Anding District, as moving significantly to the East or West would result in different hydro-climatological conditions that could significantly impact CWP. For wheat, maize, potatoes, and peas, all sites were located in Anding District or one of two adjoining counties. Estimates for flaxseed came from a study elsewhere in China's Loess Plateau, and estimates for millet, maize and wheat included North China. Average CWP for each crop was calculated as a simple average of replications included in the study. The number of studies varied considerably, and more samples were available for wheat, peas, potatoes, and maize than for millet and flaxseed, two subsistence crops that have received less attention from agronomic researchers. For maize and wheat, CWP estimates are in line with the findings of global CWP values identified by Fader et al. [29]. CWP estimates for crops were combined with survey results to estimate the average CWP of each household (denoted by i) cropping system (CWP_i) according to Equation (1).

$$CWP_i = \sum_{c=1}^{N} (CWP_c \times PA_{ci}) \tag{1}$$

where CWP_i is the crop water productivity of the ith farm expressed in kg ha^{-1} mm^{-1}; CWP_c is the mean CWP of the cth crop estimated from Table 2 expressed in kg ha^{-1} mm^{-1}; and PA_{ci} is the proportional area of the ith farmer's land dedicated to the cth crop. PA_{ci} is does not have a unit because it is presented as a proportion. PA_{ci} was calculated by dividing the area of crop c on the ith farm by the total area of the six crop types included in this study.

Table 2. Average CWP values for crops from selected with number of replications based on the following studies.

Crop	Average CWP (Kg ha^{-1} mm^{-1})	Number of Trials	Studies
Wheat	8.47	12	[10,25,30–32]
Millet	4.9	2	[31,33]
Pea	8.37	7	[10,25]
Maize	13.01	12	[21,25,31]
Flax	4.7	2	[13]
Potato	13.88	6	[11,25]

These calculations account for changes in the CWP of agricultural systems driven only by changes in cropping patterns. Changes in fertilizer application rates are likely to have resulted in additional changes to the CWP [2]. However, in our survey results, historical fertilizer application rates could not be obtained in great enough detail to make comparisons with the published studies from which the

CWP estimates were derived, because many farmers were unsure of the total amount of fertilizer that they applied, only knowing how much money they had spent on it.

After the farm-level estimates of agricultural system productivity were estimated for each year, comparisons across time were tested using a paired Wilcoxon test. Individual farms were compared for the periods 1990, 2005, and 2010. Average CWP estimates were arithmetically decomposed by seasonality of water demand into early and last season crops as follows: early-season (*es*) crops were those whose water demands typically occurred before July, and included wheat, peas, and flax. Late-season (*ls*) crops were those whose greatest water demand typically occurred in July and August, including millet, potatoes, and maize.

$$CWP_{es} = \sum_{c_{es}=1}^{N} (CWP_{c_{es}} \times PA_{ci_{es}}) \tag{2}$$

All variables are the same as for Equation 1, however the *es* subscript denotes early-season crops. A similar equation CWP_{ls} was similarly calculated.

3. Results

Table 3 presents the changes in CWP measured in kg ha^{-1} mm^{-1} of agricultural systems in the study averaged by village and for the entire study area. All villages showed increases in CWP of their agricultural systems between each of the sampled years, which were statistically significant at the 95% confidence level with the exception of village 1 between the years 2005 and 2010. From these estimates it is possible to surmise that policies supporting the introduction of cash-crop agriculture increased the overall CWP of the agricultural systems in Anding District by approximately 30%. At the village level, villages 1 and 3, which are located on valley bottom lands and have been most actively involved in green water management policies for longer periods of time, showed the largest increases.

Table 3. CWP of the cropping system by village and change in CWP (indicated by ΔCWP) during model periods measured in kg ha^{-1} mm^{-1}.

Year	All Villages	Village				
		1	2	3	4	5
CWP 1990	8.31	8.18	8.04	8.53	8.66	8.09
CWP 2005	10.06	10.98	9.87	10.59	9.88	8.66
CWP 2010	10.84	11.22	10.83	11.73	10.75	9.53
Δ1990–2005	1.75 **	2.8 **	1.83 **	2.06 **	1.22 **	0.57 **
Δ2005–2010	0.78 **	0.24	0.96 **	1.14 **	0.87 *	0.87 **
Δ1990–2010	2.53 **	3.04 **	2.79 **	3.20 **	2.09 **	1.44 **

Note: * Indicates differences significant at the 95% confidence level and ** indicates differences significant at the 99% confidence level based on a paired Wilcoxon test.

Figure 1 illustrates changes in the distribution of household CWP values in each village. Increases for village 1, which is located in a valley and is close to a railhead, had largely occurred by 2005, with relatively little change between 2005 and 2010. In Village 5, the most remote village located in a mountainous area, there was relatively little change between 1990 and 2005, and most of the increases in CWP occurred after 2005. Figure 1 also illustrates that even in those villages that have seen rapid improvements in CWP, at the household level some farms continue to have relatively lower CWP.

To understand what has driven this increase in CWP, we further decomposed the agricultural system for each by the contribution of individual crops, which were then classified as early- or late-season crops based on whether their peak water demand occurred before or after July 1st. Table 4 presents this decomposition averaged for all villages in the study.

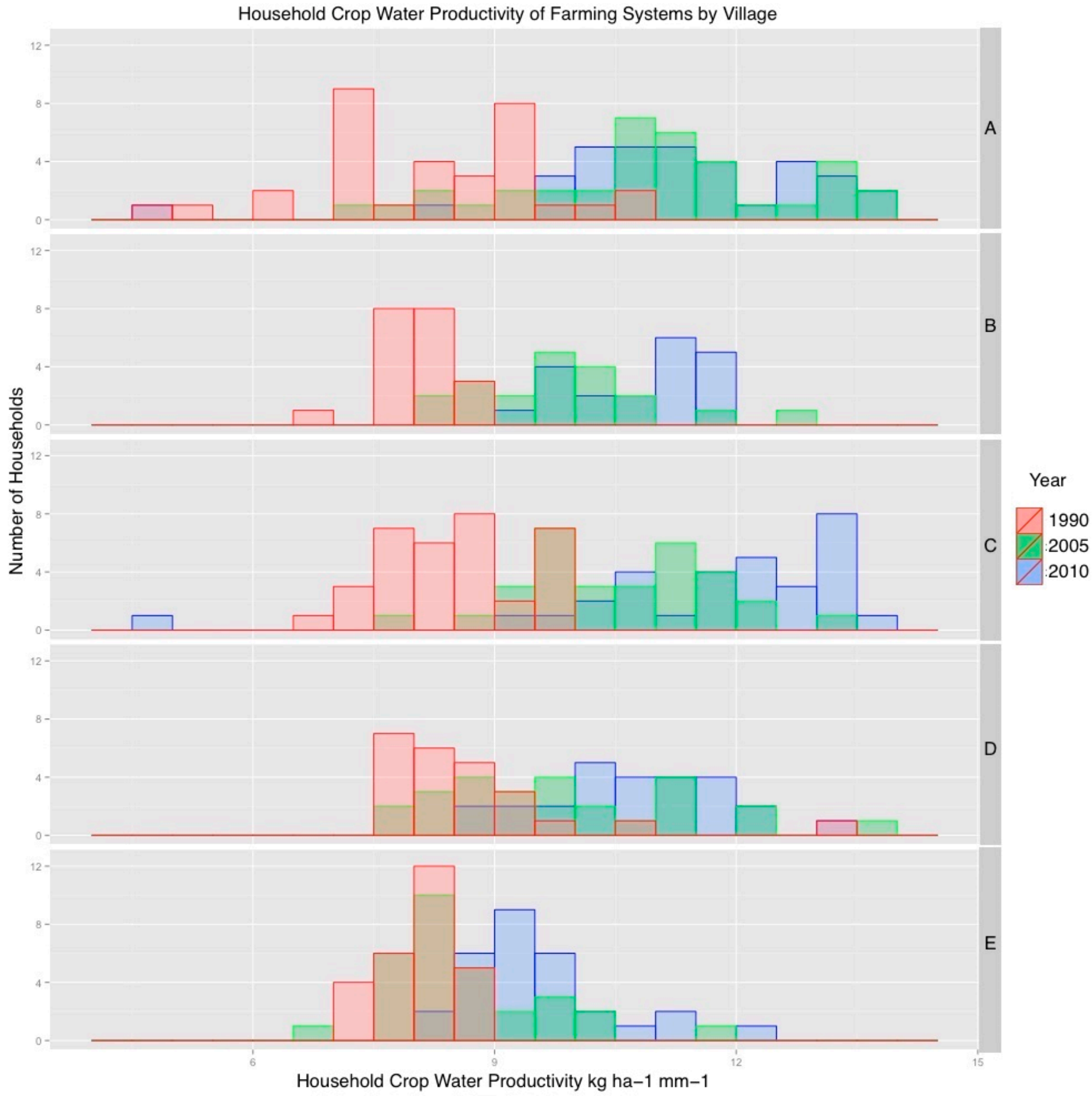

Figure 1. Household crop water productivity of farming systems by village. (**A**) Village 1; (**B**) Village 2; (**C**) Village 3; (**D**) Village 4; (**E**) Village 5.

Table 4. Decomposition of change in CWP by crop and growing season.

Crop	Mean CWP	1990		2005		2010	
		Portion of Total Area	Contribution to CWP kg ha^{-1} mm^{-1}	Portion of Total Area	Contribution to CWP kg ha^{-1} mm^{-1}	Portion of Total Area	Contribution to CWP kg ha^{-1} mm^{-1}
Early-season Crops							
Wheat	8.47	46.49%	3.94	25.47%	2.16	12.52%	1.06
Pea	8.37	9.18%	0.77	8.61%	0.72	6.99%	0.59
Flax	4.70	17.48%	0.82	15.05%	0.71	17.39%	0.82
Total for Early-season Crops		73.14%	5.53	49.12%	3.58	36.90%	2.46
Late-season Crops							
Maize	13.01	0.52%	0.07	10.21%	1.33	33.85%	4.40
Potato	13.88	15.93%	2.21	35.07%	4.87	28.25%	3.92
Millet	4.90	10.41%	0.51	5.60%	0.27	1.00%	0.05
Total for Late-season Crops		26.86%	2.79	50.88%	6.47	63.10%	8.38
Total for all crops		100%	8.31	100%	10.06	100%	10.84

4. Discussion

The increase in CWP of the agricultural systems in Anding District can be attributed to a shift from early- to late-season crops, which have their peak water demand at the same time as the highest levels of rainfall in the region, and have higher CWPs. This has been primarily a shift from wheat and millet to maize and potatoes. It should be noted that potato agriculture actually peaked in 2005, and declined slightly by 2010, during which period maize became increasingly widespread, a change that farmers reported is associated with the lower labor requirements of growing maize relative to potatoes.

The increased CWP of agricultural systems in Anding district reflects temporal vaporshift by aligning the agricultural systems' greatest evapotranspiration demand during those months with the most precipitation. This shift was facilitated by replacing subsistence agriculture that planted crops with differing degrees of water demand throughout the year with commercial cash crop production that concentrated water demand in the season of greatest precipitation. As some seasonal drought has occurred in most years in the region, subsistence crop choices previously spread the risk of drought between the early and late growing season. Cash crop agriculture, while more efficient in water use, amplifies the potential risk of drought in a single portion of the growing season. However, as rural China has become integrated with urban centers, the risk of seasonal losses has been offset by the potential to earn money in labor markets. The introduction of maize and potatoes required green water management and policy interventions by local governments, including subsidized mulches and seed, subsidized transportation to distant markets, and improved crop breeding. While such policies usually are not considered from the perspective of water management and policy, falling instead within the realm of agricultural or economic development policies, when considering green water it is important to look beyond the typical confines of water management to consider the array of management decisions that affect water use.

Analyzing farmers' individual crops choices and their impact on CWP highlights the importance of empirically-based, field-derived studies of farmer behavior. The only crop that remained basically unchanged over the 20-year period in the proportional area planted is flaxseed, which is used on a subsistence basis for making cooking oil. While millet, peas, and wheat were also raised largely on a subsistence basis, they have declined in use, leaving flax as the one crop that farmers continue to raise on a subsistence level rather than purchasing oil. While it is not entirely clear why farmers continue this behavior, this is one example of how farmers' decisions in practice may not align with economic and environmental models of their behavior, often with significant consequences for global green water use.

5. Conclusions

This study indicates that policies intended to manage green water by inducing crop shifting can increase the CWP of agricultural systems in semi-arid regions. In this study, the CWP of individual farms has increased by an average of approximately 30% since the introduction of green water management strategies in the late 1990s, changes that are statistically significant at the 5% level. This change appears to be driven primarily by the shift from crops that have high water demands in early summer (small grains), when rainfall is relatively low, to late summer (maize and potatoes), when more water tends to be available. These changes employed the use of vaporshift of two types: physical vaporshift, which blocks evaporation through the use of mulch, and temporal vaporshift, which emphasizes crops that utilize water during periods of greater abundance. These changes occurred more rapidly in villages located on valley lands closer to markets (villages 1 and 3) and most slowly in mountainous villages (villages 2 and 5), although these mountainous villages also experienced changes in CWP later in the study period. Such changes were supported by specific policies that improve CWP, namely subsidies for mulches and support for integration with national markets. While these programs have improved CWP in a semi-arid region of China, it is likely that such policies could be similarly effective in other semi-arid impoverished regions, including the Sahel region of Africa and Central Asia. This study also illustrates the value of survey-based research methods in studies of CWP. In this study survey methods could be combined with pooled agronomic trial data, however in the future such survey data could be used with average CWP estimates obtained through field-based measurements of farmers' agricultural practices to evaluate CWP in farms as they actually exist.

Supplementary Materials: The following are available online at http://www.mdpi.com/2073-4441/10/1/11/s1, Table S1: Individual trials used to estimate the CWP averages presented in Table 2.

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Conflicts of Interest: The authors declare no conflict of interest.

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