

Evaluation of Compact Bed Geometries for Water, Nutrient, and Economic Efficiency for Drip-Irrigated Tomato and Pepper

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Deliverable 5: Final Report

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Background

This report fulfills the requirements of Deliverable 5 for the project “Evaluation of Compact Bed Geometries for Water, Nutrient, and Economic Efficiency for Drip-Irrigated Tomato and Pepper.” The goal of the proposed project was to evaluate different bed geometries regarding water use, nutrient uptake, and economic sustainability for drip-irrigated tomato and pepper production in Florida. Specific objectives include:

- 1) Evaluation of compact bed geometries against the conventional bed for two seasons of single-row tomato grown at a commercial farm under typical grower management practices.
- 2) Evaluation of compact bed geometries against the conventional bed for double-row pepper at a commercial farm under typical grower (2 drip tapes) and alternative (1 drip tape) management practices for two seasons.
- 3) Evaluation of rainfall retention and flood reduction potential of compact and conventional beds for fall planted crops.
- 4) Dissemination of project results to vegetable growers, agencies, and other stakeholders.

This report summarizes Deliverable 5 of this study and includes:

- 1) Irrigation volume, fertilizer inputs, and yield for the pepper experiment conducted in the spring-fall of 2015 and 2016.
- 2) Irrigation volume, fertilizer inputs, and yield for the tomato experiment conducted in the spring-fall of 2015 and 2016.
- 3) Hydrologic data from a mulched field for quantifying water retention aspects of compact bed geometries.
- 4) Final recommendations for the addition of compact bed plasticulture to the best management practice program.

Deliverable 5: Final Report

Pepper

The field experiments were conducted during the fall growing seasons of 2015 and 2016 at C&B Farms, Clewiston, Florida. A time table of significant cultural practices for both seasons is shown in Table 1.

Table 1: Significant cultural practices during the bed geometry experiments for the fall 2015 and 2016 bell pepper growing seasons.

Season	Bedding	Planting	First Harvest	Last Harvest
Fall 2015	Aug. 21 th , 2015	Oct. 2 nd , 2015	Nov. 30 th , 2015	Feb. 8 th , 2016
Fall 2016	Sept. 29 th , 2016	Oct. 15 th , 2016	Dec. 22 nd , 2016	Mar. 1 st , 2017

The conventional bed geometry (32 in [width] × 9 in [height]) with two drip tapes, and three compact bed geometry treatments; Compact 1 (24 in × 10 in, 2 tapes), Compact 2 (24 in × 10 in, 1 tape), and Compact 3 (18 in × 12 in, 1 tape) were implemented in a complete randomized block design. Figure 1 illustrates the difference between the conventional and Compact 3 bed geometries and highlights the differences in bed width and number of drip tape.

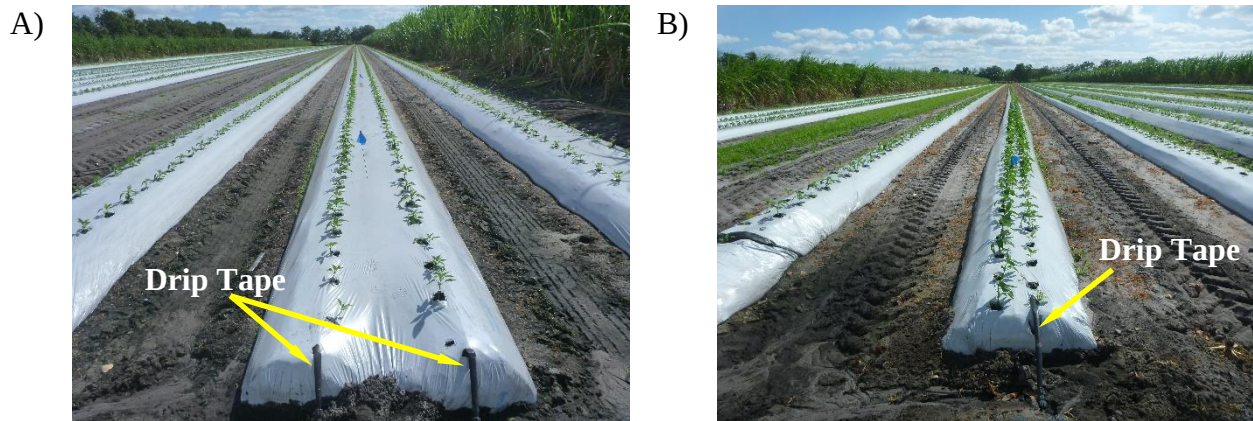


Figure 1: Bell pepper crop two weeks after transplanting seedlings. A) Conventional bed geometry (32 in x 9 in) with two drip tapes. B) Compact 3 bed geometry (18 in x 10 in) with single drip tape.

Three methods of fertilizer application were used in each treatment: 1) granular fertilizer within beds, broadcasted just prior to bedding (“cold mix”); 2) granular fertilizer applied at the

time of bedding, in concentrated band(s) on top of beds beneath the plastic mulch (“hot mix”); and 3) fertigation. Fertigation scheduling was kept the same across all treatments, with conventional and Compact 1 treatments receiving double the amount of dissolved nutrients through fertigation compared with Compact 2 and 3 treatments. The nutrients applied across both years and through each method are shown below in Table 2 and the totals are in Table 6. On average, Compact 2 and 3 received 103 lb/acre and 26 lb/acre less N and P₂O₅, respectively through fertigation compared to the conventional and Compact 1 treatments.

Table 2: Partial nutrients amounts and application methods for conventional and compact bed geometry treatments for fall 2015 and 2016 bell pepper growing seasons.

Year	Bed Geometry	Liquid Fertilizer (lb/acre)			Solid Fertilizer (lb/acre)		
		N	P ₂ O ₅	K ₂ O	N	P ₂ O ₅	K ₂ O
2015	Conventional (32 in x 9 in, 2 tapes)	184	46	184	182	126	304
	Compact 1 (24 in x 10 in, 2 tapes)	184	46	184	182	126	304
	Compact 2 (24 in x 10 in, 1 tape)	92	23	92	205	135	307
	Compact 3 (18 in x 12 in, 1 tape)	92	23	92	205	135	307
2016	Conventional (32 in x 9 in, 2 tapes)	227	57	227	182	126	304
	Compact 1 (24 in x 10 in, 2 tapes)	227	57	227	182	126	304
	Compact 2 (24 in x 10 in, 1 tape)	114	28	114	205	135	307
	Compact 3 (18 in x 12 in, 1 tape)	114	28	114	205	135	307

All other cultural practices were the same for all treatments and were conducted by the grower cooperator. Pepper is traditionally a 13-week transplant crop; however, the grower cooperator permitted 19-20 weeks for the growing period to get six harvests. Fruits harvested were graded from sub-plot areas on a bi-weekly basis over the harvest period. Each sub-plot had 26 consecutive plants that were representative of pepper plants in associated treatments. Statistical analyses of fruit yield were conducted using analysis of variance (ANOVA) with treatment as the only factor, with a statistical program (R, version 3.3.1). Yields for the four treatments ranged from 23,758- 26,527 lb/acre (950- 1,061 boxes/acre) in 2015 and from 38,969- 45,465 lb/acre (1,559- 1,819 boxes/acre) in 2016 (Figure 2). The 2015 season produced less fruit due to the unseasonably high rainfall (>10 inches) in January 2016 and as a result high instance of waterborne diseases (e.g. *Phytophthora* blight) (Figure 2). No statistical difference in crop yield was detected between treatments (p-values; 0.84 and 0.406, respectively).

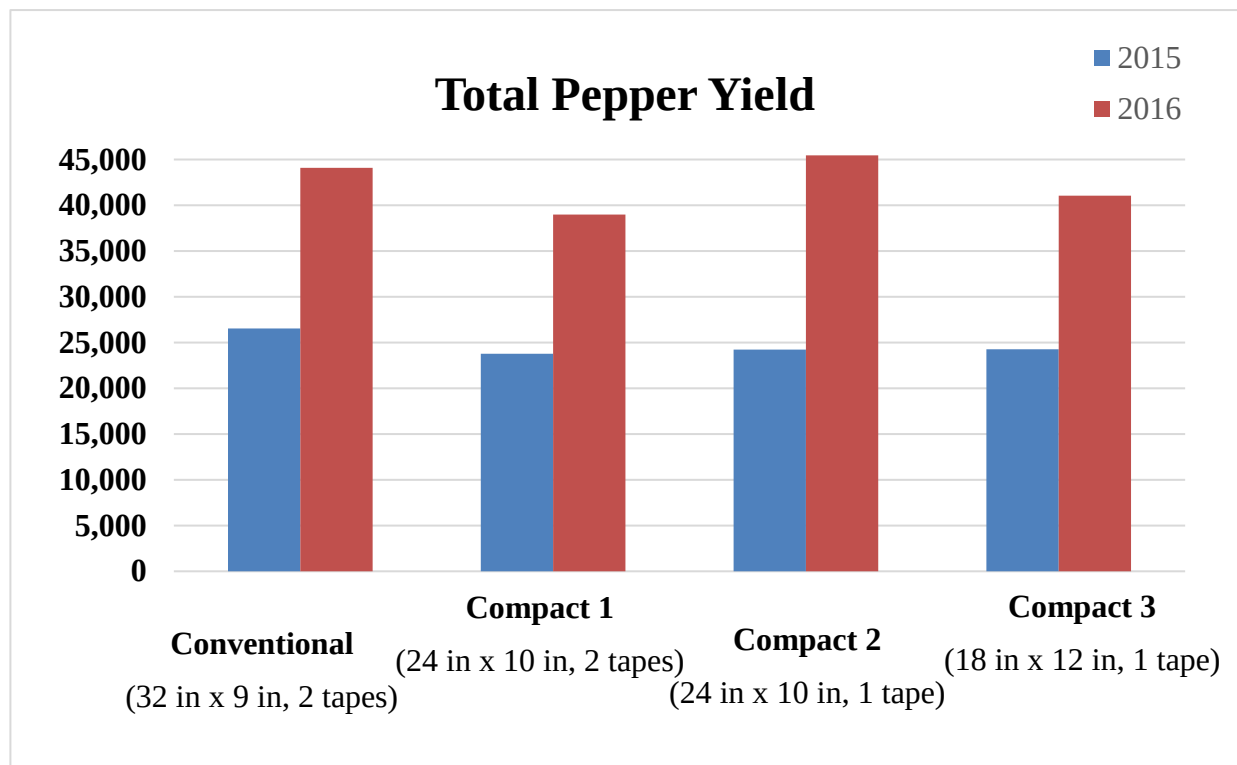


Figure 2: Total yield from the fall 2015 and 2016 bell pepper growing seasons.

Leaf and soil solution samples were collected for each treatment on a bi-weekly basis. Leaf tissue samples were analyzed for nitrogen (N), phosphorous (P), and potassium (K) concentrations. Leaf tissue analyses results (Table 3) showed no statistical difference between treatments for N (p-value= 0.70 and 0.99), P (p-value = 0.12 and 0.26) in 2015 and 2016, respectively, and for K (p-value= 0.11) in 2016. K (p-value = 0.0001) concentration showed statistically significant difference between treatments in 2015. All leaf tissue nutrient (N-P-K) concentrations were at or above minimum levels required for optimum yield across both years.

Table 3: Average leaf tissue concentration for conventional and compact bed geometry treatments for the fall 2015 and fall 2016 pepper growing seasons.

Year	Bed Geometry Treatment	Nutrients (%)		
		N	P	K
2015	Conventional (32 in x 9 in, 2 tapes)	3.87	0.33	5.07
	Compact 1 (24 in x 10 in, 2 tapes)	4.04	0.30	4.26
	Compact 2 (24 in x 10 in, 1 tape)	4.02	0.30	4.90
	Compact 3 (18 in x 12 in, 1 tape)	3.90	0.29	4.42
2016	Conventional (32 in x 9 in, 2 tapes)	4.24	0.36	4.13
	Compact 1 (24 in x 10 in, 2 tapes)	4.39	0.38	4.46
	Compact 2 (24 in x 10 in, 1 tape)	4.55	0.42	4.34
	Compact 3 (18 in x 12 in, 1 tape)	4.60	0.40	4.21

Bulk soil nutrient samples were collected on March 2nd, 2016 and March 8th, 2017. Soil samples were collected in the plant line to the 12-inch depth for three of the six replications in 2016 and for all four replications in 2017. Soil samples were sent to Analytical Research Laboratory (ARL), University of Florida for analyses of NO_x-N, NH₄-N, total kjeldahl nitrogen

(TKN), total P, Mehlich-3-P, -K, -Al (aluminum) and –Fe (iron). The results showed statistically higher $\text{NH}_4\text{-N}$ concentration in Compact 3 during the fall season of 2015. The rest of the soil nutrients showed no statistical difference (p-value= 0.12- 0.99) in the concentration (Table 4).

Table 4: Average soil nutrient concentration for conventional and compact bed geometry treatments at the end of fall 2015 and 2016 pepper growing seasons.

Year	Bed Geometry Treatment	Nutrient Concentration [mg/kg]							
		$\text{NO}_x\text{-N}$	$\text{NH}_4\text{-N}$	TKN	TP	P	K	Al	Fe
2015	Conventional (32 in x 9 in, 2 tapes)	43.7	0.65	981	729	259	25.8	96.0	69.2
	Compact 1 (24 in x 10 in, 2 tapes)	83.2	0.67	932	855	227	75.5	62.1	58.3
	Compact 2 (24 in x 10 in, 1 tape)	51.4	0.59	916	773	250	35.2	65.5	64.3
	Compact 3 (18 in x 12 in, 1 tape)	42.7	1.03*	926	740	259	29.6	55.3	57.0
2016	Conventional (32 in x 9 in, 2 tapes)	114	5.6	1152	634	249	172	168	70
	Compact 1 (24 in x 10 in, 2 tapes)	104	1.73	1146	623	200	172	141	67
	Compact 2 (24 in x 10 in, 1 tape)	67.8	1.31	1171	533	213	40.0	148	69
	Compact 3 (18 in x 12 in, 1 tape)	118	1.78	1168	688	269	50.2	161	68
*statistically significant									

For the 2016 pepper season, soil solution nutrient concentration data (Table 5) showed a statistically significant difference in $\text{NO}_x\text{-N}$ concentrations at the 6-inch and 12-inch depth (p-value= 0.003 and 0.01, respectively). At both depths, the $\text{NO}_x\text{-N}$ concentration for Compact 2 was higher than Conventional and Compact 1. This higher value is likely a result of dilution; Compact 2 and 3 reduced 50% less irrigation (1 tape) volume compared to Conventional and Compact 1 (2 tapes). Due to differences in irrigation volumes, differences in concentrations can not be used to infer water quality effects. For quantifying the nutrient loads to groundwater (and surface water), measurements will need to be combined with water flux predictions from a hydrologic model.

Table 5: Average soil solution concentration for conventional and compact bed geometry treatments at 6-inch and 12-inch depths for fall 2016 pepper growing season.

Bed Geometry Treatment	0-6 in (ppm)		6-12 in (ppm)	
	$\text{NO}_x\text{-N}$	$\text{NH}_4\text{-N}$	$\text{NO}_x\text{-N}$	$\text{NH}_4\text{-N}$
Conventional (32 in x 9 in, 2 tapes)	7.27	0.93	6.36	1.24
Compact 1 (24 in x 10 in, 2 tapes)	9.27	11.51	10.03	10.4
Compact 2 (24 in x 10 in, 1 tape)	45.29*	10.62	24.90*	4.93
Compact 3 (18 in x 12 in, 1 tape)	31.34	6.70	18.27	0.98
*statistically significant				

Irrigation monitoring was conducted from October 2, 2015 to February 23, 2016 and again from October 21st, 2016 to March 20th, 2017 and the totals are shown in Table 6. Irrigation volumes were measured using flowmeters installed in the main irrigation riser for each treatment. In 2015, for the Conventional and Compact 1 treatments (2 tapes), the average irrigation volume applied was 9.11 acre-in (247,373 gallons) and for Compact 2 and 3 treatments, the average irrigation volume applied was 4.56 acre-in (123,822 gallons). In 2016, for the conventional and Compact 1 treatments (2 tapes), the average irrigation volume applied was 14.78 acre-in (401,336 gallons) and for Compact 2 and 3 treatments, the average irrigation volume applied was

8.57 acre-in (232,710 gallons). The first season in 2015 required significantly less water application due to unseasonably high rainfall in January and February of the year. Overall, irrigation volume for the compact beds with one tape was 45% less than the conventional and compact beds with two tapes without any adverse impact on yield. Reduced irrigation volume for the compact beds represents a significant water savings for the compact beds.

Table 6: Total irrigation volume, nutrient, and yield for conventional and compact bed geometry treatments for fall 2015 (six harvests) and 2016 (six harvests) bell pepper growing season.

Year	Bed Geometry	Irrigation Volume (ac-in)	Fertilizer (lb/acre)			Yield (lb/ac)
			N	P ₂ O ₅	K ₂ O	
2015	Conventional (32 in x 9 in, 2 tapes)	9.11	366	172	488	26,527
	Compact 1 (24 in x 10 in, 2 tapes)	9.11	366	172	488	23,758
	Compact 2 (24 in x 10 in, 1 tape)	4.56	297	158	399	24,223
	Compact 3 (18 in x 12 in, 1 tape)	4.56	297	158	399	24,247
2016	Conventional (32 in x 9 in, 2 tapes)	14.78	409	183	531	44,101
	Compact 1 (24 in x 10 in, 2 tapes)	14.78	409	183	531	38,969
	Compact 2 (24 in x 10 in, 1 tape)	8.57	319	163	421	45,465
	Compact 3 (18 in x 12 in, 1 tape)	8.57	319	163	421	41,064

Tomato

The tomato (round) experiments were conducted during the fall growing seasons of 2015 and 2016 at a commercial farm near Immokalee, Florida. The timing of important cultural practices are shown in Table 7.

Table 7: Significant cultural practices during the bed geometry experiment for the fall (2015 and 2016) tomato growing season.

Event Type	Bedding	Planting	First Harvest	Last Harvest
Fall 2015	Sept. 3 rd , 2015	Oct. 8 th , 2015	Dec. 23 rd , 2015	Jan. 19 th , 2016
Fall 2016	Sept. 9 th , 2016	Oct. 8 th , 2016	Dec. 19 th , 2016	Jan. 17 th , 2017

The conventional bed geometry (30 in [width] × 8 in [height]) (Figure 3A) and three compact bed geometry treatments; Compact 1 (24 × 10 in), Compact 2 (18 in × 12 in), Compact 3 (16 in × 12 in) (Figure 3B) were implemented in an incomplete randomized block design.

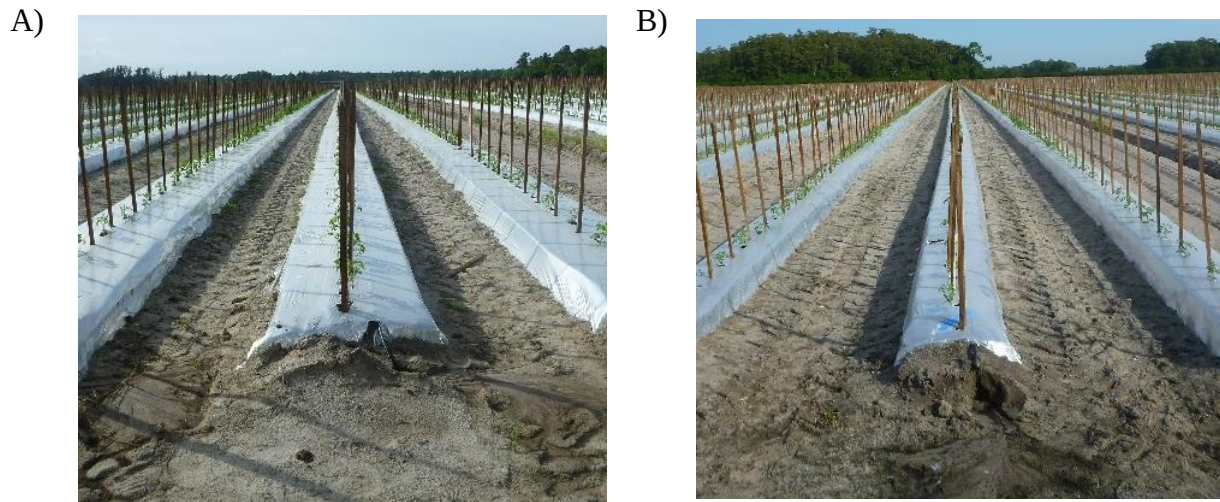


Figure 3: Tomatoes observed two weeks after transplant. A) The conventional (30 in × 8 in) treatment. B) The Compact 3 (16 in × 12 in) treatment.

Similar to pepper, fertilizer was applied to all treatments using three methods; “cold mix”, “hot mix”, and fertigation. Fertigation scheduling was the same for all treatments. Nutrients applied across both years and through each method are shown below in Table 8 and the totals are in Table 12. For 2016 experiment, grower cooperator agreed to try a reduced N (and K) fertilizer rate with the Compact 3 treatment considering higher potential nutrient use efficiency from the narrower and taller bed. There was a net reduction of 70 lb N/acre and 140 lb K₂O/acre applied to the Compact 3 treatment in 2016.

Table 8: Nutrient rate and formulation for conventional and compact bed geometry treatments for fall 2015 and 2016 tomato growing seasons.

Year	Bed Geometry	Liquid Fertilizer (lb/acre)			Solid Fertilizer (lb/acre)		
		N	P ₂ O ₅	K ₂ O	N	P ₂ O ₅	K ₂ O
2015	Conventional (30 in x 8 in, 1 tape)	156	41	166	204	120	418
	Compact 1 (24 in x 10 in, 1 tape)	156	41	166	204	120	418
	Compact 2 (18 in x 12 in, 1 tape)	156	41	166	204	120	418
	Compact 3 (16 in x 12 in, 1 tape)	156	41	166	204	120	418
2016	Conventional (30 in x 8 in, 1 tape)	130	0	259	204	120	418
	Compact 1 (24 in x 10 in, 1 tape)	130	0	259	204	120	418
	Compact 2 (18 in x 12 in, 1 tape)	130	0	259	204	120	418
	Compact 3 (16 in x 12 in, 1 tape)	130	0	259	134	120	278

All other cultural practices were the same for all treatments and were conducted by the grower cooperator. Tomato is traditionally a 13 week transplant crop; however, the grower

cooperator harvested after only 11 weeks. Yield data for three harvests were collected from sub-plots on a bi-weekly basis. Each sub-plot had 10 consecutive plants that were representative of tomato plants in associated treatments. A total of four sub-plots were used as marketable yield replications in each treatment. For three harvests, fruit were weighed and graded in the field by size (small, medium, large, extra-large) and fruit defects using a grading table. Statistical analyses were conducted with a statistical program (R, version 3.3.1) using ANOVA with treatment as the only factor. Marketable yields for the four treatments ranged from 35,008-44,746 lb/acre (1,400- 1,790 boxes/acre) in 2015 and 31,785- 44,536 lb/acre (1,271- 1,781 boxes/acre) in 2016 (Figure 4). No statistical differences in crop yields were detected between treatments for 2015 and 2016, respectively at $\alpha = 0.05$.

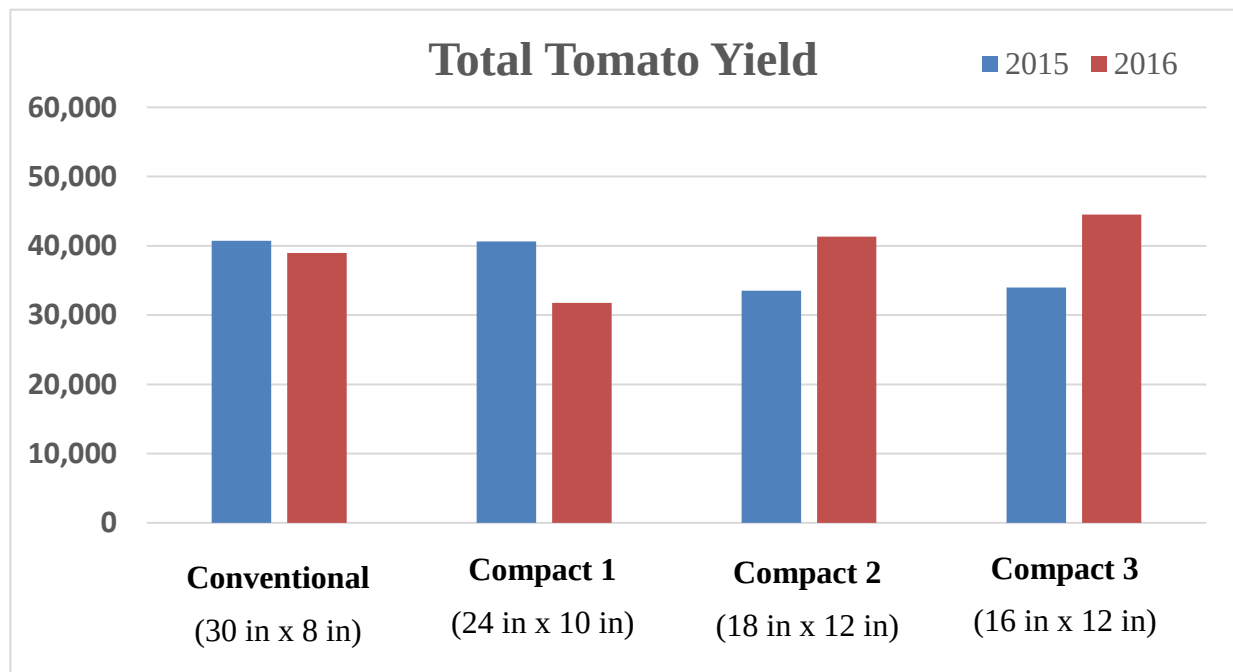


Figure 4: Total marketable yields from the fall 2015 and 2016 tomato growing seasons. Yields were not statistically different (p-value= 0.40 and 0.05, respectively for 2015 and 2016)

Leaf tissue analyses results (Table 9) showed no statistical differences between treatments for N (p-value= 0.72 and 0.99), P (p-value = 0.89 and 0.98), or K (p-value = 0.59 and 0.99) concentrations in 2015 and 2016, respectively. All leaf tissue nutrient (N-P-K) concentrations were at or above minimum levels required for optimum yield.

Table 9: Average leaf tissue concentration for conventional and compact bed geometry treatments for the fall 2015 and fall 2016 tomato growing seasons.

Year	Bed Geometry Treatment	Nutrients (%) [*]				
		N	P	K	Ca	Mg
2015	Conventional (30 in x 8 in)	4.30	0.48	2.56	-	-
	Compact 1 (24 in x 10 in)	4.34	0.46	2.47	-	-
	Compact 2 (18 in x 12 in)	4.35	0.45	2.61	-	-
	Compact 3 (16 in x 12 in)	4.16	0.49	2.61	-	-
2016	Conventional (30 in x 8 in)	4.16	0.37	2.50	3.75	0.59
	Compact 1 (24 in x 10 in)	4.21	0.39	2.55	3.92	0.60
	Compact 2 (18 in x 12 in)	4.05	0.39	2.49	3.85	0.57
	Compact 3 (16 in x 12 in)	3.96	0.39	2.53	3.75	0.56

* “-” not measured

Bulk soil nutrient samples were collected on January 21st, 2016, October 3rd, 2016 and Jan 17, 2017; around the start of the 2015 season, the start of the 2016 and end of the 2016 season, respectively. Soil samples were collected at two depths beneath the bed top (0-6 and 6-12 inch) for each of the four replications. Soil samples were sent to ARL for analyses of NO_x-N, NH₄-N, total kjeldahl nitrogen (TKN), total P, Mehlich-3-P, -K, -Al (aluminum) and -Fe (iron). Results showed a decrease in TKN for both sampled depths for all treatments (Table 10).

Table 10: Average soil nutrient concentration for conventional and compact bed geometry treatments at the end of fall 2015 and the start and end of fall 2016 tomato growing season.

Year	Bed Geometry Treatment	Nutrient Concentration [mg/kg]*							
		NO _x -N	NH ₄ -N	TKN	TP	P	K	Al	Fe
2015 Final	Conventional (30 in x 8 in)	24.8	0.50	438	353	141	24.5	88.3	50.4
	Compact 1 (24 in x 10 in)	30.3	0.57	446	342	118	53.7	71.2	42.1
	Compact 2 (18 in x 12 in)	16.6	0.76	404	343	129	129	77.1	44.3
	Compact 3 (16 in x 12 in)	8.19	0.54	447	368	139	123	86.8	45.5
2016 Start	Conventional (30 in x 8 in)	25.8	29.1	401	344	121	45.0	-	-
	Compact 1 (24 in x 10 in)	16.7	19.4	387	386	120	52.0	-	-
	Compact 2 (18 in x 12 in)	13.0	12.6	356	280	127	57.4	-	-
	Compact 3 (16 in x 12 in)	19.4	22.5	393	367	125	81.5	-	-
2016 Final	Conventional (30 in x 8 in)	7.90	0.40	318	290	99.3	25.3	43.4	72.7
	Compact 1 (24 in x 10 in)	3.93	0.51	356	353	107	38.6	35.8	74.9
	Compact 2 (18 in x 12 in)	3.90	0.50	361	366	92.8	33.9	35.2	62.6
	Compact 3 (16 in x 12 in)	3.37	0.41	357	386	112	26.3	41.4	71.5

* “-” not measured

Results for soil solution nutrient concentration data collected in 2016 (Table 11) showed statistically significant higher NO_x-N concentrations in the conventional bed treatment at the 6-inch (p value < 0.001) and 12-inch depth (p value < 0.0007).

Table 11: Average soil solution concentration for conventional and compact bed geometry treatments at 6-inch and 12-inch depths for fall 2016 tomato growing season.

Bed Geometry Treatment	0-6 in (ppm)		6-12 in (ppm)	
	NO _x -N	NH ₄ -N	NO _x -N	NH ₄ -N
Conventional (30 in x 8 in)	11.37*	0.44	9.71*	0.45
Compact 1 (24 in x 10 in)	2.76	0.37	2.25	0.45
Compact 2 (18 in x 12 in)	3.10	0.67	4.20	0.77
Compact 3 (16 in x 12 in)	2.56	0.48	2.39	0.37
*statistically significant				

Irrigation monitoring was conducted from October 2, 2015 to February 23, 2016 and again from October 21st, 2016 to March 20th, 2017 and the totals are shown in Table 12. Irrigation volumes were measured with flow meters installed at the main irrigation riser for each treatment. In 2015, for all treatments, total irrigation volume applied during the growing season (October 16th, 2015 - January 20th, 2016) was 9.98 acre-in (271,000 gallons) (Table 12). In 2016, for all treatments, total irrigation volume applied during the growing season (October 11th, 2016 - January 19th, 2017) was 8.97 acre-in (243,571 gallons) (Table 12).

Table 12: Total irrigation volume, nutrients, and yield data for conventional and compact bed geometry treatments for fall 2015 and 2016 tomato growing season.

Year	Bed Geometry Treatment	Irrigation Volume (ac-in)	Fertilizer (lb/ac)			Yield (lb/ac)
			N	P ₂ O ₅	K ₂ O	
2015	Conventional (30 in x 8 in)	9.98	370	161	584	42,795
	Compact 1 (24 in x 10 in)	9.98	370	161	584	44,746
	Compact 2 (18 in x 12 in)	9.98	370	161	584	35,008
	Compact 3 (16 in x 12 in)	9.98	370	161	584	36,934
2016	Conventional (30 in x 8 in)	8.97	333	120	677	39,025
	Compact 1 (24 in x 10 in)	8.97	333	120	677	31,785
	Compact 2 (18 in x 12 in)	8.97	333	120	677	41,382
	Compact 3 (16 in x 12 in)	8.97	263	120	537	44,536

Hydrologic Experiment

A hydrologic experiment was conducted at the research farm of the UF/IFAS Southwest Florida Research and Education Center, Immokalee, Florida to evaluate the bed geometries with regards to water retention. Conventional and compact bed geometries were installed in a field that consists of six adjacent plots (area = 0.6 ac) that are hydrologically isolated with a high density polyethylene liner. Prior to bed installation, all plots were leveled using laser-level controlled ejector-scraper equipment by a private contractor. The conventional bed geometry (32 in [width] x 8 in [height]) (Figure 5A) and the most compact bed geometry (16 in x 12 in)

(Figure 5B) were implemented randomly across the six plots (two treatments, three replications each). No irrigation or fertilizer was applied to the field, with rainfall being the only form of water input. Rainfall was measured by an on-site weather station which is part of the UF/IFAS Florida Automated Weather Network (FAWN) station located within 300 ft of the experimental plots.

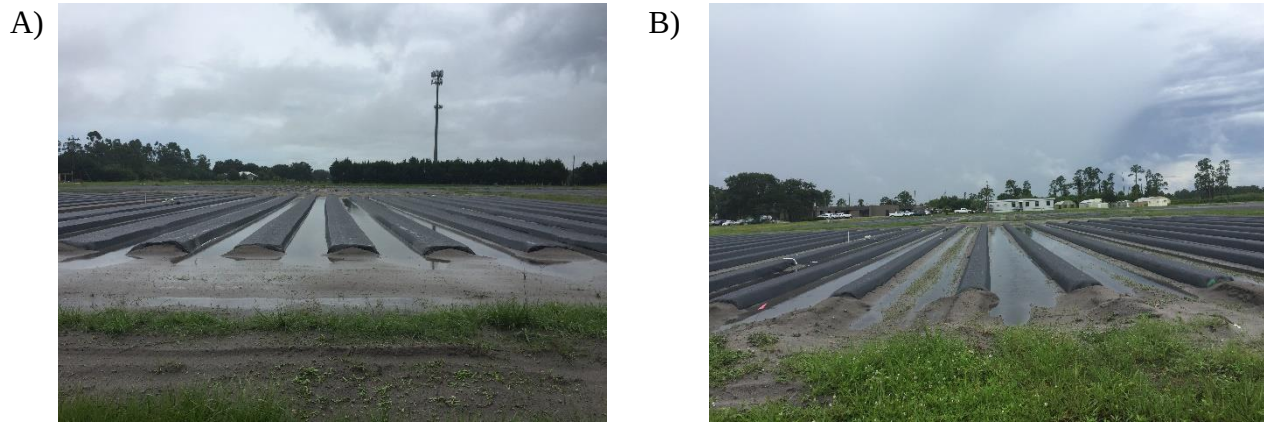


Figure 5: A) View of the conventional bed geometry (32 in $\times$ 6 in), with flood water (in row middle); B) View of the compact bed geometry (16 in $\times$ 12 in) with flood water in the row middles, but much below the bed top after the same rainfall event.

A single well was installed at the center of each plot to monitor water levels using a pressure transducer. Well casings were screened so both ground water and surface water levels can be monitored. Each plot was fitted with a drainage box that uses riser boards to control water drainage through drain tiles installed three feet (0.91 m) beneath the ground surface. A 90° v-notch was cut into the top board for each drainage box to mimic sharp crested weir flow. A pressure transducer was installed to measure water column height in the drainage box for each plot.

An example of instruments installed in the middle bed of each of the three replications for each treatment is shown Figure 6. Two 12 in (30 cm) soil moisture sensors were installed horizontally (side of the bed) at 6 in (15 cm) and 12 in. (30 cm) below the top of the bed. A third soil moisture sensor (10 cm, vertical) was installed in the center of the bed top to monitor soil moisture in the plant root zone. Soil moisture and water levels data collected over the summer and fall of 2017 were used to evaluate the differences in extent of saturation, ponding, and discharge from conventional and compact beds.

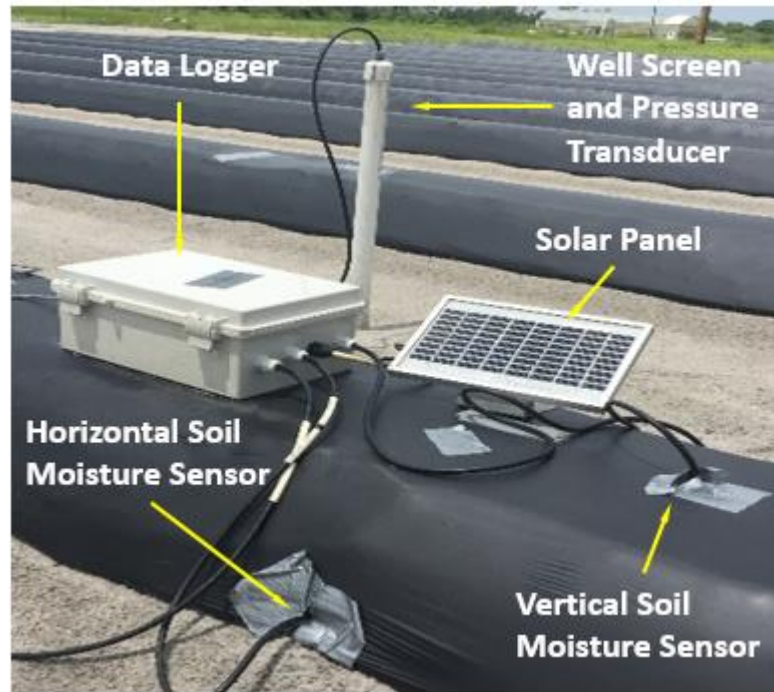


Figure 6: The instrumentation installed in each of the six plots.

The average soil moisture levels in the conventional bed were higher than the compact bed with lower soil moisture peaks in compact beds compared to the conventional beds (Figure 7). A quick reduction in soil moisture was also noticeable in compact beds after Hurricane Irma (September 15th, 2017) when the drainage network connected to the hydrologic experiment was not able to accept excess water due to pump failure on the farm. Hurricane Irma also caused 40-90% loss in plastic from the conventional beds, with compact beds losing only 0- 5% of plastic. Almost no damage of compact beds was a surprising discovery and shows an added advantage. It not only indicates the economic benefit of not having to re-bed the fields but also additional gains in having the produce when the prices are high after an extreme event. Input from stakeholders indicate that saving the beds would lead to almost \$2000/acre investment made in inputs (plastic, drip tape, pesticide, labor, fertilizer) for making the beds.

The average water table elevation across the compact treatments decreased more rapidly than the conventional treatment after the rainfall events (Figure 8). This may be due to additional 14

inches of row middle space causing increased soil water storage and evaporation. Hurricane Irma raised the water table significantly reducing the ability of excess water to discharge from the site.

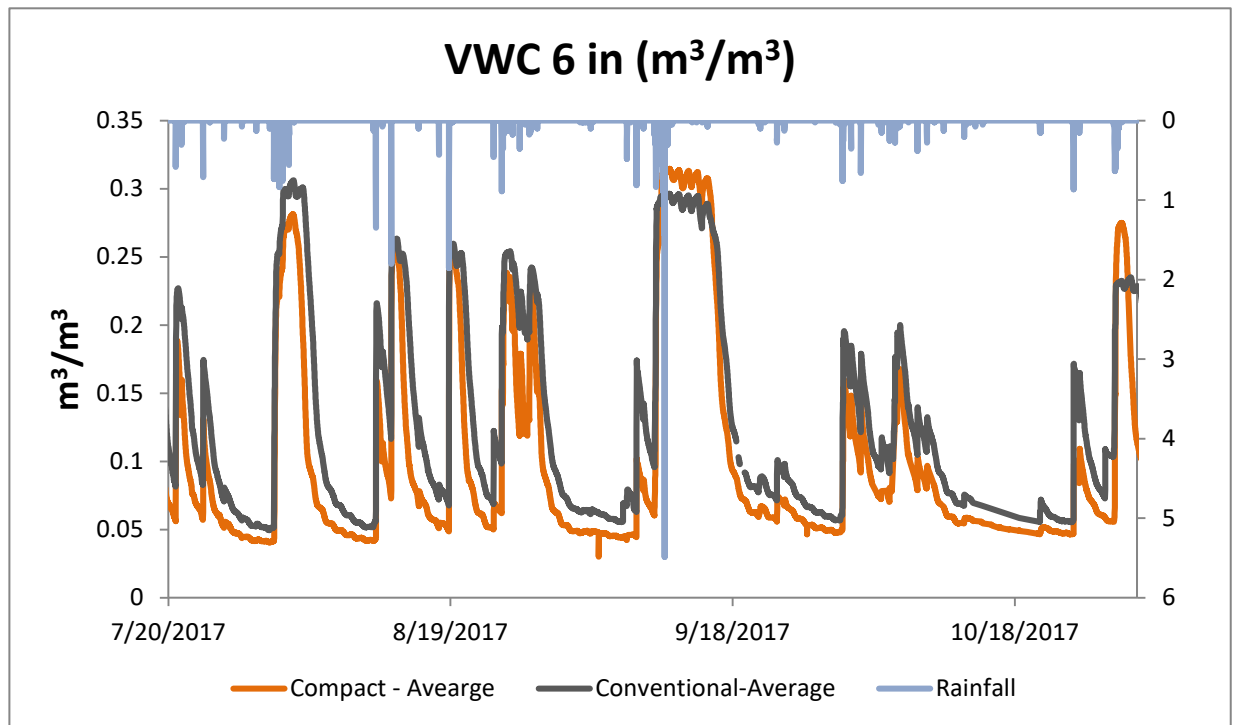


Figure 7: The treatment average soil moisture at the 6 in depth in the hydrologic experiment from July to October.

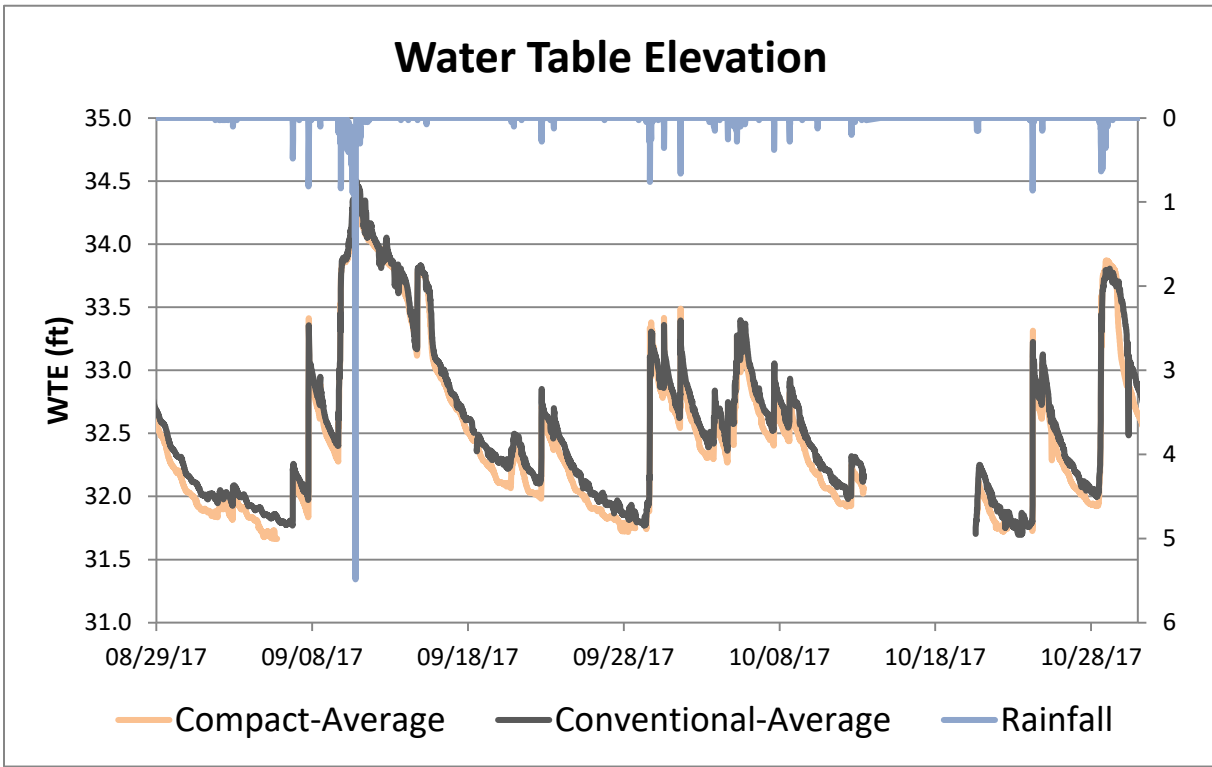


Figure 8: The treatment average water table elevation (WTE) in the hydrologic experiment from July to October 2017.

Figures 9 and 10 shows a closer look at the measured water table elevation and soil moisture at six inches from the top of the bed during a series of rainfall events from August 17th, 2017 to August 30th, 2017, respectively. The soil moisture directly after rainfalls peaked at lower levels in the top 6 inches (15 cm) of the compact beds and receded more rapidly than the conventional bed. This allows the soil moisture in the bed to return to field capacity ($\sim 0.08 \text{ m}^3/\text{m}^3$) within 2 days, while the conventional bed reached field capacity by 4th day after rainfall (Figure 9). Extended excessive wetting of the compact bed is likely to result in greater dissolution and leaching of dry fertilizer in the bed as well as on the top of the bed in two grooves. During moderate rainfall events ($<1 \text{ in}$), the water table elevation and soil moisture in the bed increase similarly in both the compact and conventional beds (Figure 10). The larger rainfall event on August 19th, both the conventional and compact beds water table peak at similar heights but the water table in the compact beds receded more rapidly than the water table in the conventional bed (Figure 10).

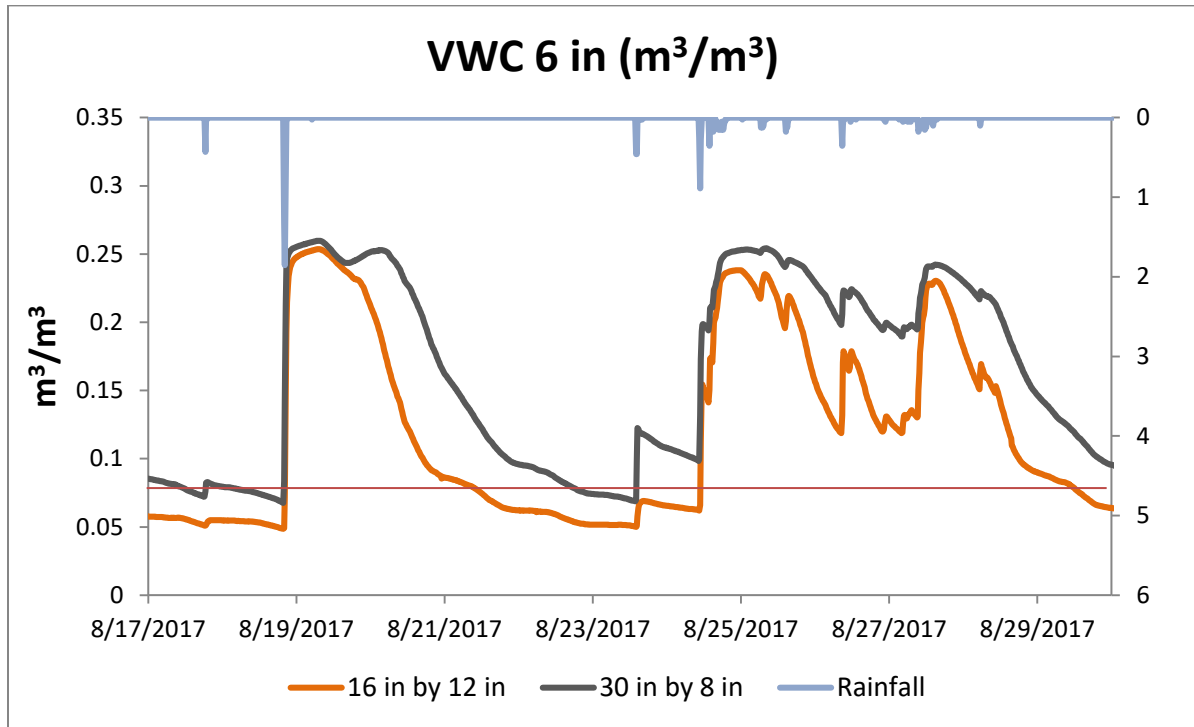


Figure 9: The average soil moisture (% by volume) at the 6 in depth in the compact (16 in x 12 in) and conventional (30 in x 8 in) beds during August 17- 30, 2017 period.

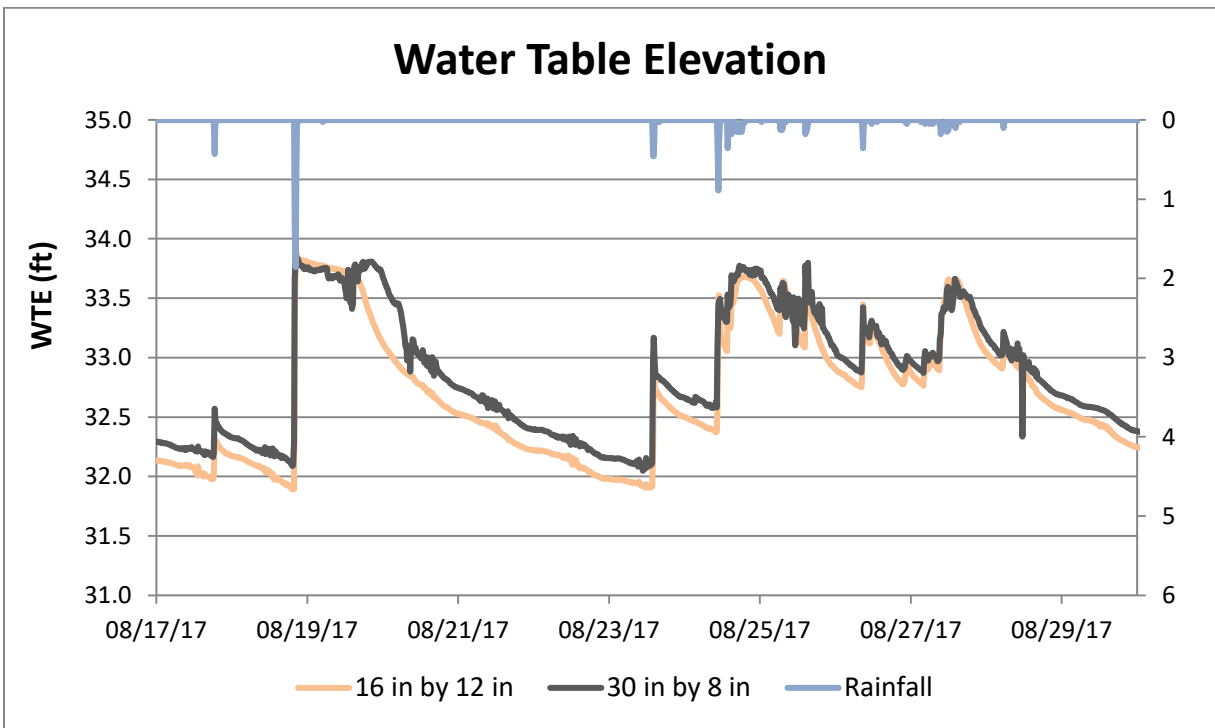


Figure 10: The average water table elevation in the compact (16 in x 12 in) and conventional (30 in x 8 in) beds during August 17- 30, 2017 period.

Summary and Recommendations

The compact beds did not reduce the yields significantly compared to conventional beds. The compact beds can reduce the inputs (soil fumigant, plastic), water and nutrient leaching, and runoff losses from tomato farms in Florida. The reduced cost of production and potential for water quality improvement makes this innovation a win-win by improving both economic and environmental sustainability. For pepper production system, the compact beds with one tape did not significantly reduce yields. Compact beds with one tape reduced the inputs (50% less irrigation volume, fumigant, fertilizer, plastic, drip tape) compared to conventional beds with two tapes. During the 2015-2016 pepper experiment, compact beds also experienced reduced incidence of *Phytophthora* blight, a waterborne disease with significant impact to production. As a result of this study, both tomato and pepper grower cooperators adopted the compact beds with pepper grower cooperator started using only one drip tape. The dissemination of results from this study, resulted in one of the major tomato producers in the state adopting the compact beds. Several tomato and pepper growers have reached out to the Principal Investigator during the stakeholder events to get more information to start testing the compact beds for their operations. To achieve large-scale adoption of compact beds in Florida, the use of systems approach where potential pest control, labor, and production (increased plant population) are evaluated in combination with yield and environmental benefits. One input received from the producers is that narrower and compact beds may improve labor efficiency due to reduced bending/stooping for different operations (e.g. staking, tying, harvesting), and reduced liability in applying fumigants through drip tape in compact beds. Labor availability is one of the most important issues faced by the vegetable and fruit producers in Florida and the nation. The compact beds have the potential to be a Best Management Practice (BMP). Cost share funds to help growers may help increase the adoption of the compact beds. The adoption of compact beds achieved to date in Florida as a result of this study is mainly a result its win-win aspect which can potentially increase the economic competitiveness of the state's tomato and pepper producers. Future studies should focus on quantifying the nutrient loads and pest control and labor efficiency aspects for tomato and pepper and designing and evaluating the compact beds for

other crop produced using raised-bed plasticulture (e.g. cucurbits). One accidental discovery of this study was almost no damage from Hurricane Irma for the most compact beds. Further evaluations of reduced risk of damage from hurricane due to reduced wind force and flooding effects are needed to further refine the bed geometry design to help the producers save their investment with large-scale water quality benefits derived from avoiding the re-bedding.