Evaluation of a Low–Cost, Low-Tech Micro-Irrigation System Designed for Small Plots

Daniel Smeal, Michael K. O'Neill, and Richard N. Arnold

New Mexico State University Agricultural Science Center at Farmington

Water-use efficiency (WUE) is of utmost importance to many small-scale farmers and gardeners living on arid lands throughout the world. Some rely on small, low-output wells or unreliable surface sources to provide water for irrigating food crops for sustenance or for supplementing income. This is common even in the southwest U.S. where, on many Indian reservations, water must be transported from community wells or ponds to the irrigation site in containers. In other rural or urban settings, the volume of water available for irrigating agricultural fields and small vegetable plots may become limited by water restrictions or use-limits imposed during droughts or other water-short situations. In any case, it's important to maximize WUE (crop yield/water used).

The area of land that can be irrigated from a given volume of water can be significantly increased by converting from traditional surface irrigation to drip irrigation. Drip or trickle irrigation involves frequent application of small amounts of water directly to the base of plants. Water is applied under low pressure and only a small area around each plant is wetted. If managed properly, water is saved because it is not applied to the soil area in-between plants as in flood or sprinkler irrigation and soil water evaporation is decreased. Since large areas of ground remain dry, weeds are less problematic than when the entire soil surface is wetted.

Due to the costs and complexity of conventional state-of-the-art micro-irrigation systems, however, small-scale farmers have been reluctant to convert from familiar flood and sprinkler irrigation to drip irrigation. One purpose of this experiment was to evaluate the potential for using a simple, low-cost drip irrigation system that might receive wider acceptance by these farmers. The system, while originally developed in India (and promoted by International Development Enterprises for use in developing, resource-poor countries) could potentially be used in many situations where water conservation is of concern.

Regardless of the irrigation system used, WUE cannot be maximized without proper system management. This includes appropriate system maintenance and irrigation scheduling based on estimated crop water requirements. Other purposes of this experiment were to evaluate yield/water relationships (water production functions) for selected vegetable crops irrigated with the drip system and to formulate recommendations for scheduling irrigations on these crops.

Objectives

Evaluate the practicality of use and water conservation potential of a simple, low-cost drip irrigation system.

Identify water production functions of various vegetable crops when drip irrigated.

Materials and Methods

A randomized complete block design (Figure 1 and Figure 2) consisting of three replications (blocks) of three different drip-irrigation treatments (zones) was used to evaluate the yield/water relations of chile peppers, tomatoes, and sweet corn in 2005 and 2006 in northwestern New Mexico. The study was conducted on a very fine sandy loam soil at a site having an elevation of 1710 m (5600 ft) above mean sea level, and an annual average precipitation of 208 mm (8.2 in). Irrigations were applied every two to three days at volumes required to replace 50%, 75%, and 100% of Penman-Monteith (tall) reference ET (ETrs) in 2005 and 65%, 85%, and 105% of ETrs in 2006.

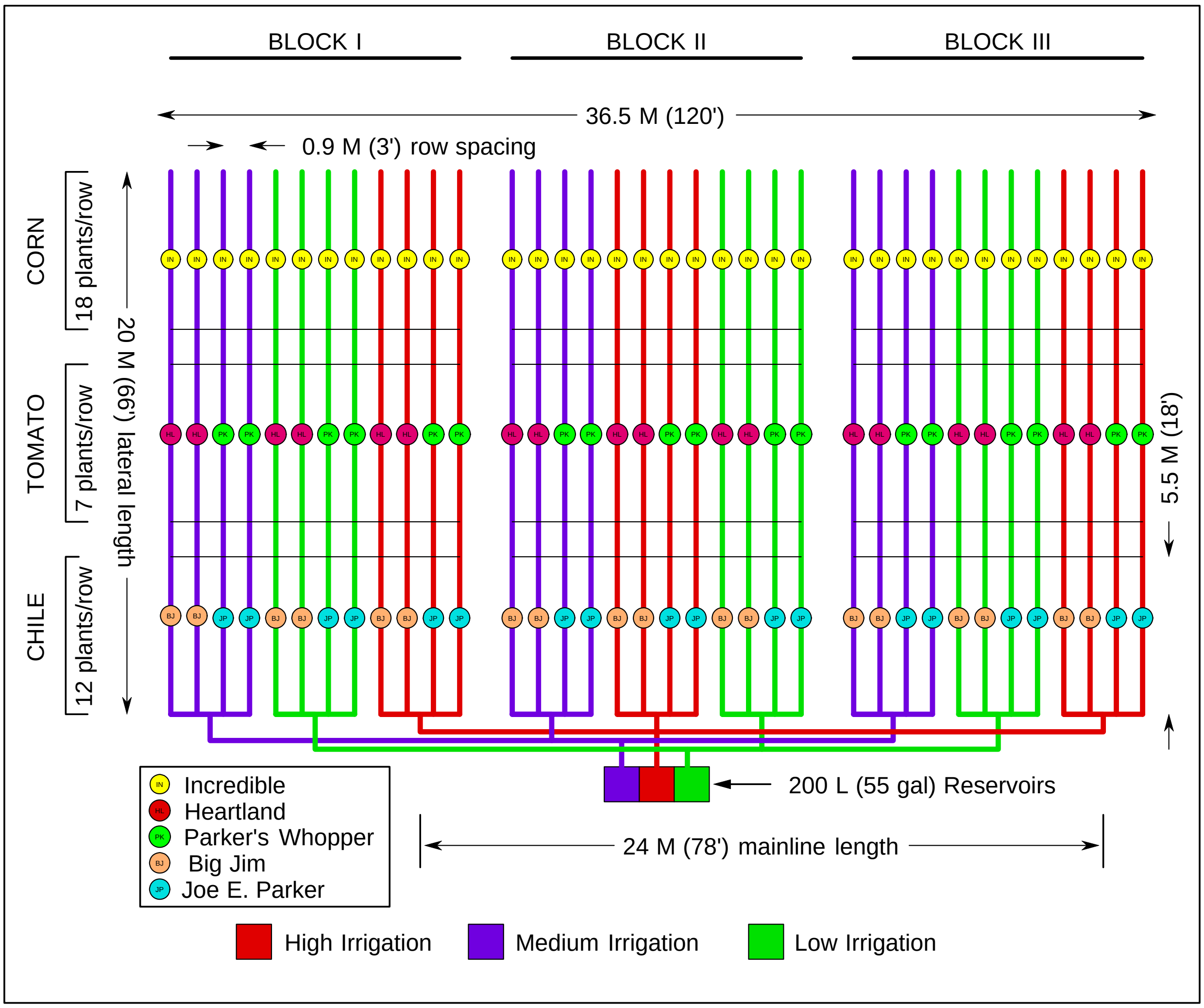

Figure 1. Diagram of the low-cost, low-tech drip garden (randomized complete block) used to evaluate yield/water relations of vegetable crops in 2005.

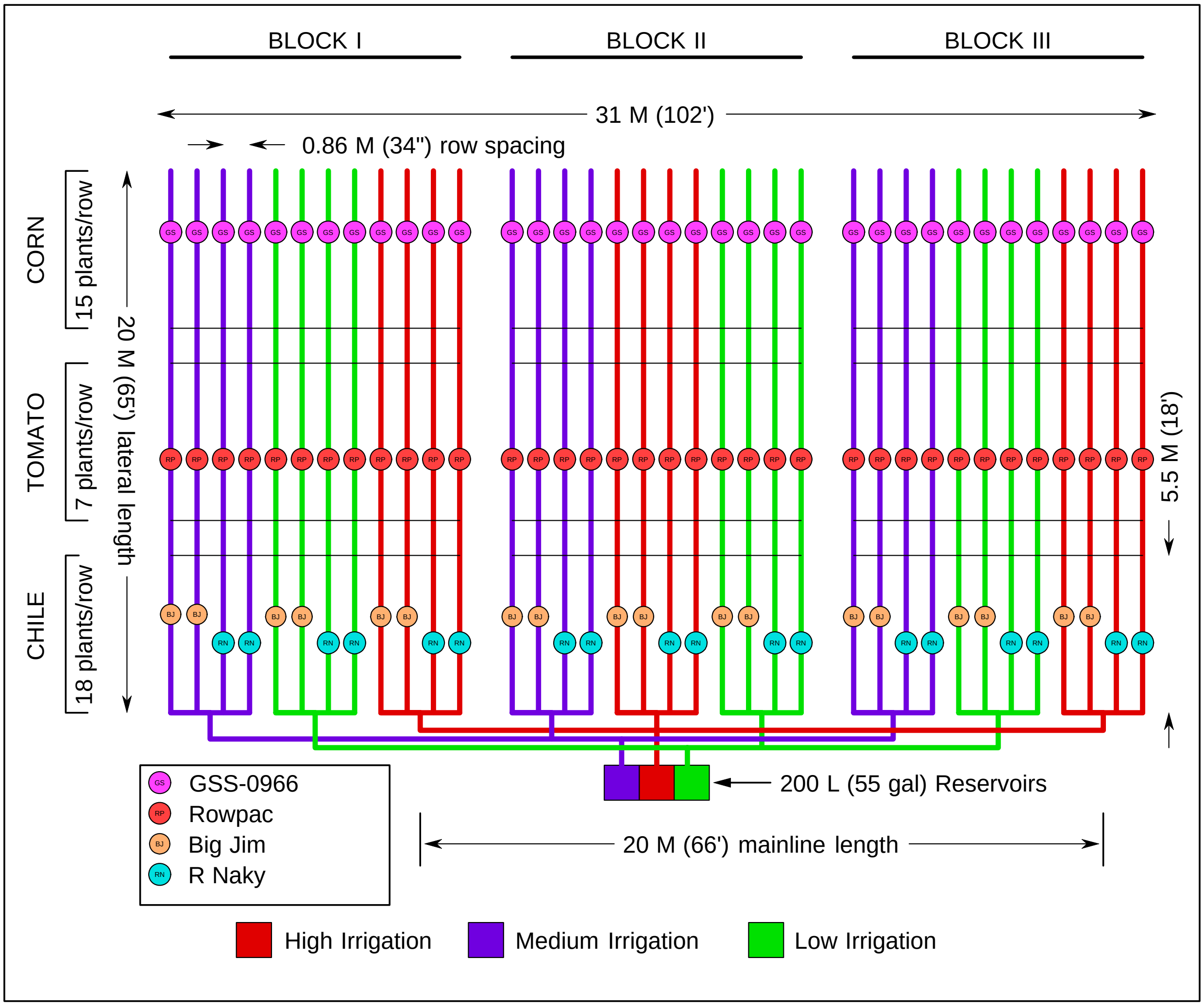

Figure 2. Diagram of the low-cost, low-tech drip garden (randomized complete block) used to evaluate yield/water relations of vegetable crops in 2006.

Major System Components

Water reservoirs: Three plastic, 208 L (55 gallon) drums, laid on their sides and elevated to a height of about 6 feet above the soil surface of the garden, were used to store and supply water to the three drip zones. A hinged access door, about 300 mm (12 in) by 400 mm (16 in), was cut into the topside of each drum to provide easy access for filling the drums with water and/or fertilizer when needed (Figure 3).

Water distribution systems including filters and microtubule emitters: In 2005, water was delivered from the reservoirs to the laterals of each zone through a 25 mm (1 in) black polyethylene (poly) pipe mainline and a 24 m (78 ft) long, 13 mm (½ in) poly pipe sub-main (Figure 4). Twelve, 20 m (66 ft) long drip-tape laterals spaced 0.9 m (3 ft) apart (Figure 4) delivered water to 250 mm (10 in) long microtubule emitters placed at each plant (Figure 5.) within each zone.

The distribution system in 2006 was similar to that of 2005 except each mainline was 20 m (66 ft) long (instead of 24 m) and the diameter of all mains and submains was 19 mm (3/4 in). Additionally, the microtubule emitters were cut in half to 125 mm (5 in) long (rather than 250 mm). In both years, an inline screen filter was installed on all mainlines.

A summary of system specifications and cropping information is presented in Table 1.

Figure 3. Elevated reservoirs (left) and access doors (right.)

Figure 4. Mains and submains (left) and laterals (right).

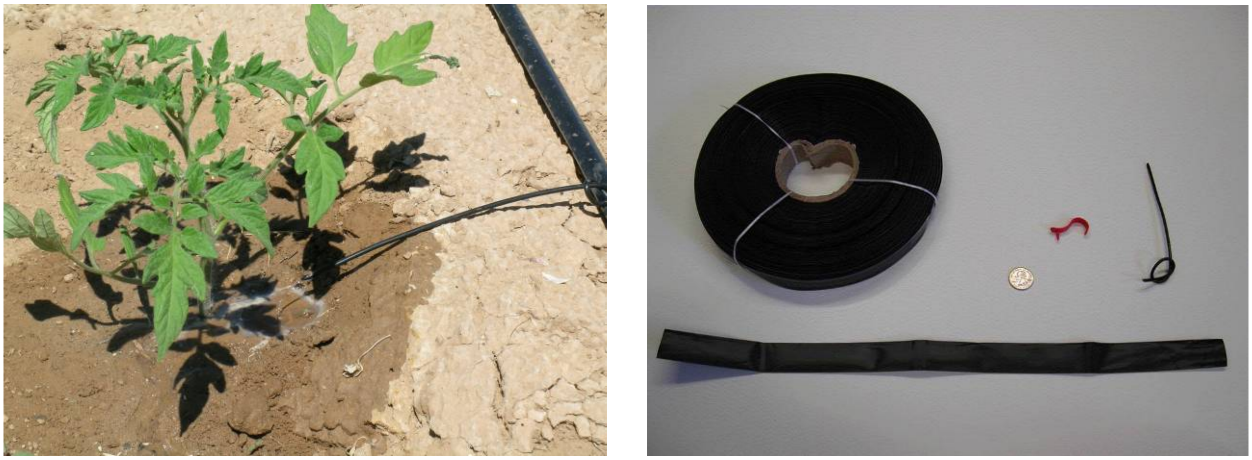

Figure 5. Microtubule emitter watering tomato plant (left), drip tape roll and short section, hole punch, and microtubule emitter (right).

Table 1. Specifications of each block (3 blocks total) in the randomized complete block design used to evaluate drip irrigation treatment effects on three vegetable crops in 2005 and 2006.

Component	2005			2006		
Lateral size	200 μm (8-mil) thickness, 15 mm (0.59”) ID					
Laterals per block	12			12		
Lateral spacing, cm (in)	91 (36)			86 (34)		
Lateral length w/borders, M (ft)	20 (65)			20 (66)		
Microtube emitters per lateral	37			40		
Microtube emitter length, cm (in)	25 (9.8)			12.5 (4.9)		
Total emitters per block	444			480		
Flow rate/emitter, ml min^{-1} (gph)	43 (0.68), 28 (0.45)†			35 (0.55)		
Flow rate per block, l min^{-1} (gpm)	19.1 (5.0), 12.4 (3.3)			16.8 (4.4)		
	Chile	**Tomato**	**Corn**	**Chile**	**Tomato**	**Corn**
Plant (emitter) spacing, cm (in)	46 (18)	76 (30)	30 (12)	30 (12)	61 (24)	30 (12)
Plants per lateral	12	7	18	18	7	15
Planting Date	9-11 June	12-13 June	17 June	23-24 May	23-24 May	1 June
Transplants (T) or Seed (S)	T	T	S	T	T	S
Planting method	Hand	Hand	Hand	Machine	Machine	Hand

†Flow rates measured before and after installation of timers, respectively.

Planting and Fertilizer Information

The plot area was prepared for planting (disked, fertilized, rototilled, leveled, and pre-irrigated) in May of both years. In 2005, pre-plant fertilizer (11-52-0) was incorporated into the soil on 20 May at a rate of 49 kg N ha^{-1} and 233 kg P_2O_5 ha^{-1} (44 lbs. N and 208 lbs. P_2O_5/acre). The area was pre-irrigated with approximately 50 mm (2 in) of sprinkler-applied water on 25 May. On 5 June (prior to planting) the garden area was sprayed with glyphosate (3% solution) to kill small weed seedlings that had emerged.

In 2006, the plot was established in a different area previously planted to turfgrass, Pre-plant fertilizer (11-52-0) was incorporated on 11 May at a rate of 25 kg N ha-1 and 116 kg P_2O_5 ha-1 (22 lbs N and 208 lbs P_2O_5/acre). Sprinklers were used to apply a 20 mm (0.75 in) deep irrigation on 19 May prior to planting and a 3 mm (0.50 in) irrigation on 24 May after planting but prior to set-up of the drip system.

In both years, chile pepper and tomato seedlings from 25 mm (1-inch) pots (six-packs) were transplanted into rows at spacings shown in Table 1. In 2005, plants were set into holes that were pre-wetted with about 350 ml (12 oz) of a water-fertilizer solution (500 ml dry all purpose fertilizer [Table 3] to 4 gallons of water) by hand. In 2006, a mechanical, three-point hitch transplanter was used and a similar fertilizer volume was applied with each transplant through the transplanter.

Drip-tape laterals were laid out in rows next to the plants and emitters were installed (pointing downstream) into the water-filled laterals at each plant location after planting in both years. Sweet corn seeds were planted by hand about 1 week after the transplants in both years and then microtubule emitters were installed into the drip line next to each seed. The total plot area was about 720 m^2 (7750 ft^2) in 2005 and about 620 m^2 (6670 ft^2) in 2006 (Figure 1 and Figure 2). In 2006, row spacing was slightly narrower and borders between blocks were eliminated.

Maintenance Fertilization

In addition to the pre-plant fertilizer, the garden was fertilized through the drip system (fertigation) six times during the 2005 season by adding liquid nitrogen and a micronutrient solution to the reservoirs during irrigation (Table 2). Soluble fertilizers (Table 3) were dissolved in 11-19 L (3-5 gals) water before being added to reservoirs. A similar fertilization program was followed in 2006.

Table 2. Dates and amounts of drip fertigation per block in 2005.

Date	Product*	Total Product† g (oz)	Rate per Plant† g (oz)
24 June	$CaNO_3$ (15.5% N)	285 (10)	0.64 (0.0225)
	Peter's	285 (10)	0.64 (0.0225)
1 July	20-0-0	285 (10)	0.64 (0.0225)
	Peter's	285 (10)	0.64 (0.0225)
12 July	UAN (32% N)	480 (16)	1.08 (0.0360)
	Peter's	285 (10)	0.64 (0.0225)
22 July	UAN (32% N)	700 (23)	1.58 (0.0527)
	Peter's	425 (15)	0.96 (0.0338)
29 July	UAN (32% N)	400 (14)	0.95 (0.0315)
	Peter's	285 (10)	0.64 (0.0225)
12 August	UAN (32% N)	700 (23)	1.58 (0.0527)
	Ace	340 (12)	0.77 (0.0270)

†Value represents ml (liquid ounces) for UAN.

Table 3. Nutrient analyses of dry plant foods used in fertigation of vegetables in the low-tech drip garden during 2005.

Peter's Professional (20-20-20)	Ace All-Purpose (15-30-15)

Nutrient	%	Nutrient	%
N (2% NO_3-N, 18% Urea N)	20.0	N (5.8% Amm. N, 9.2% Urea N)	15.0
P_2O_5	20.0	P_2O_5	30.0
K_2O	20.0	K_2O	15.0
Mg	0.5	B	0.02
B	0.02	Cu	0.07
Cu	0.05	Fe	0.10
Fe	0.10	Mn	0.05
Mn	0.05	Mo	0.0005
Mo	0.0005	Zn	0.06
Zn	0.05		

Other cultural information

Weeds were controlled by hand-hoeing or pulling during both seasons and no pesticides were used. All crops were harvested by hand as they matured.

Irrigation

In 2005, due to very slow establishment attributed to disease (curly top virus), the entire plot area was drip-irrigated uniformly at near 100% of ETrs up through 24 July (6 weeks after planting) at a frequency of three irrigations per week. Irrigation treatments (volumes sufficient to replace 50%, 75%, and 100% of ETrs) commenced on July 27 and continued through the end of September (Table 4). In 2006, varying drip treatments (volumes to replace 65%, 85%, and 105% of ETrs) were started on 15 June (Table 5) and continued to the end of season (not yet established). An average value of plant canopy area for all three crops was used to adjust irrigation volumes during the growing season.

The equation used to calculate water volumes for the irrigation treatments was:

$$I = ETrs \times TF \times 0.62 \times CA \quad \text{[Eq. 1]}$$

Where:

I = irrigation in gallons
ETrs = Penman-Monteith Reference ET tall (inches)
TF = treatment factor (0.50, 0.75, or 1.00 in 2005 and 0.65, 0.85, or 1.05 in 2006)
0.62 = gallons of water to cover 1 square foot to a depth of 1 inch
CA = plant canopy area (square feet)

Daily weather parameters from a New Mexico Climate Center (NMCC) weather station (Campbell Scientific) located within 100 m (328 ft) were used to calculate ETrs (http://weather.nmsu.edu).

In 2005, plant canopy area (CA) increased from 230 cm^2 (0.25 ft^2) per plant after planting to a maximum of 0.21m^2 (2.25 ft^2) per plant on 27 July. In 2006, plant canopy area increased from 190 cm^2 (0.2 ft^2) after planting to 0.24 m^2 (2.6 ft^2) on 21 July and afterwards.

The water volume applied to each treatment was controlled by timing the irrigations. In 2005, random measurements of emitter flow rates during the season indicated 43 ml min^{-1} (0.68 gph) from June 19 through about mid-August. Subsequent measurements indicated a decrease in flow rate to 28 ml min^{-1} (0.45 gph) per emitter and run times were adjusted accordingly. Total flow rate per block (444 plants) then ranged from about 1145 L hr^{-1} (5 gpm) during the first half of the season, to 745 L hr^{-1} (3.3 gpm) during the last half of the season. The decreased flow rate per emitter as the season progressed appeared to be caused either by algae or other precipitates in the emitters or possibly by mainline flow restriction after installation of timers. As of this writing, the timer theory has yet to be tested.

In 2006, flow rate per emitter averaged 35 ml min^{-1} (0.55 gph) from June through 21 August and then increased to 49 ml min^{-1} (0.78 gph) when the laterals were shortened after corn harvest (see further discussion below). Total average flow rate per block then was 1008 L hr^{-1} (4.44 gpm) prior to 21 August (480 emitters) and 882 L hr^{-1} (3.88 gpm) after that (300 emitters).

Results and discussion

Irrigations and System Evaluation

The garden was irrigated 45 times between 19 June and 4 October in 2005 and 33 times between 31 May and 28 August in 2006. The total volumes of irrigation water applied to each plant in the high, medium, and low irrigation treatments were 162, 135, and 113 L (42.8, 35.6, and 29.9 gallons), respectively in 2005 and 140, 117, and 95 L (37, 31, and 25 gallons), respectively, up to 29 August in 2006. An additional 99 mm and 74 mm (3.9 and 2.9 in) of precipitation fell on the plots during the 2005 and 2006 seasons, respectively. Sweet corn was harvested before 7 September in 2005 and before 17 August in 2006 so water applied after those dates did not contribute to corn yield. Additionally, since fruit production has not yet ceased in the tomatoes and chile peppers as of this writing, the totals shown in Table 5 for 2006 are sub-totals only.

In 2005, total ETrs from planting (13 June) to the final harvest of tomatoes in October was 965 mm or 38 in (Table 4). In 2006, ETrs from planting 24 May to August 28 totaled 807 mm or 32 in (Table 5).

Table 4. Calculated reference ET (ETrs) and average water volumes applied to each plant during the 2005 season at three irrigation treatments with the low-tech, low-cost drip irrigation system†.

			Irrigation Treatment Level					
	ETrs	ETrs	High (100% ETrs)		Med. (75% ETrs)		Low (50% ETrs)	
Date	mm	in	Liter	Gallon	Liter	Gallon	Liter	Gallon
19-Jun	-	-	0.39	0.10	0.39	0.10	0.39	0.10
19-Jun	55.6	2.19	1.35	0.36	1.35	0.36	1.35	0.36
21-Jun	20.3	0.80	3.69	0.97	3.69	0.97	3.69	0.97
24-Jun	25.4	1.00	3.69	0.97	3.69	0.97	3.69	0.97
26-Jun	16.5	0.65	3.20	0.84	3.20	0.84	3.20	0.84
27-Jun	10.4	0.41	1.23	0.32	1.23	0.32	1.23	0.32
28-Jun	10.9	0.43	2.46	0.65	2.46	0.65	2.46	0.65
30-Jun	17.0	0.67	2.87	0.76	2.87	0.76	2.87	0.76
1-Jul	8.9	0.35	1.85	0.49	1.85	0.49	1.85	0.49
3-Jul	20.3	0.80	2.87	0.76	2.87	0.76	2.87	0.76
6-Jul	30.0	1.18	5.33	1.41	5.33	1.41	5.33	1.41

8-Jul	21.6	0.85	3.08	0.81	3.08	0.81	3.08	0.81
10-Jul	20.6	0.81	3.69	0.97	3.69	0.97	3.69	0.97
12-Jul	19.8	0.78	4.72	1.25	4.72	1.25	4.72	1.25
14-Jul	21.8	0.86	2.67	0.70	2.67	0.70	2.67	0.70
15-Jul	11.9	0.47	1.23	0.32	1.23	0.32	1.23	0.32
16-Jul	10.2	0.40	0.81	0.21	0.81	0.21	0.81	0.21
17-Jul	11.2	0.44	0.81	0.21	0.81	0.21	0.81	0.21
18-Jul	9.9	0.39	3.24	0.86	3.24	0.86	3.24	0.86
20-Jul	22.4	0.88	3.24	0.86	3.24	0.86	3.24	0.86
22-Jul	25.4	1.00	3.24	0.86	3.24	0.86	3.24	0.86
24-Jul	20.1	0.79	0.81	0.21	0.81	0.21	0.81	0.21
27-Jul	25.4	1.00	5.37	1.42	3.70	0.98	2.05	0.54
29-Jul	18.8	0.74	2.48	0.66	1.86	0.49	1.27	0.34
31-Jul	22.9	0.90	2.03	0.54	1.62	0.43	1.22	0.32
1-Aug	9.1	0.36	2.59	0.68	1.84	0.49	1.08	0.29
3-Aug	18.8	0.74	2.70	0.71	2.03	0.54	1.35	0.36
5-Aug	16.3	0.64	2.43	0.64	1.76	0.46	1.08	0.29
10-Aug	33.8	1.33	3.92	1.03	2.70	0.71	2.84	0.75
12-Aug	12.4	0.49	1.89	0.50	1.89	0.50	0.81	0.21
15-Aug	19.8	0.78	2.97	0.78	2.21	0.58	1.49	0.39
19-Aug	29.2	1.15	3.16	0.83	2.38	0.63	2.54	0.67
22-Aug	21.8	0.86	5.08	1.34	3.81	1.01	2.54	0.67
24-Aug	15.2	0.60	3.24	0.86	2.43	0.64	1.62	0.43
26-Aug	15.0	0.59	3.67	0.97	2.84	0.75	2.13	0.56
29-Aug	24.9	0.98	5.27	1.39	3.94	1.04	2.62	0.69
31-Aug	17.8	0.70	4.48	1.18	3.16	0.83	1.84	0.49
2-Sep[‡]	18.3	0.72	4.86	1.28	3.51	0.93	2.16	0.57
7-Sep	35.8	1.41	4.05	1.07	5.89	1.56	7.97	2.10
13-Sep	45.7	1.80	12.29	3.25	6.62	1.75	4.05	1.07
16-Sep	24.9	0.98	4.73	1.25	3.51	0.93	2.30	0.61
19-Sep	23.1	0.91	6.13	1.62	4.08	1.08	2.86	0.76
22-Sep	19.1	0.75	5.13	1.36	3.78	1.00	2.43	0.64
26-Sep	33.0	1.30	7.67	2.03	5.94	1.57	4.05	1.07
3-Oct	42.9	1.69	7.02	1.85	7.02	1.85	4.59	1.21
4-Oct	10.7	0.42	2.43	0.64	0.00	0.00	0.00	0.00
Totals	**965**	**38.0**	**162**	**42.8**	**135**	**35.6**	**113**	**29.9**

[†]Water volumes do not include 98 mm (3.9 in) of precipitation.

[‡]Sweet corn was harvested between 9/2 and 9/7.

Table 5. Calculated reference ET (ETrs) and average water volumes applied to each plant during the 2006 season at three irrigation treatments with the low-tech, low-cost drip irrigation system[†‡].

			Irrigation Treatment Level					
	ETrs		High (105% ETrs)		Med. (85% ETrs)		Low (65% ETrs)	
Date	**mm**	**in**	**Liter**	**Gallon**	**Liter**	**Gallon**	**Liter**	**Gallon**
31-May	67.8	2.67	3.84	1.01	3.84	1.01	3.84	1.01
2-Jun	19.8	0.78	3.84	1.01	3.84	1.01	3.84	1.01

5-Jun	29.2	1.15	1.92	0.51	1.92	0.51	1.92	0.51
7-Jun	22.4	0.88	3.84	1.01	3.84	1.01	3.84	1.01
12-Jun	40.9	1.61	4.80	1.27	4.80	1.27	4.80	1.27
15-Jun	35.8	1.41	0.80	0.21	0.64	0.17	0.48	0.13
18-Jun	28.7	1.13	2.34	0.62	1.92	0.51	1.44	0.38
20-Jun	20.6	0.81	1.60	0.42	1.28	0.34	0.96	0.25
22-Jun	17.5	0.69	2.46	0.65	2.02	0.53	1.54	0.41
25-Jun	31.5	1.24	1.54	0.41	1.25	0.33	0.96	0.25
27-Jun	18.8	0.74	3.62	0.96	3.30	0.87	2.46	0.65
30-Jun	26.7	1.05	3.94	1.04	3.14	0.83	2.50	0.66
1-Jul	10.2	0.4	3.84	1.01	2.88	0.76	2.24	0.59
5-Jul	33.5	1.32	2.69	0.71	2.30	0.61	1.79	0.47
12-Jul	41.4	1.63	3.20	0.85	2.56	0.68	1.92	0.51
14-Jul	17.8	0.7	3.04	0.80	2.72	0.72	1.92	0.51
17-Jul	30.5	1.2	3.84	1.01	2.88	0.76	1.92	0.51
19-Jul	18.8	0.74	5.76	1.52	4.48	1.18	3.68	0.97
21-Jul	17.0	0.67	4.80	1.27	4.00	1.06	3.20	0.85
24-Jul	25.7	1.01	6.78	1.79	5.92	1.56	4.48	1.18
26-Jul	16.8	0.66	5.28	1.39	3.84	1.01	2.88	0.76
28-Jul	14.2	0.56	4.80	1.27	3.94	1.04	3.04	0.80
31-Jul	22.9	0.9	4.80	1.27	3.84	1.01	2.88	0.76
2-Aug	14.2	0.56	5.28	1.39	4.32	1.14	3.36	0.89
3-Aug	8.6	0.34	4.16	1.10	2.72	0.72	1.60	0.42
8-Aug	31.5	1.24	2.40	0.63	2.08	0.55	1.44	0.38
10-Aug	13.2	0.52	5.76	1.52	5.12	1.35	4.16	1.10
14-Aug	30.7	1.21	8.32	2.20	6.82	1.80	5.38	1.42
16-Aug§	12.7	0.5	3.78	1.00	3.20	0.85	2.66	0.70
18-Aug	15.7	0.62	3.97	1.05	3.20	0.85	2.46	0.65
21-Aug	23.6	0.93	7.25	1.92	5.88	1.55	4.41	1.17
24-Aug	19.1	0.75	8.48	2.24	6.52	1.72	4.41	1.17
28-Aug	29.2	1.15	8.58	2.27	7.84	2.07	4.66	1.23
Totals	**807**	**31.8**	**141**	**37.3**	**119**	**31.4**	**93**	**24.6**

†Data up to 28 August 2006. Tomato and chile pepper season not yet complete.
‡Water volumes do not include 75 mm (2.9 in) of precipitation.
§Sweet corn harvest – 17 August 2006.

System Evaluation

With careful management and close supervision, the irrigation system performed satisfactorily under the conditions of this study. After starting each irrigation sequence, the system was inspected for leaks, lateral kinking, emitter clogging, etc. While emitter clogging was of primary concern, it was usually not a significant problem except after rain storms when the emitter outlets would become clogged from pointing down into mud puddles. Most other times, less than 5% of the emitters became clogged. These emitters were removed, blown out and reinstalled, or replaced. It appeared that some clogging could be prevented by flushing the laterals as they filled. This was done by pulling off a short sleeve of drip line that was slipped over the folded lateral end (serving as an end cap) and allowing water to free-flow for a few seconds. Also, when installing the emitters, the opening was pointed downstream inside the lateral.

Since, in our situation, the irrigation water was relatively clean and free of sediments, filter clogging was usually not a problem during this study. Because our filter housings were transparent, however, algal growth occasionally occurred in the filters, especially after N fertigations. In these cases, the housing was removed and the filter screen flushed. The addition of about 120 ml (0.5 cup) of household bleach was added to the filled reservoirs occasionally to prevent algal build-up.

Drip tape kinking, primarily due to expansion and contraction with temperature changes, occurred but was a minor nuisance. To minimize the effects of these changes, and to avoid irrigating through hot drip tape, all irrigations were applied in early morning. The drip line was cool and contracted at this time so kinking was minor. To insure unrestricted water flow, the laterals were pulled taught from the ends to straiten and eliminate kinks at the beginning of each irrigation. Landscape staples or U-shaped wires were used to hold the laterals in place when empty.

Leakage was nominal with the system when first installed and remained minimal throughout the study period. Occasionally however, gophers chewed holes into drip laterals that were in close proximity to their burrow entrances. Traps were used to control these occasional rodents and affected drip lines were repaired with couplers.

As with all irrigation systems, water distribution uniformity (DU) is a primary concern when evaluating the efficiency of drip irrigation systems. During this study, an estimate of DU was obtained by measuring the output (flow rates) from several system emitters using a small glass beaker (which was slipped carefully under the emitter), a watch with a second hand (to keep track of the outflow duration), and a graduated cylinder (to precisely measured the emitter-output water during that duration). Usually, measurements were taken from the 1st, 18th, 26th, and 40th (last) emitter along several selected laterals within each block of the plot layout. In 2006, mean single-emitter flow rate averaged 35.6 ml min^{-1} from 27 June to 14 August and did not differ significantly between three sampling dates (Table 6). The coefficient of variation (*cv*) increased (from 0.116 to 0.166) and the low-quarter DU decreased (from 0.85 to 0.79) however, (Table 6) indicating an increase in flow variability between emitters with time. All laterals were cut shorter by 6 m (20 ft) on 21 August (after the sweet corn was harvested) eliminating 15 emitters from the ends of each lateral. Mean flow rate of the remaining emitters increased to 49.4 ml min^{-1} (from 35.3 ml min-1 on 14 August), cv decreased to 0.135 (from 0.166 on 14 August), and DU increased to 0.84 (from 0.79 on 14 August). Total block flow rate decreased to 889 L hr^{-1} or 3.92 gpm (from 1017 L hr^{-1} or 4.48 gpm).

Table 6. Average measured flow rate, coefficient of variation (*cv*), and low-quarter distribution uniformity (DU_{lq}) from emitters on four dates in 2006.

Date	Number of Samples	Mean Flow Rate (ml min-1)	*cv*†	DU_{lq}‡
27 June	40	36.4	0.116	0.85
21 July	26	35.1	0.158	0.82
14 August	40	35.3	0.166	0.79
29 August	26	49.4§	0.135	0.84

†Mean divided by standard deviation

‡Distribution uniformity (low quarter) = avg. measured output of lowest ¼ of emitters divided by the avg. output of all emitters
§ Laterals were shortened from 20 m (65 ft) to 14 m (45 ft) after corn harvest.

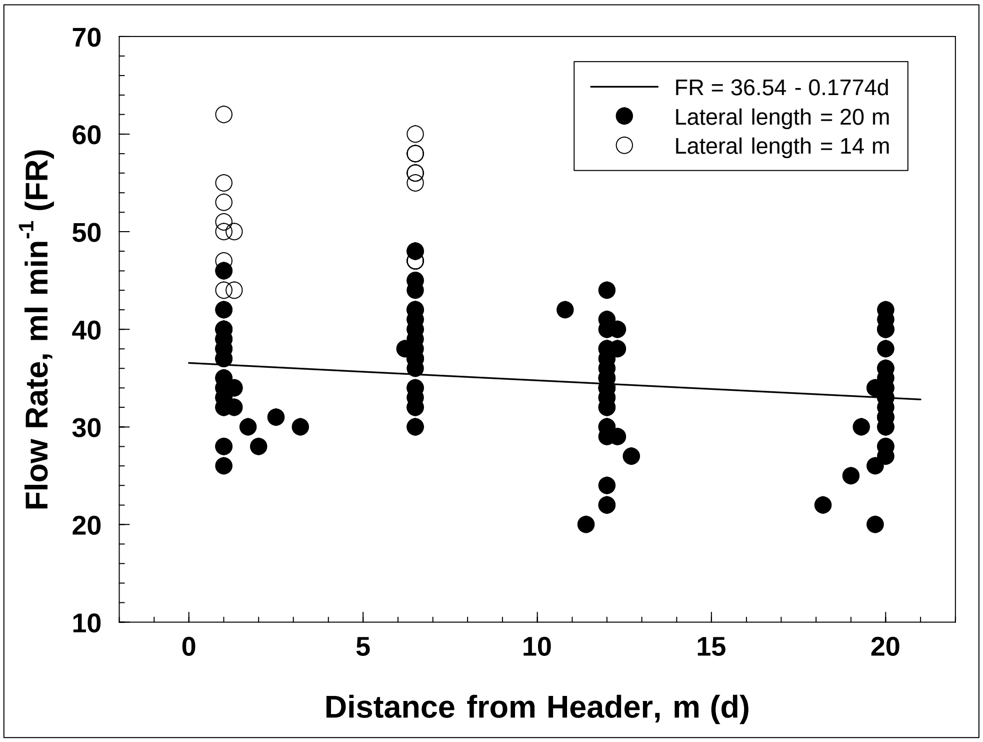

Figure 6. Measured flow rates of emitters located different distances down various laterals from the sub-main header during 2006 prior to, and after shortening each lateral by 6 m (15 emitters).

Note: The linear function applies only to the measurements taken before shortening the lateral. No significant trend was noted in measurements after shortening the lateral.

Prior to shortening the laterals in 2006, there was a trend of decreasing emitter flow-rate with increasing distance of the emitter away from the sub-main header (Figure 6). The regression function indicates a linear decrease in flow rate from 36.4 ml min^{-1} at the 1st emitter (1 m from the header) to 33.0 ml min^{-1} at the last emitter (20 m from the header).

Crop Production

Since the low-tech drip system evaluated in this study is designed for use on small plots (generally less than 0.5 ha or 1 acre), crop yields and components of yields are expressed in units per 100 m^2 (or 1000 ft^2). These terms may be more meaningful to the small-scale farmer than per ha (or per acre) units.

Sweet Corn

In 2005, there was no significant difference between sweet corn yields or components of yield at the different irrigation treatments (Table 7). The number of ears per plant, ears per unit area, weight per ear, and total yield, however, were all greater at the highest irrigation level (106 L per plant or 100% ETrs) than at the medium (75% ETrs) and low (50% ETrs) irrigation levels (95 and 83 L per plant, respectively). The number of marketable ears produced per 100 m^2 averaged 606 (563 per 1000 ft^2) and total yield of unhusked ears averaged 208 kg 100 m^{2-1} or 427 lbs per 1000 ft^2 (Table 7).

Table 7. Yield and yield components of sweet corn (cv. Incredible) at three, drip-irrigated water application levels in 2005†.

Component of Yield and Yield	Irrigation Level, L/plant (gal/plant)‡			
	106 (28)	95 (25)	83 (22)	Mean
Plants per 100 m^2 (plants/1000 ft^2)	302 (281)	316 (293)	344 (320)	321 (298)
Ears per plant	2.2	1.8	1.7	1.9
Ears per 100 m^2 (ears/1000 ft^2)	658 (611)	581 (540)	578 (537)	606 (563)
Weight per husked ear, g (oz)	266 (9.4)	249 (8.8)	252 (8.9)	255 (9.0)
Yield with husk, kg 100 m^{2-1} (lbs/1000 ft^2)	226 (464)	204 (418)	195 (399)	208 (427)
Yield w/o husk, kg 100 m^{2-1} (lbs/1000 ft^2)	172 (354)	146 (298)	148 (303)	155 (317)

†ANOVA indicated no significant difference between treatments for any factor.
‡Irrigation between planting (17 June) and harvest (8 Sept.). Does not include 60 mm (2.37 in.) of precipitation

In 2006, sweet corn yield and the number of husked ears per plant and per unit area were significantly lower at the lowest level of irrigation (88 L per plant or 65% ETrs) than at the medium (111 L or 85% ETrs) and high (133 L or 105% ETrs) irrigation levels (Table 8).

Table 8. Yield and yield components of sweet corn (cv. GSS-0966) at three, drip-irrigated water application levels in 2006†.

Component of Yield and Yield	Irrigation Level, L/plant (gal/plant)‡			
	133 (35)	111 (29)	88 (23)	Mean
Plants per 100 M^2 (plants/1000 ft^2)	367 (340) ab	356 (330) b	369 (342) a	364 (338)
Ears per plant	2.0 a	1.9 a	1.5 b	1.8
Ears per 100 M^2 (ears/1000 ft^2)	743 (690) a	665 (618) a	561 (521) b	656 (610)
Weight per husked ear, g (oz)	199 (7.0)	196 (6.9)	184 (6.5)	193 (6.8)
Yield with husk, kg 100 M^{2-1} (lbs/1000 ft^2)	203 (416) a	177 (363) a	141 (289) b	174 (356)
Yield w/o husk, kg 100 M^{2-1} (lbs/1000 ft^2)	148 (303) a	131 (268) ab	104 (213) b	128 (262)

†Means in a row followed by the same letter within a row are not significantly different at the 5% level of confidence based on Tukey's HSD means comparison.
‡Irrigation between planting (1 June) and harvest (17 Aug.). Does not include 73 mm (2.89 in.) of precipitation.

While ear weight is important for marketability, sweet corn is usually sold by number of ears. When ear number data from both years are combined, a highly significant linear relationship was found between the number of marketable ears produced per unit area and the volume of water applied per plant (Figure 7).

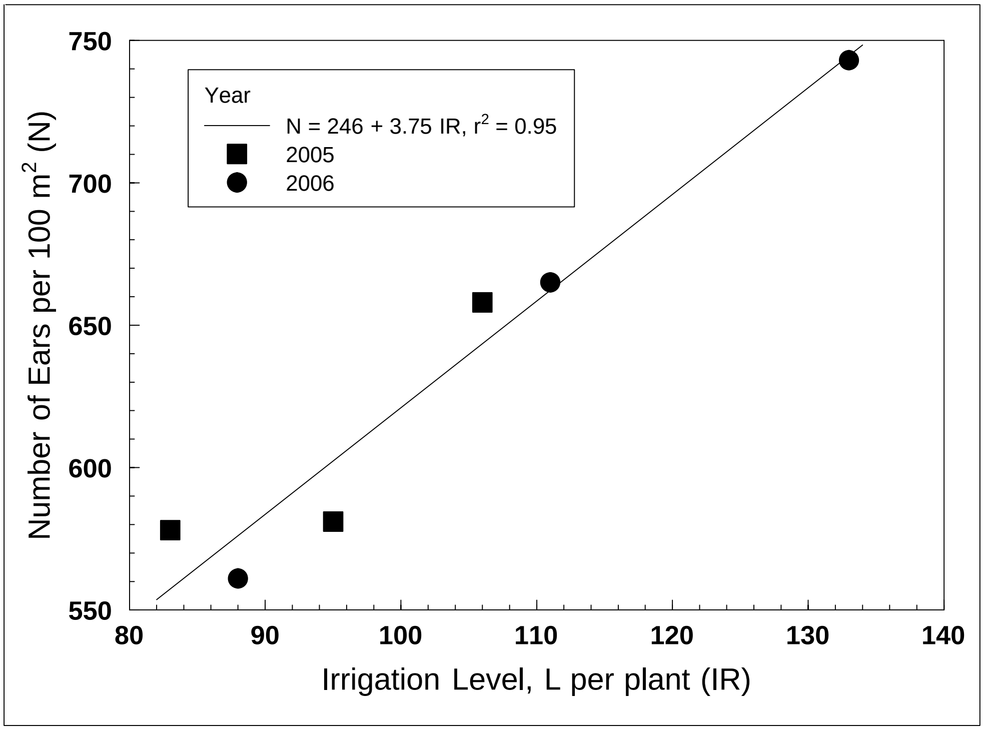

Figure 7. Marketable number of sweet corn ears produced per 100 m2 as related to the volume of water applied per plant with the drip system in 2005 and 2006.

Tomato

In 2005, a suspected case of curly top virus killed about 60% of the tomato plants so data for that year are not presented in this report.

In 2006, no significant difference was found among irrigation treatments between marketable yields, fruit weights per plant, weights per fruit, and numbers of fruit per plant (Table 9). Marketable yield (up to 29 August) averaged 491 kg 100 M^{2-1} (Table 9). While this yield is about half of that achieved for the same cultivar when grown under full sprinkler irrigation in previous studies at this site, the 2006 tomato season is still in progress.

Table 9. Yield and yield components of tomato (cv. Rowpac) at three drip-irrigation levels in 2006[†‡].

Component	Irrigation Level, L/plant (gals/plant)[§]			
	141 (37)	**119 (31)**	**93 (25)**	**Mean**
Marketable Yield, kg 100 M^{2-1} (lbs/1000 ft^2)	512 (1050)	478 (980)	484 (992)	**491 (1007)**
Fruit Weight per Plant, kg (lbs)	2.70 (6.0)	2.65 (5.8)	2.64 (5.8)	**0.62 (1.37)**
Weight per Fruit, g (oz)	143 (5.0)	140 (4.9)	127 (4.5)	**137 (4.8)**
No of Mkt. Fruit per plant	19.1	18.8	20.9	**19.6**

[†]Anova indicated no significant difference between treatments for any factor.
[‡]Cumulative data up to 29 August 2006. Tomato season still in progress.
[§]Irrigation between planting (24 May) and 29 August. Does not include 75 mm (2.9 in) of precipitation.

Chile Peppers

In 2005, marketable yields of Big Jim peppers were significantly greater at the highest irrigation level (163 L per plant) than at the lowest (114 L per plant), 363 kg m^{2-1} vs. 208 kg m^{2-1}, respectively (Table 10). There was also a decreasing trend in chile weight per plant and number of marketable fruit per plant with decreased irrigation in this cultivar and the Joe E. Parker cultivar in 2005. There were no significant differences between pepper yields or components of yields among irrigation treatments in the Big Jim and R. Naky cultivars in 2006 (Table 11) but the harvest season is not yet completed.

Table 10. Yield and yield components of two chile pepper varieties at three, drip-irrigation levels in 2005[†].

Component	**Big Jim**				**Joe E. Parker**			
	Irrigation Level, L/plant (gals/plant)[‡]				**Irrigation Level, L/plant (gals/plant)[‡]**			
	163 (43)	**136 (36)**	**114 (30)**	**Mean**	**163 (43)**	**136 (36)**	**114 (30)**	**Mean**
Market Yield, kg 100 M^{2-1} (lbs/1000 ft^2)	363 (744) a	246 (537) ab	208 (427) b	**278 (569)**	354 (725)	269 (551)	246 (505)	**287 (588)**
Chile Weight per Plant, kg (lbs)	1.68 (3.7)	1.27 (2.8)	1.00 (2.2)	**1.32 (2.9)**	1.72 (3.8)	1.41 (3.1)	1.22 (2.7)	**1.45 (3.2)**
Weight per Green Fruit, g (oz)	54 (1.9)	48 (1.7)	48 (1.7)	**51 (1.8)**	51 (1.8)	51 (1.8)	48 (1.7)	**51 (1.8)**
No of Mkt. Fruit per plant	33	27	22	**27**	34	29	26	**30**

[†]Means followed by the same letter within a row within a variety are not significantly different at the 5% level of confidence based on Tukey's HSD means comparison. The absence of letters indicates no significant difference between treatments for that factor.
[‡]Irrigation between planting (13 June) and final harvest (21 October). Does not include 89 mm (3.5 in) of precipitation.
[§]Assuming 100% plant survival.

Table 11. Yield and yield components of two chile pepper varieties at three, drip-irrigation levels in 2006[†‡].

Component	**Big Jim**				**R. Naky**			
	Irrigation Level, L/plant (gals/plant)[§]				**Irrigation Level, L/plant (gals/plant)[§]**			
	141 (37)	**119 (31)**	**93 (25)**	**Mean**	**141 (37)**	**119 (31)**	**93 (25)**	**Mean**
Market Yield, kg 100 M2-1 (lbs/1000 ft2)	232 (476)	231 (474)	233 (478)	**232 (476)**	268 (549)	243 (498)	259 (531)	**257 (527)**
Chile Weight per Plant, kg (lbs)	0.62 (1.36)	0.61 (1.34)	0.62 (1.37)	**0.62 (1.37)**	0.71 (1.57)	0.65 (1.44)	0.69 (1.52)	**0.68 (1.50)**
Weight per Green Fruit, g (oz)	61 (2.2)	64 (2.3)	66 (2.3)	**64 (2.3)**	50 (1.8)	52 (1.8)	55 (1.9)	**52 (1.8)**
No of Mkt. Fruit per plant	10.1	9.6	9.6	**9.8**	14.4	12.8	12.7	**13.3**

[†]Anova indicated no significant difference between treatments for any factor.
[‡]Cumulative data up to 29 August 2006. Chile pepper season still in progress.
[§]Irrigation between planting (24 May) and 29 August. Does not include 75 mm (2.9 in) of precipitation.

Summary

This study has shown that a simple, low-cost drip irrigation system can be effectively used to irrigate small vegetable plots. Sweet corn, tomato, and chile pepper production was acceptable as compared to those from similar sprinkler-irrigated trials conducted at this study site. Sweet corn yields increased with increasing irrigation indicating that, for maximum production, irrigations should be scheduled at 100% (or more) of ETrs. Water-use efficiencies (yield per water applied) were about 2 times greater in drip irrigated chile peppers than in those grown under sprinkler irrigation in previous years at this site.

There are limitations on the number of plants that can be reasonably irrigated from a reservoir that must be filled with buckets by hand. During this study, for example, flow rates to irrigate more than 400 plants were in excess of 15 L (4 gal) per minute. At this rate, a 200 L (55 gal) reservoir (effective capacity of 170 L or 45 gals laid on side) would empty in less than 15 minutes and would have to be filled about 4 times a day during peak plant water-use periods (1.5 L or 0.4 gal per plant per day). We used pressurized irrigation lines controlled by float valves to keep our reservoirs full but this may be beyond the means of small, resource poor farmers.

The information collected during this study provides some guidelines that might be used when planning a small drip-irrigated plot.