Rainwater Harvesting for Domestic Household Use and
Small Scale Horticulture Production in Yemen: A Multi-Use Water System Approach

"When the well is dry, we learn the worth of water."
- Ben Franklin, Poor Richard's Almanac 1733

USAID experience in small scale agriculture production using improved inputs (high quality seed, organic fertilizer, etc.), rainwater harvesting, and low tech drip irrigation systems combined with production and marketing support has been shown to increase rural household income.[1] A recent study indicates that Yemen's horticulture sector is increasing and offers greater marketing opportunities for small scale producers.[2] Production located adjacent to homes has been reported to increase the likelihood that women will be involved in production and marketing decisions.[3] In terms of impact on gender issues, a study by Netherlands Aid found that when domestic water issues were better addressed in Yemen, more girls attended school.[4] Rainwater harvesting can potentially serve both domestic and agriculture production needs by providing families with additional income, create an opening for women to manage an economic activity that is essentially located in, or adjacent to, their homes, and provide supplemental water. According to a global analysis of "multi-use" water systems the cost-benefit ratios range from 2.9 to 27 with benefits greatly outweighing costs.[5]

Producer associations targeting women for small scale production via home gardens – approximately 50 square meters (5 m by 10 m) – could produce two vegetable crops a year and, with an effective marketing program, could provide net returns of approximately $250 per year (see attachment one - cost benefit analysis). Production should be market-focused and linked to community markets. While not without risk, the diverse and numerous small scale production units envisioned in this approach have been successful in developing countries and could be successful in Yemen if supported with appropriate production and marketing assistance.[6]

In terms of market potential, Yemen's horticulture sector is growing; production increased by more than 65% from 1995 to 2009, while total area increased from 53,522 ha to 88,990 ha and now represents approximately 7% of total cultivated area. The total national vegetable production reported by the Ministry of Agriculture and Irrigation (MIA) in 2011 was 988,463 MT with a value in excess of US$771 million. Major vegetable crops are potato, tomato,

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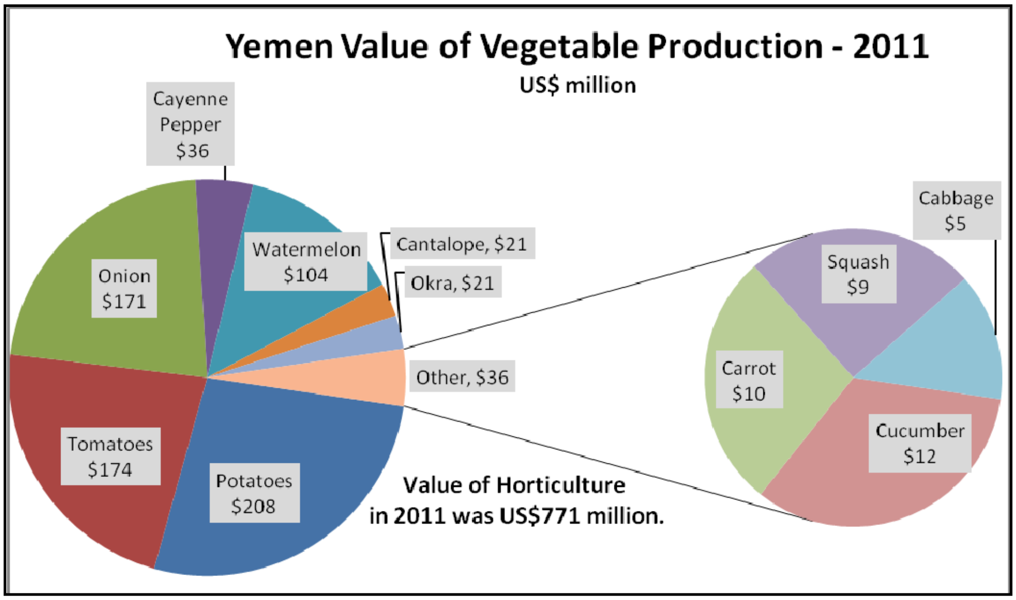
[1] "Evaluation of USAID/OFDA Small Scale Irrigation Programs in Zimbabwe and Zambia 2003-2006: Lessons for Future Programs by FANRPAN" - Douglas J. Merrey, Amy Sullivan, Julius Mangisoni, Francis Mugabe, and Mwalimu Simfukwe.
[2] "Vegetable Production and Consumption of Vegetables in Republic of Yemen" T. H. Al-Gahaifi and J. Svetlik, Acta univ. agric. et silvic. Mendel. Brun., 2011, LIX, No. 4, pp. 9–18.
[3] Water and Livelihoods Initiative (WLI) research found that small scale agriculture production provides greater opportunity for woman's involvement especially if this seen as an in-home activity. Women's Empowerment in Agriculture Index: Case Studies, Dr. Sandra Russo (Univ. of Florida) and Dr. Samia Akroush (Jordan NCARE), in collaboration with International Center for Agricultural Research in the Dry Areas (ICARDA). See Case Study – Production, p. 9 "Key Findings," August 2012.
[4] Evaluation of Netherlands Support to Rural Water Supply and Sanitation in Dhamar and Hodeidah Governorates – October 2008. http://www.oecd.org/countries/yemen/42400796.pdf.
5 "Multiple-use Water Services: Cost-effective Investments to Reduce Poverty" Jojoh Faal, Alan Nicol, & Josephine Tucker. MUSGroup., See http://www.rippleethiopia.org/documents/stream/20090901-briefing-paper.
[6] IFAD – http://www.ifad.org/operations/projects/regions/pa/factsheets/ci_e.pdf

watermelon and onion; their combined yield was 85% of the total vegetable production. Total production levels appear driven by an expansion of cultivated area rather than increased productivity.



Water, a critical limiting factor for increased vegetable production, is primarily from wells or water catchments which are under increasing stress from ground water depletion. A recent World Bank financed study indicated that agriculture investments depending on groundwater in the Sana'a Basin will be untenable within 5 to 6 years and that Sana'a city, under current use patterns, will exhaust the Central Plains aquifer by 2020.[7] At that point, water will have to be imported from other aquifers in Sana's region which will greatly increase its value and make continued flood irrigation impractical. Water costs are expected to increase in other governorates as well as diesel subsidies are removed and deep well pumping of water becomes more costly. This situation, increased domestic water demand and rising water costs, can increase the feasibility of small scale horticulture production using rainwater harvesting, water storage, and micro-irrigation (see attachment three). Also, the economic value for harvested rainwater could offset costs incurred by families that either have to expend a disproportionate amount of family labor on fetching water or directly substitute water purchases made by the family.[8]

As one of the most water stressed countries in the world (Yemen ranks seventh and is categorized as an "extreme risk" due to water scarcity), the critical limiting factor for increased

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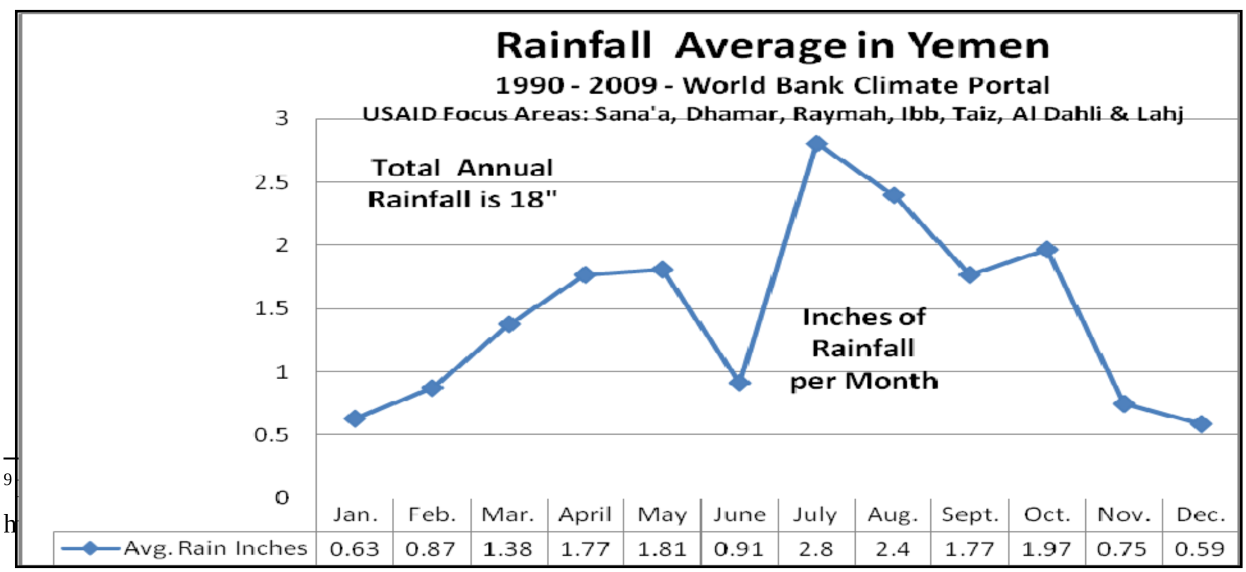
[7] "The Sana'a Water Issues and Options Study – Final Report" June 25, 2012. RTI International prepared for The World Bank.

[8] Urban water costs according to the Yemen Obsever,, Feb. 16, 2013, are 3,000 YER per 3 cubic meters (this translates to $3.7 per 1,000 gallons

vegetable production in Yemen is lack of water resources.[9] A review of development literature indicates that the introduction of low pressure drip irrigation combined with rainwater harvesting and storage as well as agronomic and marketing support can promote sustainable small scale vegetable production. USAID experience with low tech drip systems in other countries has been successful. For example, in Zimbabwe, more than 24,000 drip irrigation vegetable plots have been established. Designed to save labor and water, enhance nutrition and improve food security, the average drip-irrigation kit is low cost, easy to install, and far more water efficient than traditional watering systems. Surplus vegetables produced by drip irrigation generated additional income for participants that contributed to expanding agriculture activities, keeping their children in school and obtaining better healthcare.[10] Other evaluation findings have indicated the importance of providing production and marketing support when providing low tech drip systems to relatively poor famers.

Low Tech Drip System
USAID Zimbabwe

A successful rainwater harvesting and micro-irrigation program design requires determining the amount of rainfall and estimating the potential amount of water that can be harvested and available. It is estimated that surface runoff to the sea in Yemen exceeds 270 million m^3 of water annually.[3] A large portion of that surface runoff is in the USAID agriculture focus areas of Sana'a, Dhamar, Raymah, Ibb, Taiz, Al Dahli, and Lahj. The graph below, compiled from World Bank data (see World Bank Climate Portal), indicates that these seven governorates have received an average of 18 inches of rain per year over the last twenty years.



[10] See http://transition.usaid.gov/stories/zimbabwe/ss_zimbabwe_dripirrigation.pdf
[3] See http://www.eoearth.org/article/Water_profile_of_Yemen.

Based on the World Bank rainfall data for these governorates, the potential rainwater harvesting capacity of a roof top or a tile paved patio that is 10 meters by 5 meters (50 square meters or 540 square feet) is 5,147 gallons of water (see attachment one). This amount of rainfall is sufficient to produce at least two crops of cucumbers under micro-irrigation and supply part of a rural family's domestic water needs. Storage would be accomplished with the construction of an earthen storage pit measuring 1 m high by 2 m wide and 1 m long (2 cubic meters) with plastic lining and covered; this structure would serve as a water cistern with a storage capacity of more than 500 gallons.[11] Using low cost drip-irrigation technology, this amount water would be sufficient to irrigate two 50 square meter cucumber crops and provide part of the domestic water needs for a rural family.[12]

Rainwater Harvesting, Domestic Water Use, Agriculture Use and Monthly Deficit*
Gallons of Water

Months	Avg. Rain	H_2O Storage	Rainfall on Veg.	Total Rainwater	Total H_2O Needs	Water Deficit
Jan.	0.63	184		184	675	491-
Feb.	0.87	254		254	675	421-
Mar.	1.38	402	447	850	1,881	1,031-
April	1.77	516	573	1,090	1,881	791-
May	1.81	528	586	1,114	1,881	767-
June	0.91	265		265	675	410-
July	2.8	816	907	1,724	1,881	157-
Aug.	2.4	700	778	1,477	1,881	404-
Sept.	1.77	516	573	1,090	1,881	791-
Oct.	1.97	574		574	675	101-
Nov.	0.75	219		219	675	456-
Dec.	0.59	172		172	675	503-
	17.65	5,147	3,865	9,012	15,336	6,324-

Notes: (1) Average rainfall is based on the 20 year data from World Bank Climate Portal; (2) Water storage is the amount of rainfall that could be harvested each month with a 50 square meter catchment area (rooftop or patio) minus 10% loss – see attachment two for calculation; (3) Rainfall on vegetable plot is the average monthly rainfall during production season; (4) Total rainfall is the harvested rainfall plus rainfall on crop; (5) Total water needs is the estimated domestic water use based on a DFID survey in Africa (15 liters/person/day – Yemen - 6 family members) at 675 gallons per month plus water needed for vegetable crop at 1,206 gallons per month; (6) Water deficit is the total rainwater minus the total water needs (domestic and agriculture).[13] In terms of increased domestic water supply, supplementary methods of water collection might be attempted (e.g., fog collectors – see attachment six).

[11] 1 cubic meter equals 264.2 gallons

[12] The estimation is based on cucumbers have a 9 week growing season and requiring under normal conditions approximately 7.5 gallons of water per square foot per week. The total amount of water required for 50 square meters or 535 square feet of cucumber production would be 36,113 gallons (7.5 gallons per square foot) times 9 weeks of the growing season). With a drip irrigation system at 90 percent efficiency, the amount of water needed to produce the cucumber crop could be reduced to 3,618 gallons or 0.75 gallons per square foot.

[13] "Handbook for the Assessment of Catchment Water Demand and Use" DFID HR Wallington, Zimbabwe and Swaziland, pp. 90 – 91. May 2003 "

As indicated in the notes section on the previous page, the rainwater harvesting system can provide 1,668 gallons for domestic water supply during those months in which this water is not used for agriculture (January, February, June, October, November and December). Urban water costs are reported to 2,500 YER for a 3 cubic meter tank of water; this translates to roughly US$0.0147 per gallon and is equivalent to more than $14.70 per 1,000 gallons (over seven times the average cost of water in the US).[14] The amount of water provided for domestic water use under this multi-use water system would have, based on these estimated cost of urban water, an annual value of $30.[15]

This analysis shows the magnitude of constraints faced in providing sustainable water supplies for domestic and agriculture uses in Yemen where, in one of the highest rainfall areas of the country with relatively high efficiency irrigation systems and very limited domestic water use, we still have a significant household annual water deficit – more than 6,324 gallons a year for a family of six.

Coping with Yemen's water problem is going to require a concerted effort by the ROYG, local communities, private sector entities, Other Donors and International Non-governmental Organizations. The subject of improved water use in agriculture will be discussed at an ICARDA (International Center for Agriculture Research in Dry Areas) Water Sector Meeting in Sana'a on February 25, 2013. Various donor and ROYG (Republic of Yemen Government) entities have confirmed their attendance to the meeting. Among the attendees will be the Social Fund for Development (SFD) which has implemented rainwater harvesting activities as part of its effort to provide increased water supply to rural areas. Their goal is to increase water availability to 30 l/c/d (liter per capita per day) within a 30 minute roundtrip throughout the year using rooftop rainwater harvesting; public rainwater harvesting – closed cisterns; public rainwater harvesting – open cisterns; surface water (springs and reservoirs); and ground water (shallow and deep wells). Some interesting research done in association with SFD and local Non-governmental Organizations has focused on fog collectors (see attachment six). Supporting multi-use water systems, possibly combined with more than one water collection systems, may offer the potential to address Yemen's water scarcity issues in a sustainable and economically practical manner.

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[14] "Water: What You Need to Know" EPA - http://www.epa.gov/ogwdw/wot/pdfs/book_waterontap_full.pdf - The national average cost of water is $2.00 per 1,000 gallons. The average American family spends about $474 each year on water and sewage charges.

[15] Yemen Observer – Feburary 16, 2013 – p. 6 – Business Section – Commodity Prices – Non-food - Water

Attachment One - Horticulture Cost Benefit Analysis

Cucumber Value Chain*	**Item**	**Without Project**	**Year 1**	**Year 2**	**Year 3 - 5**
Gross Revenue	Total Value of Production	$176	$350	$467	$526
Cash Sales		$141	$280	$373	$420
Costs	Variable Costs	$65	$175	$175	$175
Net Revenue	Gross Margin	$76	$105	$198	$245
CASH Project Investment - $800	Overhead	0	$200	$200	$200 for Year 3 & 4
	Profit	$76	$105	$198	$245
Profit plus family labor	Net Farm Income**	$76	$105	$198	$245

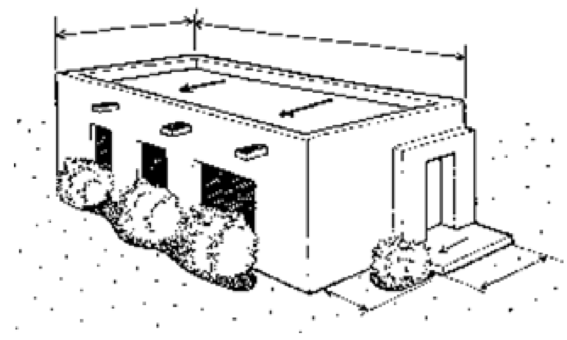
Price for cucumber in 2011 in Taiz, Ibb, Dhamar, Al Dali, Sana'a, Lahj and Rahmah averaged 180 YER per kg. However, this price fluctuates during the year from a low of 85 YR to 171 YR per kg. The farm-gate price received per kilogram for cucumber is estimated at 125 YER.

“Without Project” cucumber yield is estimated to be one fourth of US average cucumber yields in the US or approximately three metric tons per hectare. In a fifty square meter production area, the “Without Project” scenario will yield approximately 150 kgs of cucumber in two growing season (March – May & July – Sept.) which at 125 YR per kg would result in gross revenue of $176. Variable costs in the "Without Project" scenario are estimated to be $65 (labor, seed and soil preparation).

”With Project" yields are based on two crops a year with supplemental rainwater harvesting used for micro-irrigation (March –May and July – September). Total annual production area is estimated to be 100 sq. meters (two production cycles on a 50 sq. meter plot) with the following yields: Year One yield is 600 kg; Year Two 800 kg; Year Three through Five – 900 kg. Variable costs in the "With Project" scenario are estimated to be $175 (labor, seed, fertilizer, soil preparation and low tech drip system). Grant support provides rainwater harvesting system and water storage tank - $200 per year – and is not counted against production costs. Cash sales are estimated at 80% of Gross Revenue (with 20% of production being consumed by the family).

Attachment Two

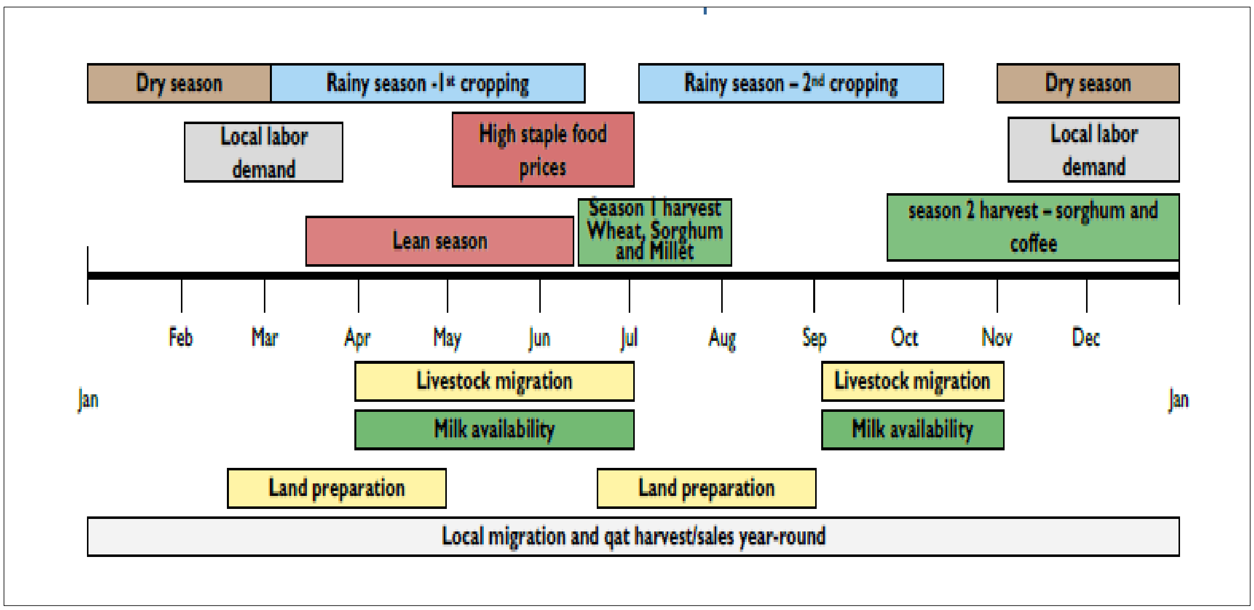
American Rainwater Catchment Systems Association - http://www.arcsa.org/



Area of flat roof - Length X width

Table 2 --Annual Supply Form Roof Catchement

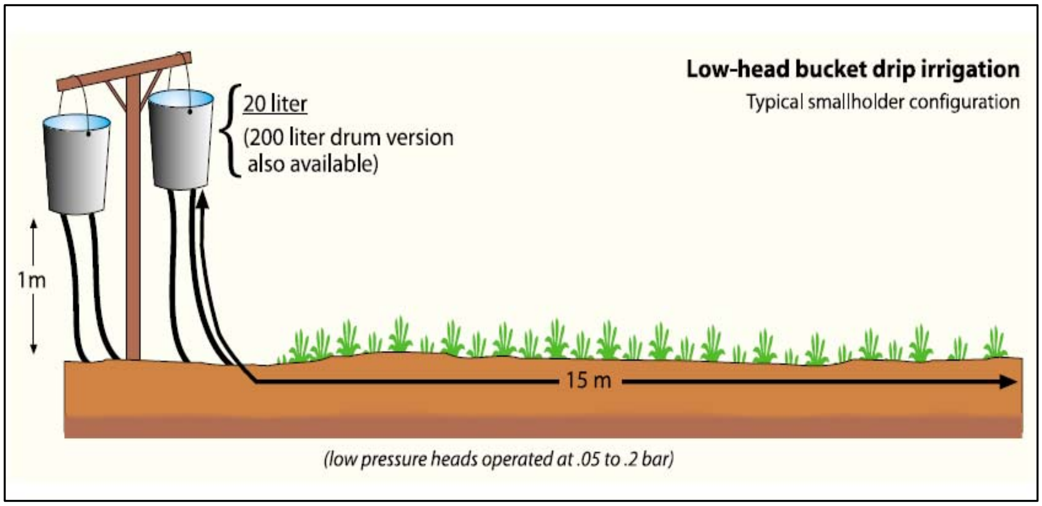
Inches/Rainfall	Gallons/Square Foot
0	0
1	.6
2	1.3
3	1.9
4	2.5
5	3.1
6	3.7
7	4.4
8	5.0
9	5.6
10	6.2
11	6.8
12	7.5
13	8.1
14	8.7
15	9.3



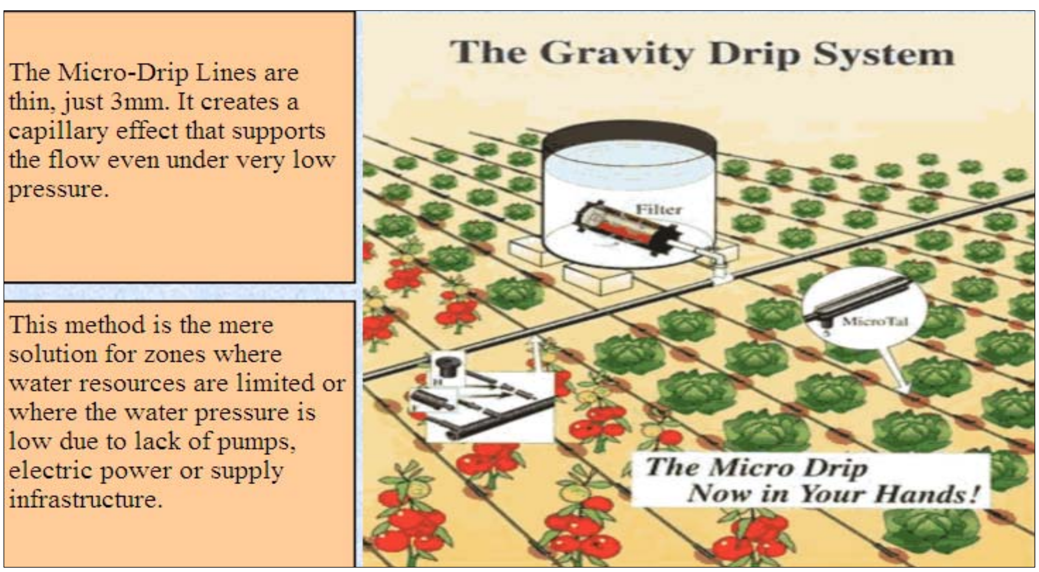
Yemen's Agriculture Seasons

Attachment Three – Micro-Irrigation Systems

Two potential approaches could be used either a low pressure system from Ein-Tal Irrigation Systems or very low tech gravity feed system promoted by the International Water Management Institute.



International Water Management Institute

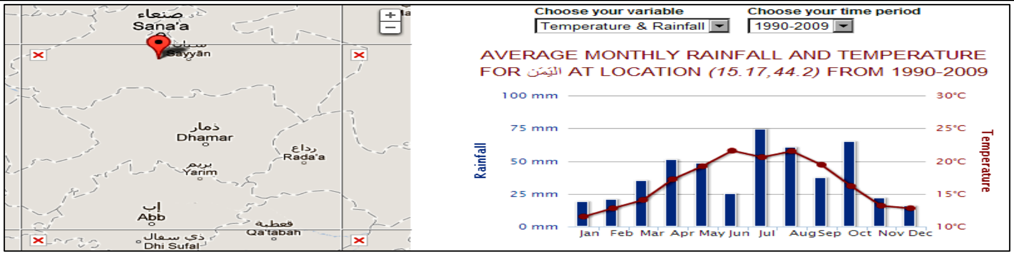


Ein-Tal Irrigation

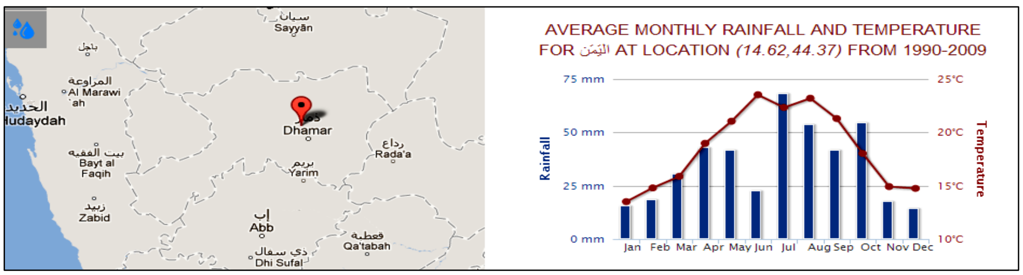
Attachment Four

World Bank Climate Portal - Yemen Rainfall & Temperature Data

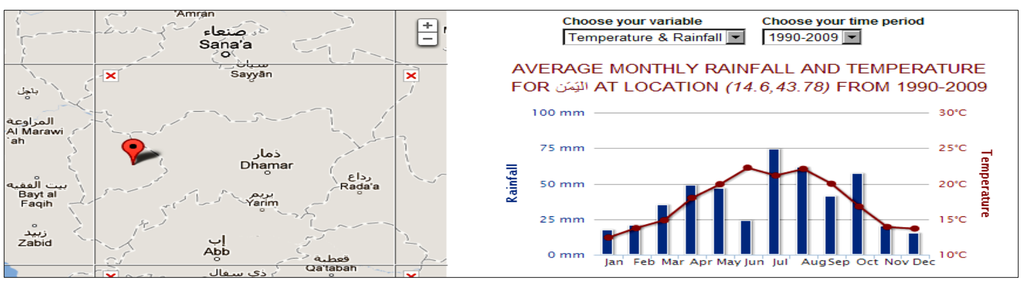
http://sdwebx.worldbank.org/climateportal/index.cfm?page=country_historical_climate&ThisRegion=Asia&ThisCCode=YEM#



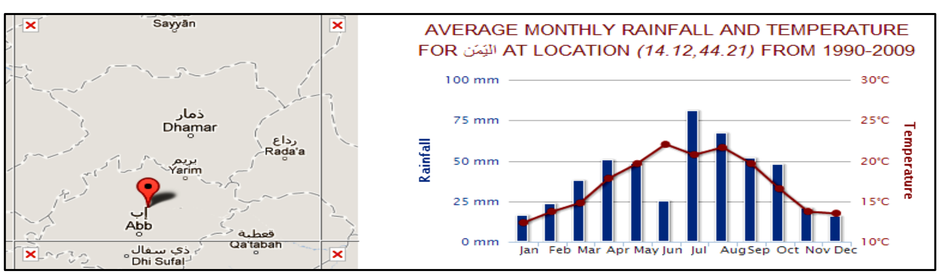
SANA'A - Jan. – 19 mm; Feb. – 21mm; Mar. – 35 mm; April – 51mm; May – 48mm; June – 25mm; July – 74mm; Aug. – 61mm; Sept. – 37mm; Oct. – 65mm; Nov. – 22mm; Dec. – 16mm



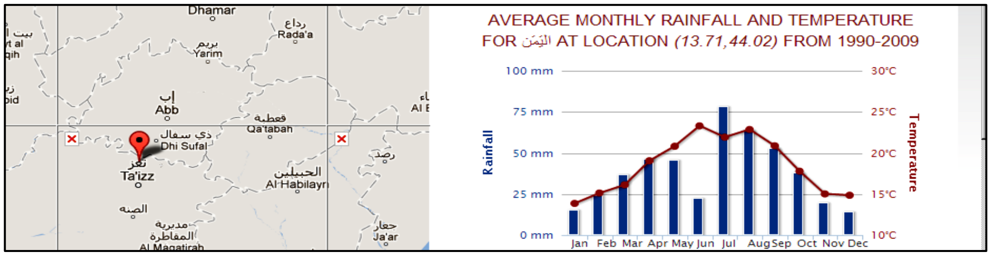
DHAMAR - Jan. – 15.5 mm; Feb. – 18.6 mm; Mar. – 31 mm; April – 43 mm; May – 42 mm; June – 23 mm; July – 68 mm; Aug. – 54 mm; Sept. – 42 mm; Oct. – 54 mm; Nov. – 18 mm; Dec. – 14 mm



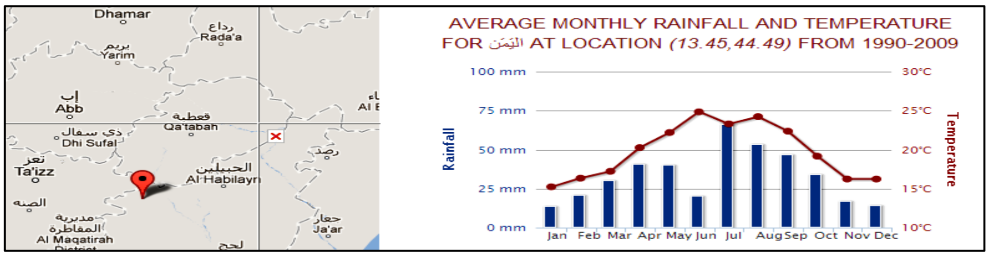
RAYMAH - Jan. – 18mm; Feb. – 21mm; Mar. –35mm; April – 49mm; May – 47mm; June – 24mm; July – 74 mm; Aug. – 61mm; Sept. – 41mm; Oct. – 57mm; Nov. – 20mm; Dec. – 15mm



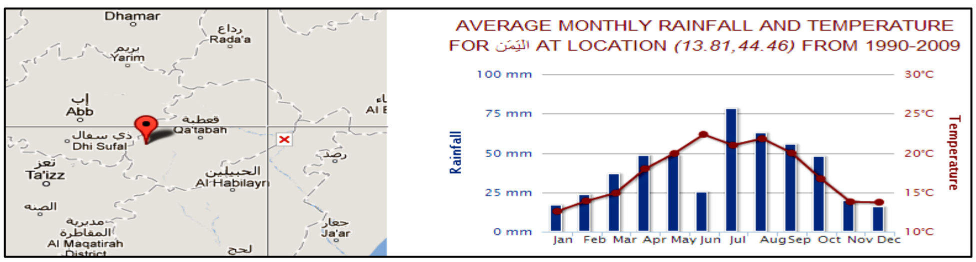
IBB - Jan. – 17mm; Feb. – 24mm; Mar. – 38 mm; April – 50 mm; May – 48mm; June – 25mm; July – 81mm; Aug. – 67mm; Sept. – 52 mm; Oct. – 48 mm; Nov. – 21 mm; Dec. –16 mm



TAIZ - Jan. – 15mm; Feb. – 24mm; Mar. – 37mm; April – 46mm; May – 45mm; June – 22 mm; July – 78mm; Aug. –64mm; Sept. – 53mm; Oct. – 38mm; Nov. – 20mm; Dec. – 14mm



LAHJ - Jan. – 14mm; Feb. – 21mm; Mar. –30mm; April – 40mm; May – 40mm; June – 20 mm; July – 66mm; Aug. – 54mm; Sept. – 47mm; Oct. – 34mm; Nov. – 17mm; Dec. – 14mm



AL DALI - Jan. – 17mm; Feb. – 24mm; Mar. –37mm; April –48 mm; May – 48mm; June – 25 mm; July – 78mm; Aug. –63 mm; Sept. –56 mm; Oct. – 48mm; Nov. – 19mm; Dec. – 16mm

Attachment Five – ROYG and Donor Activities

The Social Fund for Development (SFD) has implemented rainwater harvesting activities as part of its effort to provide increased water supply to rural areas. Building on systems first established before the rise of the Roman Empire, SFD's interventions in the water sector focus on renewable water resources such as rainwater and springs. Their goal is to increase water availability to 30 l/c/d (liter per capita per day) within a 30 minute roundtrip throughout the year. In Phase IV (2011-2015), SFD has selected 4,400 communities based on needs criteria (100% of the houses don't have water in their premises; population at or above 300; and poverty index exceeds 50%). To provide communities with water for domestic use, SFD supports: rooftop rainwater harvesting; public rainwater harvesting – closed cisterns; public rainwater harvesting – open cisterns; surface water (springs and reservoirs); and ground water (shallow and deep wells).

Other donors are interested in rainwater harvesting and additional research may be needed to assess how to best provide domestic and agriculture water. ICARDA (International Center for Agriculture Research in Dry Areas) is hosting a Water Sector Meeting in Sana'a on February 25, 2013. Various donor and ROYG (Republic of Yemen Government) entities have confirmed their attendance to the meeting.

Two key areas for discussion are:

(1) What is the potential of using water catchments and drip irrigation to maintain or expand current coffee production areas? Yemini coffee is severely water stressed and suffers lower lowers yields, what is the potential to focus USAID coffee production support to areas that have sufficient rainfall (possibly combined with water catchments) to raise yields. Yemen's per hectare average coffee yields are 1/3 to 1/2 of similar production in Uganda (250 kg/ha in Yemen versus 500 kg/ha in Uganda) – sufficient water, husbandry, quality control in harvesting, drying and processing, could result in raising yields and increasing quality which if combined with an effective export marketing program could increase net returns to small producers; and

(2) How can we expand horticulture under rainwater harvesting systems? The Communities Livelihoods Project (CLP) is assessing the horticulture market and testing pilot activities in drip irrigation (they have already set up greenhouses using solar pumping and aeration systems to reduce disease problems). The key constraint over the medium term is water and there needs to be an assessment of horticulture systems that could be self-sufficient – that is, could include water harvesting systems that meet their ag production requirements. One idea would be to explore is the potential of establishing "production pockets" linked to "community markets" where small scale producers (home gardens) are provided rainwater harvesting systems (collecting rainwater that runs off rooftops), horticulture production assistance, and marketing assistance linked to major wet markets as well as hotels and other institutions.

Attachment Six - Fog Collectors - http://www.geo.puc.cl/observatorio/cereceda/C38.pdf

In 2002 a study was conducted in Hajja governorate in Yemen of a series of fog collectors. This work was done in conjunction with (1) FogQuest (a Canadian company), (2) Geography Institute of the Pontifical Catholic University, and (2) International Community Services. Nineteen different sites were chosen and tested between January and March 2003. The best sites averaged 4.5 liter per square meter of mesh per day over the three month winter period. Elevations of sites ranged from 1,650 m to 2.800 m (the best collection rates were at sites between 2,000 to 2,200 m elevation). Also, as part of the study, 25 large collectors (25 square meters) were built in January 2004 and grouped in arrays to provide water for village homes. Production from the collectors was estimated to be 4,500 liters of water per day.

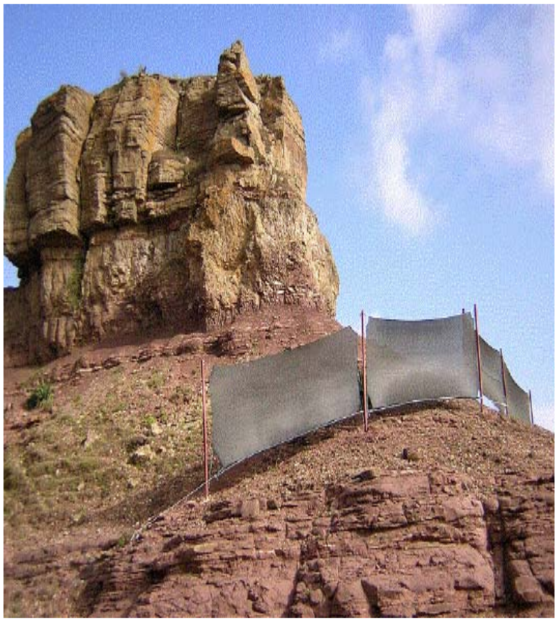


Table 1. Locations of Standard Fog Collectors in the Hajja Governorate, Yemen.

Area name	Average ($L\ m^{-2}\ day^{-1}$)	SFC Number	Location UTM (WGS 72)	Orientation	Elevation
Schiraqi	0.34	1	352061 - 1729727	180	2260
Schiraqi	0.32	2	352061 - 1729727	270	2260
Schiraqi	0.61	3	352530 - 1730131	170	2450
Schiraqi	0.25	4	352530 - 1730131	270	2450
Schiraqi	0.49	5	352662 - 1730058	240	2450
Schiraqi	0.30	6	352887 - 1730132	180	2450
Schiraqi	0.33	7	352312 - 1729695	190	2300
Mabyan	4.49	8	346743 - 1739771	230	2020
Mabyan	4.54	9	346622 - 1739871	215	2030
Mabyan	2.92	13	347000 - 1739300	270	2000
Mabyan	0.93	10	347416 - 1737470	200	1650
Hajja City (Antenna)	0.98	11	350366 - 1735330	225	1820
Hajja City (MOA)	0.36	12	350114 - 1734950	180	1750
Humlan	0.77	14	351331 - 1733100	230	1775
Humlan	0.52	16	351420 - 1732770	270	1835
Humlan	0.71	15	351520 - 1732080	250	1890
Aschmur	0.05	17	366230 - 1735710	270	2840
Aschmur	0.04	18	366230 - 1735710	180	2840
Aschmur	0.06	19	366230 - 1735710	0	2840
Maswar Bait Sheim	0.05	20	357050 - 1728100	180	2640
Maswar Bait Sheim	0.02	21	357050 - 1728100	250	2640
Maswar Bait Sheim	0.02	22	357220 - 1728100	0	2660
Maswar Bait Saad Salah	1.12	23	355000 - 1727600	0	2440
Maswar Bait Saad Salah	2.08	24	355000 - 1727600	270	2440
Maswar Bait Saad Salah	0.88	25	355000 - 1727350	180	2485
Maswar Bait Saad Salah	1.42	26	355000 - 1727350	270	2485