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Sustaining Chili Pepper Production in Afghanistan through Better Irrigation Practices and Management

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Abstract: Water management and utilization is an ongoing problem in developing countries with semi-arid to arid climates such as Afghanistan. The lack of effective irrigation systems are oftentimes the most limiting factor for maximizing agricultural productivity in these countries. In Afghanistan, the most widely used irrigation methods are basin/border for cereal crops and furrow for vegetables and grapes, although drip irrigation is a technology that could be used to significantly improve water use efficiency (WUE) in horticultural crop production. Therefore, three irrigation methods (basin, furrow, and drip) were evaluated for their influences on chili pepper production and WUE at the Afghanistan Ministry of Agriculture, Irrigation and Livestock (MAIL) Badam Bagh Agricultural Research and Demonstration Farm in Kabul over the 2009 and 2010 growing seasons. Results from this study indicated that both drip and furrow irrigation provided similar high chili pepper plant growth and yield responses compared to the low amounts provided by basin irrigation ($p \leq 0.05$). The drip and furrow irrigation methods provided a similar low incidence of *Phytophthora* blight disease, as 4% and 7% of chili pepper plants were visually afflicted by this disease, respectively, while an astounding 69% of chili peppers grown with basin irrigation had symptoms of this disease. Drip irrigation resulted in the best overall WUE ($p \leq 0.05$), as this water delivery method utilized the least amount of water and provided the highest chili pepper yield. Furrow irrigation provided a lower WUE compared to drip, but was greater than that of basin irrigation. Although this study indicated that drip irrigation had the greatest WUE for chili pepper production, furrow irrigation is still the method of choice by farmers in Afghanistan to provide water to this crop. The associated costs with pressurized drip irrigation systems are too expensive for farmers to purchase and maintain, which has led to the widespread use of surface irrigation. Moreover, the resistance of growers to change to newer and more advanced technologies is commonplace in many developing countries, and without some type of improvement to current water management practices at the farm level, there is a bleak outlook to maximize agricultural productivity in these areas of the world with limited rainfall and minimal water resources. Although it is essential to sustain this important resource through better irrigation management practices, on-farm agricultural economics are often more important than the needs of future generations and the environment.

Keywords: agricultural extension; Badam Bagh; Afghanistan; food security; sustainable agriculture; water-use efficiency; vegetable production

1. Introduction

Irrigation is crucial to maximize agricultural productivity in arid or semi-arid areas, and is often the most limiting factor for crop production in countries having these climate types. Over the last 40 years, irrigation has been a major contributor to the growth of food and fiber supply for a global population that has more than doubled [1]. Irrigation becomes even more of an issue in developing countries such as Afghanistan given the relatively small amounts and variable rainfall events in areas that have suitable soils for crop production [2]. Although there are significant water resources available for irrigation of crops and water for livestock, Afghanistan suffers from damaged or poorly maintained irrigation infrastructure and poor overall performance of existing irrigation systems [3]. About two-thirds of the cultivated managed land utilizes some type of irrigation practice and irrigated areas produce almost 85% of all agricultural products in Afghanistan, with most waters delivered by various canal networks [2]. Although a complex array of problems influence water availability in this country, most agree that the primary limiting factor to crop production in Afghanistan is the inefficient use of available water [4,5]. Recently, the overall water efficiency was estimated to be only about 25%–30% for crop production in Afghanistan [6]. Due to the low water-use efficiencies and lack of adequate inputs for maintenance of irrigation systems, yields of horticultural crops tend to be very low [2].

Chili pepper is an important horticultural crop in Afghanistan since this crop performs well in hot, dry environments and suffers less postharvest losses compared with many other fleshy fruited crops. This crop is sold either fresh or as a dried product that is often processed in some manner; for the dried product, fruit are either allowed to dry on the plant or are pulled at a mature stage and sun-dried (Figure 1). Water is critically important during the production season for high value crops, such as chili pepper. Moreover, chili pepper is highly sensitive to limited and excessive water in the root zone, with the period from flowering to fruiting being the most critical [7]. Thus, horticultural crops, such as chili pepper, are especially sensitive to moisture stress and maintaining consistent moisture throughout the growing season is essential to maximize fruit quality and yield [8]. Therefore, in arid/semi-arid climates, irrigation is generally used in chili pepper production schemes to maximize fruit quality and yield. The dominant irrigation methods used in Afghanistan are basin/border irrigation for cereal crops and furrow irrigation for vegetables and grapes [2]. Basin/border irrigation is probably the most widely utilized method to supply water to crops in Afghanistan. This irrigation system supplies water onto the surface of a defined land area surrounded by embankments (bunds) with the basin then flooded; water then eventually percolates over time down into the soil profile. Basin irrigation works best in soils with relatively low infiltration rates. Furrow irrigation in the most common irrigation practice used for chili peppers in Afghanistan, with water requirements typically ranging from 7000 to 12,000 m^3/ha [8]. With this type of irrigation system, water runs in small, parallel channels (furrows) between crop rows that are usually elevated on ridges between the furrows. Although furrow irrigation provides reasonable water use efficiency (WUE), the overall proficiency of this system is influenced by several factors including field slope, length of run, soil type, water infiltration rates, length and rate of application, as well as evaporative, seepage, and drainage losses that can occur at multiple locations in the system. Additionally, waterlogging of soils is commonplace with this type of irrigation.

Agricultural water management is one of the most important factors required to achieve sustainable food production throughout the world, especially in more arid regions [9]. Therefore, utilization of the most appropriate irrigation system is crucial to improve agricultural production and irrigation efficiency in both irrigated and rainfed regions of the world [10]. Drip systems are a widely used irrigation method to improve WUE, especially in arid or semi-arid environments, and are valuable production tools in areas where water is limiting. This irrigation method has several advantages over furrow systems including reduced water use, the ability to apply fertilizers through system, more precise water distribution, and reduced soil-borne diseases and weed growth as row middles remain drier than those with furrow irrigation [11]. However, the increased water efficiency in drip irrigation systems is generally related to reduced soil percolation and surface evaporation compared with other irrigation systems. A more precise application of water through drip irrigation systems will provide more efficient water use for certain agricultural activities, especially fruit and vegetable production in Afghanistan. However, numerous considerations must be taken into account when selecting the most suitable irrigation system, as these will vary depending on location, crop grown, production year utilized, and farmer [10]. Moreover, information regarding research on agricultural water management activities in Afghanistan is limiting. Therefore, a field study was conducted in Afghanistan comparing basin, drip, and furrow irrigation for chili pepper production during the 2009 and 2010 growing seasons.

Figure 1. Mature red chili pepper fruit sun-drying in a village near Mazar-Sharif, Afghanistan.

2. Materials and Methods

2.1. Field Experiment Location, Setup, and Maintenance

A field study was conducted during 2009 and 2010 at the Afghanistan Ministry of Agriculture, Irrigation and Livestock (MAIL) Badam Bagh Agricultural Research and Demonstration Farm in Kabul, which has a sandy loam soil. This study was initiated to compare the influence of various irrigation methods (basin, drip, and furrow) on the productivity of chili pepper and resulting disease development. The experiment was set up in a completely randomized design (CRD) with 4 replications. The size of each experimental plot area was 20 m in length and 20 m in width, with rows spaced 1.5 m apart. A local chili pepper landrace was utilized, with seed germinated in early April each year and grown in 128 cell plug trays. Transplants at the two- to three-leaf stage were placed into the field during early May each year with 0.3 m in-row spacings. Plants were harvested by hand at the red-ripe stage five to seven times during each growing season, with harvests beginning in July and ending in early October.

Raised beds approximately 0.3 m in height were used for the drip and furrow irrigation methods, while no raised beds were used for basin irrigation. Irrigation was applied about 10–15 times during the growing season (or once or twice per week), which depended on rainfall and chili pepper water requirements. The total amount of water applied over the chili pepper growing season in both years was 130, 184, and 236 m^3 for drip, furrow, and basin, respectively. During the growing season, minimal amounts of rainfall were provided each year (between 70 and 103 mm).

Fertilization practices for chili pepper included the application of urea (46-0-0), diammonium phosphate (DAP; 18-46-0), and potassium (K; 0-0-60). Prior to chili pepper transplanting, urea, DAP and K were incorporated into the soil during tillage operations at 100 kg, 175 kg, and 125 kg/ha, respectively. Urea was also applied by side-dressing to chili pepper plants by hand at 75 kg/ha at one and two months after transplanting.

2.2. Data Collection

Various data were collected for chili pepper regarding specific responses to the irrigation methods evaluated. For each experimental unit, plant height (cm), number of fruit per plant, and *Phytophthora* blight disease incidence (0% to 100% of plants infected) were all collected at mid-season growth (mid-August). The total yield (ton/ha) was determined from all harvests for each experimental unit. The WUE of irrigation systems for chili pepper yields were calculated by the formula: Y/WR, where Y = yield of crop (kg/ha) and WR = total water consumed for crop production (m^3/ha).

2.3. Data Analysis

Data were subjected to analysis of variance procedures using general linear models procedure of SAS (SAS Inst., Cary, NC, USA) appropriate for a completely randomized experimental design to determine the effects of irrigation type on chili pepper growth, yield, *Phytophthora* blight disease incidence, and WUE. Fisher's least significance difference (LSD) test was used to separate differences among irrigation treatments at $p \leq 0.05$.

3. Results

3.1. Statistical Analyses

Both years were similar as there was no interaction ($p > 0.05$) of year by irrigation method for the variables evaluated. Therefore, data were combined and presented over the two years.

3.2. Chili Pepper Growth and Yield

Irrigation type had a tremendous influence on chili pepper growth and yield (Table 1). Both drip and furrow irrigation provided similar higher plant height responses compared to basin irrigation, which was reduced by approximately 40% compared to the other irrigation methods. The lower amount of plant growth observed by basin irrigation had a definite negative influence on the resulting pepper fruit yields. The average number of fruit obtained per plant at peak production (mid-August) was reduced by about 76% in the basin irrigation method compared to the other two irrigation methods evaluated, which were again similar in their responses. Although drip and furrow irrigation provided similar yields (ton/ha), these irrigation methods provided 55% and 50% more fruit weight/ha, respectively, compared with basin irrigation.

Table 1. Chili pepper plant height, fruit produced per plant, yield, and *Phytophthora* blight disease incidence as influenced by irrigation type at Afghanistan Ministry of Agriculture, Irrigation and Livestock (MAIL) Badam Bagh Agricultural Research and Demonstration Farm in Kabul over the 2009 and 2010 growing seasons.

Irrigation Method	Plant Height (cm)	Number Fruit per Plant	Yield (ton/ha)	*Phytophthora* Disease Incidence (%)
Basin	29 b	9 b	5 b	69 b
Drip	49 a	39 a	11 a	4 a
Furrow	48 a	38 a	10 a	7 a

Data are the means of 4 replications for each growing season. Plant height, fruit number per plant, and *Phytopthora* disease incidence (0% to 100% of plants infected) were collected in mid-August each year. Yield was a summation of all harvests over the growing season. Means followed by the same letter are not significantly different according to Fisher's least significant difference (LSD) test at $p < 0.05$.

3.3. *Phytophthora* Blight Disease Incidence

Irrigation method played a major role regarding the incidence of *Phytophthora* blight that developed in chili peppers (Table 1). The drip and furrow irrigation methods had a similar low incidence of this disease, as 4% and 7% of plants were affected by *Phytophthora* blight, respectively. However, 69% of chili peppers grown with basin irrigation were afflicted by this disease (Figure 2). This indicates that the over-application of water along with growth on flat areas with no raised beds (which restricted water drainage) provided ideal conditions for the development of this disease.

Figure 2. Significant chili pepper plant stand reduction (as noted by missing plants in each row) in basin irrigation due to *Phytophthora* blight at the Afghanistan Ministry of Agriculture, Irrigation and Livestock (MAIL) Badam Bagh Agricultural Research and Demonstration Farm in Kabul.

3.4. Water Utilization and WUE

The amount of water utilized for chili pepper production differed ($p \leq 0.05$) among all irrigation methods utilized, with basin irrigation using the most (236 m^3/ha) followed by furrow (184 m^3/ha) and drip (130 m^3/ha) (Table 2). These results indicate that furrow irrigation used about 22% less water than basin and 29% more than drip, while drip irrigation used 45% less water than basin. Although the greatest amount of water was utilized with basin irrigation for chili pepper production, this water delivery method provided the lowest growth and yields, as well as the highest *Phytophthora* blight incidence compared with the other irrigation methods.

Table 2. Water utilization and water use efficiency (WUE) by irrigation method for chili pepper grown at Afghanistan Ministry of Agriculture, Irrigation and Livestock (MAIL) Badam Bagh Agricultural Research and Demonstration Farm in Kabul over the 2009 and 2010 growing seasons.

Irrigation Method	Water Utilization (m^3/ha)	WUE
Basin	236 c	21.2 c
Drip	130 a	84.6 a
Furrow	184 b	54.3 b

Data are the means of 4 replications for each growing season. Means followed by the same letter are not significantly different according to Fisher's LSD test at $p < 0.05$. The WUE of irrigation systems were calculated by the formula: Y/WR, where Y = yield of crop kg/ha and WR = total water consumed for crop production (m^3/ha).

The WUE for chili pepper production differed ($p \leq 0.05$) among the irrigation delivery systems evaluated (Table 2). Drip irrigation resulted in the best overall WUE, as this water delivery method utilized the least amount of water and provided the highest chili pepper yield, which resulted in the highest WUE compared with the other irrigation methods. Furrow irrigation provided a lower WUE compared to drip, but was greater than basin, which had the lowest WUE.

4. Discussion

4.1. Water Management and Utilization in Afghanistan

Although Afghanistan faces a complex array of agricultural problems that are detrimental to its economic development, the lack of sufficient water and inefficient use of this limited resource is the primary limiting factor to crop production. Water management and utilization is an ongoing problem in developing countries with semi-arid/arid climates such as Afghanistan, given the relatively small amounts and variable rainfall events in areas that have suitable soils for crop production [2]. This is further exacerbated by the over-exploitation of groundwater resources which has resulted in shrinking water reserves for not only agricultural activities but also for drinking water supplies for both urban and rural populations. Thus, there is definitely a need for better water management and utilization for agricultural activities in this country.

4.2. Crop WUE in Afghanistan and Associated Problems

The most appropriate strategy to accelerate the growth of the rural Afghanistan economy is to increase crop productivity per unit land area rather than expanding into more environmentally unsuitable areas [5]. The most likely way to achieve this goal is through the improvement of irrigation technologies, as well as better field production and management practices, along with the development of human and institutional capacity [2]. During the last 50–60 years, crop WUE's have increased mostly because of greater potential yields through genetic manipulation and improved efficiency of irrigation methods [12]. Drip irrigation is a technology that is well known to significantly improve WUE through the controlled and timely application of water, which leads to a more effective utilization of resources, including available land, fertilizer, and water [13]. Furthermore, this technology is known to provide higher vegetable yields, improved WUE, and higher product quality compared with other irrigation methods [14–19]. Results from this study provide further evidence that drip irrigation in semi-arid/arid climates provide the best overall WUE for horticultural crops, such as chili pepper. However, although drip irrigation may provide the best overall yields and WUE, it may not always be the most practical or provide the greatest economical returns. Significant efforts have been made to introduce drip irrigation to communities across Afghanistan over the past decade, but this effort has largely failed [2]. High material costs, insufficient pressures required to effectively operate these systems, drip line and plastic disposal, and clogging of emitters by water sediments or root intrusion are problems commonly associated with attempts to deploy drip irrigation systems in Afghanistan. Similarly, clogging of emitters is the main concern for vegetable growers in semi-arid regions of Botswana, but this problem can be minimized by using appropriate filters and flushing out the main, sub-main, and lateral lines on a regular basis [20].

Most farmers in Afghanistan generally lack knowledge on how to optimize crop water requirements. Although effective water resource management practices are critical for maintaining food security in Afghanistan, under- and over-irrigation of crops is common. While under-irrigation can lead to vegetable yield and quality loss, over-irrigation can lead to devastating disease problems, such as *Phytophthora capsici* in various vegetable crops [5]. Indeed, this study provided further evidence that too much water delivered through basin irrigation is connected to reduced chili pepper growth and yields, as well as the highest *Phytophthora* blight incidence, compared with the other irrigation methods.

4.3. Drip versus Furrow Irrigation Systems

The small increase observed for chili pepper yield in this study using drip systems compared to furrow irrigation is most likely too small to offset the associated establishment, maintenance, and management costs for drip irrigation systems. Therefore, although the WUE is much greater for drip irrigation, furrow irrigation appears to be the most practical irrigation method for growers in Afghanistan with limited availability of inputs. A common assumption often made is that converting from furrow to drip irrigation will significantly improve crop yield, but this is not necessarily true, and this was the case with this study on chili peppers. Most vegetable growers in Afghanistan are reluctant to adopt drip irrigation for multiple reasons, even though it is the best method to obtain the highest WUE for chili peppers. Moreover, drip irrigation using water from an on-farm storage facility is a much better method compared with trying to improve irrigation scheduling for furrow systems based on soil moisture requirements, as scheduling water flow into a field once the soil is depleted of moisture is not a simple process in Afghanistan. Most farmers cannot schedule a furrow irrigation event when it is most needed for their crops (even if they had the equipment required to detect soil moisture levels), as they receive water only at specific, designated times, and this can be less than once per month during the driest portion of the growing season. Furthermore, there is usually a waste of irrigation water in surface systems during the first half of the growing season, through unregulated floodwater entering canals, and a shortage of water during the second half of the season, when river flow decreases to its annual minimum [2].

Currently, furrow irrigation is the most widely utilized method for commercial chili pepper production in Afghanistan (Figure 3); moreover, since growers understand the management requirements for this water application method, they will most likely continue to use this type of irrigation for years to come despite the fact that it has higher water requirements than drip irrigation. Furrow irrigation systems have low associated production costs compared with drip, so it is really the most economical method for farmers in Afghanistan. Based upon chili pepper yields and WUE's obtained from this study, furrow irrigation is an acceptable water delivery system for this vegetable crop in Afghanistan, although careful management is necessary to ensure sufficient water for maximum crop growth, while preventing excessive evaporative, seepage, or drainage losses.

Figure 3. A typical commercial chili pepper field utilizing furrow irrigation near Mazar-Sharif, Afghanistan.

Furrow irrigation is oftentimes not as water-efficient as it is portrayed due to the loss of water that occurs in canals prior to reaching the field. Most times, this is not considered when determining the WUE of this irrigation system, whereas water used for drip irrigation is generally pumped from wells into small reservoirs, making this irrigation method much more efficient compared with the unseen wastes that often occur in transporting furrow-irrigation water to a field. In Afghanistan, rural watercourses and canals (which are used to get water to furrow-irrigated fields) are generally unimproved earthen trenches with water losses occurring via seepage, over-bank spillage, and evaporation [2]. Furthermore, in both basin and furrow irrigation systems in Afghanistan, irrigation waters are often improperly drained from fields, which can lead to reduced crop stands and yields. Inadequate drainage impacts agricultural production by causing soil compaction, soil erosion, salt accumulation, and even crop failure. Due to low water use efficiencies and a lack of adequate inputs for the maintenance of canals and all types of irrigation systems, yields of horticultural crops tend to be very low in Afghanistan [2]. However, WUE and crop yields of furrow irrigation systems can be improved with laser-leveling of production fields, as this facilitates surface-water runoff and eliminates pooling for several years following treatment; for example, chili pepper yields under furrow irrigation in Afghanistan increased by almost 15% in laser-leveled fields compared with those that were not laser-leveled [21].

5. Conclusions

Water is a crucial resource for food production and ultimately, human survival throughout the world. An inconsistent and inadequate supply of water to farmers is the most important limiting factor that prevents accelerated agricultural expansion in Afghanistan [5]. Moreover, since the majority of the populace resides in rural areas that depend on irrigated agriculture, improving access to this vital resource is essential to improving the quality of life in Afghanistan. Thus, effective water resource management practices are essential for maintaining food security in developing countries like Afghanistan, which is further exacerbated by the arid or semi-arid climate [2]. Agriculture must meet the future food security challenges by increasing production while conserving this important natural resource [1]. However, fresh water is an ever dwindling resource that is oftentimes mismanaged, especially in areas that have limited supplies and low rainfall. Efforts to improve water use management and efficiencies for crop growth must be a high priority for farmers in arid/semi-arid countries. Although current water extraction rates for irrigation is not sustainable in these areas (even without considering future climate warming and precipitation changes), irrigation demand is expected to increase in the future [22]. In this study, drip irrigation resulted in the best overall WUE ($p \leq 0.05$), as this water delivery method utilized the least amount of water and provided the highest chili pepper yield. However, furrow irrigation is still the method of choice for farmers in Afghanistan and many other developing countries with arid/semi-arid climates to provide water to chili pepper and other crops for several reasons. Most importantly, the costs associated with pressurized drip irrigation systems are too expensive to be widely used, which has led to the widespread use of surface irrigation [10]. Moreover, the resistance of growers to change to newer and more advanced technologies is commonplace in many developing countries [20]. Without some type of improvement to current water management practices at the farm level, the outlook of maximizing agricultural productivity in these areas of the world with limited rainfall and minimal water resources is bleak. However, drip irrigation is a relatively simple, low-input technology that can substantially expand the ability of smallholder farmers in developing countries to plant high value horticultural and agronomic crops even with fluctuating water supplies in a changing climate [13]. Growers of horticultural crops in arid/semi-arid climates really need to focus on utilizing more efficient water saving and irrigation technologies to sustain water resources for future generations. Although it is essential to sustain this important resource through better irrigation management practices, on-farm economics are oftentimes more important than the needs of future generations and the environment.

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Author Contributions: S. Alan Walters collected the mid-season data, analyzed all data, interpreted results, and wrote most of the manuscript. Ajay K. Jha designed the study, was responsible for planting, maintenance, and harvesting activities, and contributed to the writing/editing of the manuscript.

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