Wetland Reservoir Subirrigation Systems

(WRSIS)

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1) System Concept

A Wetland Reservoir Subirrigation System, or WRSIS for short, is an innovative agricultural water management system. WRSIS is comprised of a wetland and a water storage reservoir linked to a network of subsurface pipes used at different times to either drain or irrigate crops through the root zone. Runoff and subsurface drainage are collected from cropland into a constructed wetland. Natural processes in the wetland treat the water by removing some of the nutrients, pesticides, and sediment. The water is then routed to a storage reservoir and held until needed to subirrigate the crops during dry parts of the growing season. The storage reservoir also provides a further opportunity for sediment and adsorbed nutrients to settle out of the water. The integration of these components allows WRSIS to operate in a closed loop mode most of the time, thus restricting offsite water release (fig. 1). WRSIS can offer a number of benefits including (1) enhanced crop yields, (2) reduced offsite release of nutrients, pesticides, and sediment, (3) additional wetland vegetation and wildlife habitat, (4) more carbon sequestration in soil, and possibly, (5) decreased flooding potential downstream.

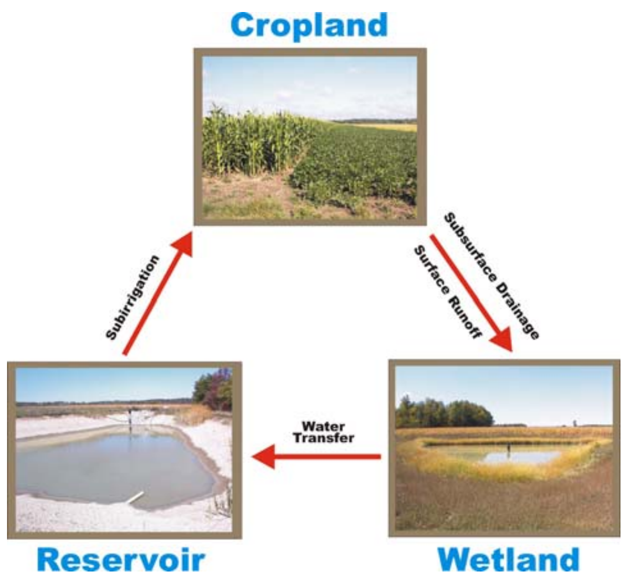

Figure 1. Schematic of the WRSIS concept showing interrelationship between wetland, reservoir, and subirrigated cropland components.

2) Initial Design Considerations

There are three WRSIS demonstration sites now in operation that are located in the northwest Ohio portion of the Maumee River Basin, one each in Defiance, Fulton, and Van Wert Counties (fig. 2). All have been in operation long enough to experience seven to eight complete growing seasons. Key advantages for the Fulton and Van Wert County locations were that they already had some of the needed WRSIS infrastructure installed, including storage reservoirs and a functioning subsurface drainage system.

Figure 2. Map showing WRSIS test site locations.

In fields where subirrigation is planned, since the water table is to be maintained at a substantially higher level than with conventional subsurface drainage, it is often necessary to design the drain spacing using a high drainage coefficient of 38 to 51 mm (1.5 to 2 in.) per day in order to remove water from the soil quickly enough during heavy or prolonged rainfall events. The consequence of using a high drainage coefficient for design purposes is a smaller spacing between drain lines for subirrigated fields, typically 33% to 50% less than what is used in fields having only subsurface drainage. In addition to allowing faster water removal while in drainage mode, a smaller spacing is also important in providing a more uniform water distribution in the soil during subirrigation. For reasons just discussed, new drain lines at both the Fulton and Van Wert County sites were placed between the old ones already present and then integrated into the pre-existing subsurface drainage system. Control plot(s) having subsurface pipe for drainage only were included at each site for comparison with crop yields obtained through subirrigation.

Subirrigation requirements were established through model simulations with the computer program, DRAINMOD. From this, the size of the storage reservoir at the Defiance County site was determined based on the irrigation water needed for crops in eight out of every ten years. The existing reservoirs at the other two locations did not meet optimal storage requirements, however, other water sources were available which could be used for subirrigation, including a ground water well at the Van Wert County site and a local stream at the Fulton County site.

The wetland at the Van Wert County site was constructed initially to hold the 2 year, 24 hour storm event runoff and subsurface drainage from all 20 ha (50 acres) of the encompassing watershed. In northwest Ohio, a storm event of this magnitude provides approximately 66 mm (2.6 in.) of rainfall. During summer of 2003, the wetland at the Van Wert County site was re-engineering into a single wetland/reservoir complex to provide greater water storage capacity. The designed wetland storage capacities at the other two sites were somewhat less than that needed to totally capture a 2 year, 24 hour magnitude rainfall event. Should the need arise, all three locations were built with the capability to allow direct offsite release of water from either the wetland or storage reservoir. Although similar in concept, design details differ among the three WRSIS locations.

3) WRSIS Demonstration Site Descriptions

Defiance County, Ohio

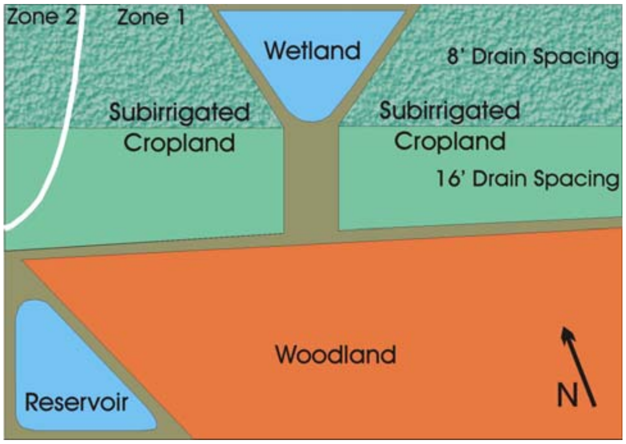

Figure 3. Defiance County WRSIS site schematic. The control plots with conventional drainage treatments are not shown.

Construction of the Defiance County, Ohio site occurred during June 1995, principally with volunteer contractors and donated material during an Ohio Land Improvement Contractors Association field exhibition. This location contains two 1.4 ha (3.5 acre) subirrigated fields and 8.1 ha (20 acres) of cropland with various conventional drainage treatments. Runoff and subsurface drainage are funneled into a 0.12 ha (0.30 acre) wetland having a storage capacity of 700 m^3 (185,000 gal) (fig.3). A 2.4 m (8 ft) wide bench at an elevation coinciding with the permanent pool position was excavated along one side of the Defiance County wetland in spring 1999, providing additional wildlife/vegetation habitat and better water treatment capability. After detention within the wetland, water is routed through an adjacent concrete sump, containing two 0.75 kW (1 hp) submersible pumps, to a 0.16 ha (0.39 acre) reservoir having 2950 m^3 (780,000 gal) of storage. Water held in the reservoir is used for subirrigation of corn and soybeans during periods when rainfall alone is not sufficient to meet crop demand.

Although both subirrigated fields are down-gradient from the reservoir, a 0.37 kW (0.5 hp) submersible pump located in a concrete sump next to the reservoir is used to enhance flow rate.

Subsurface drain pipes at all three WRSIS sites were installed at a nominal depth of 0.76 to 0.91 m (2.5 to 3 ft) beneath the surface. Half of the 2.8 subirrigated hectares (7 acres) at the Defiance County site contain 10 cm (4 in.) diameter corrugated plastic tubing (CPT) drain line spaced 2.4 m (8 ft) apart, and the other half has 10 cm (4 in.) diameter CPT drains spaced 4.9 m (16 ft) apart (fig. 3). The site is mostly covered by Paulding clay (mesic Typic Haplaquepts) with some Roselms silty clay (mesic Aeric Ochraqualfs) also present. From particle size analysis of samples taken at the surface, percent sand was 0% to 11%, silt ranged from 34% to 50%, and the amount of clay was between 48% and 66%.

Saturated horizontal hydraulic conductivity values measured within the soil profile (0 to 0.8 m [0 to 2.8 ft]) with a velocity permeameter ranged from 7×10^{-6} cm/s (0.01 in./hour) to 2×10^{-5} cm/s (0.03 in./hour). These are dense, very low permeability clayey materials which hinder water transfer from the drain pipe to the soil during subirrigation, in turn making it difficult to maintain the target range of water table depths (25 cm [10 in.] at the drain and 46 - 51 cm [18 - 20 in.] midway between drains). In comparison to the 4.9 m (16 ft) spacing, the 2.4 m (8 ft) spacing is better adapted for consistently keeping ground water levels within the desired range, but expected crop yield increases may not be enough to offset the cost of having to install twice the amount of drain pipe. Initially, two hydraulic control structures, one for each subirrigated field, were installed to regulate ground water levels. A wet area within the northwest corner of the west subirrigated field required installation of an additional hydraulic control structure in September of 1999. By doing this, the west field is now divided into two separate zones for water table management (fig. 3). Capital costs for WRSIS construction at the Defiance County site totaled $44,700 U.S.

Fulton County, Ohio

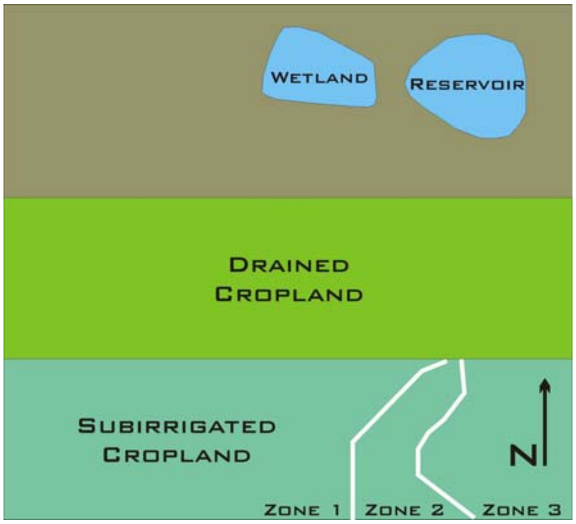

Figure 4. Fulton County WRSIS site schematic.

The Fulton County, Ohio site has two 8.1 ha (20 acre) fields, one that is subirrigated and the other a control plot with drain pipe for subsurface drainage only (fig. 4). Drain pipes within the subirrigated field are spaced about 4.6 m (15 ft) apart, with two newer 10 cm (4 in.) diameter corrugated plastic tubing drain lines placed between each of the existing drains comprised of 10 cm (4 in.) diameter clay tile. The control plot contains only the clay tile lines and the spacing is 13.7 m (45 ft). To regulate the subirrigated field ground water levels, three hydraulic control structures were installed. This provides three separate water table management zones within the subirrigated field (fig. 4).

Subsurface drainage from both fields is routed by gravity to a 0.57 ha (1.4 acre) wetland having a storage capacity of 3790 m^3 (1.0 million gal). There is very little surface runoff that enters the wetland. Water transfer between the wetland and a 0.64 ha (1.57 acre), 8706 m^3 (2.3 million gal) capacity reservoir occurs via a 3.7 kW (5 hp) submersible pump or a 1.5 kW (2 hp) submersible pump, both located within an adjacent concrete sump. Either pump can also be used to route water to the field when the system is in subirrigation mode. A stream running between the wetland and reservoir provides additional water supply for subirrigation.

The Fulton County, Ohio WRSIS site was completed by local contractors during spring 1996 at a total capital cost of $60,100 U.S. Corn and soybeans are grown predominantly on Nappanee loam (mesic Aeric Ochraqualfs). From particle size analysis of samples taken at the surface, percent sand was 17% to 66%, silt ranged from 12% to 37%, and the amount of clay was between 20% and 46%. Saturated horizontal hydraulic conductivity values measured with a velocity permeameter ranged from 4 x 10^{-4} cm/s (0.6 in./hour) near the surface to 7 x 10^{-5} cm/s (0.1 in./hour) through the rest of the soil profile down to a depth of 1.2 m (4.0 ft).

Van Wert County, Ohio

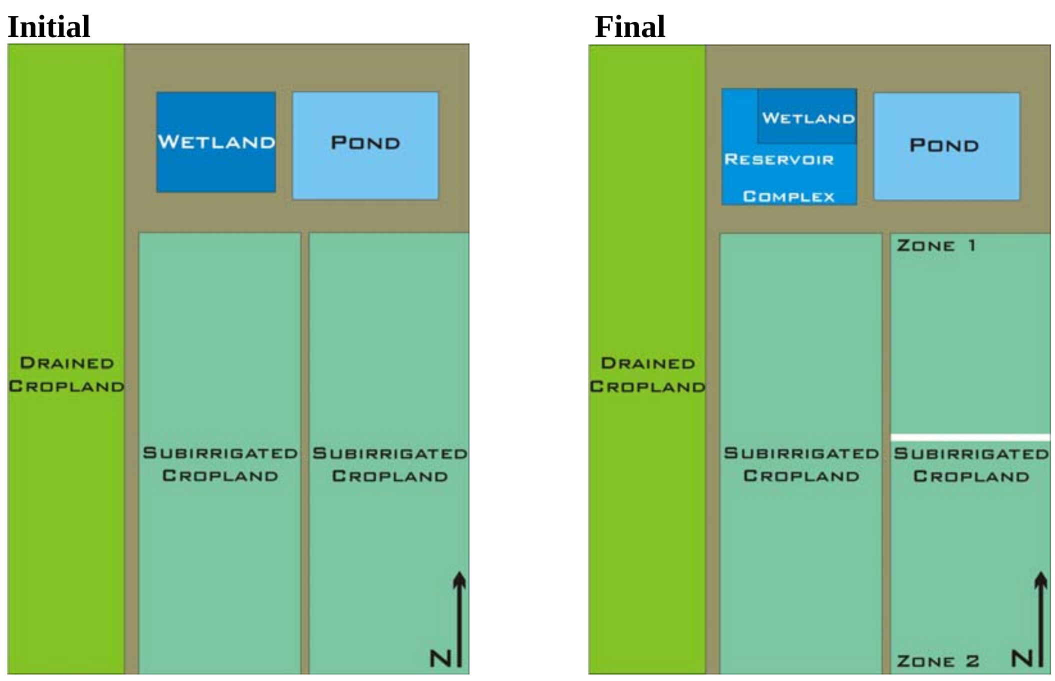

Figure 5. Van Wert County WRSIS site schematic.

Local contractors completed Van Wert County WRSIS site construction in fall 1996 at a total capital cost of $86,300 U.S. This site has Hoytville clay (mesic Mollic Ochraqualfs) covering three 6.1 ha (15 acre) fields, two that are subirrigated, and one with buried pipe used for subsurface drainage only (fig. 5). From particle size analysis of samples taken at the surface, percent sand was 2% to 36%, silt ranged from 18% to 41%, and the amount of clay was between 47% and 56%. Saturated horizontal hydraulic conductivity values measured with a velocity permeameter ranged from 4 x 10^{-4} cm/s (0.6 in./hour) near the surface to 2 x 10^{-4} cm/s (0.3 in./hour) through the rest of the soil profile down to a depth of 1 m (3.3 ft).

As with all the WRSIS sites, subsurface drain pipes were installed at a nominal depth of 0.76 to 0.91 m (2.5 to 3 ft) beneath the surface. Drain lines within the two subirrigated fields have a spacing distance of 5.3 m (17.5 ft), and older 10 cm (4 in.) diameter clay tile pipe alternates with newer 10 cm (4 in.) diameter corrugated plastic tubing. The control plot has only the clay tile drain lines which are spaced 10.7 m (35 ft) apart. At the start, two hydraulic control structures, one for each subirrigated field, were installed to regulate shallow ground water levels. However, much like the Defiance County WRSIS site, a wet area in the north end of the east subirrigated field necessitated placement of an additional hydraulic control structure in June 1999. Consequently, the east subirrigated field is now partitioned into north and south zones for water table management purposes (fig. 5).

Initially, surface and subsurface drainage from all 18.2 ha (45 acres) of corn and soybean cropland were routed, via two 1.11 kW (1.5 hp) submersible pumps contained in a concrete sump, to a 0.79 ha (1.95 acre), 8710 m^3 (2.3 million gal) capacity wetland and then a 1.21 ha (3.0 acre), 12870 m^3 (3.4 million gal) capacity pond. In the summer of 2003, the wetland was converted to a wetland/reservoir complex comprised of a 0.36 ha (0.9 acre) wetland and a 0.85 ha (2.1 acre) reservoir. Within this complex, the wetland has a storage capacity of 3680 m^3 (1 million gal), and the total reservoir storage capacity is 28330 m^3 (7.5 million gal), of which

13550 m^3 (3.6 million gal) can be drained by gravity. The wetland and reservoir are connected via a 30 cm (12 in.) diameter pipe with water flow regulated by a hydraulic control structure. A shallow earth embankment extending out into the wetland from its southeast corner increases the residence time of water flowing from the inlet to the outlet. By doing this, wetland effectiveness for water treatment is improved. The sump is located directly south between the wetland/reservoir complex and the pond. A 0.75 kW (1 hp) submersible pump, also located in the concrete sump, is used for subirrigation. Besides the wetland/reservoir complex and the pond, a ground water well located at the site can also supply water for subirrigation.

4) WRSIS Climate Data (1996 - 2006)

Table 1: Mean Monthly Growing Season Climate Data Averaged Over the WRSIS Sites

Month	**Precip.$_{M}$**[1] **mm** (inches)	**PET$_{M:Corn}$**[2] **mm** (inches)	**PET$_{M:Soybeans}$**[2] **mm** (inches)	**Precip.$_{M}$ – PET$_{M:Corn}$ mm** (inches)	**Precip.$_{M}$ – ET$_{M:Soybeans}$ mm** (inches)
May	**91** (3.6)	**35** (1.4)	**30** (1.2)	**56** (2.2)	**61** (2.4)
June	**94** (3.7)	**97** (3.82)	**94** (3.7)	**-3** (-0.1)	**0** (0.0)
July	**92** (3.6)	**149** (5.9)	**141** (5.6)	**-57** (-2.2)	**-49** (-1.9)
August	**78** (3.1)	**122** (4.8)	**115** (4.5)	**-44** (-1.7)	**-37** (-1.5)
September	**81** (3.2)	**61** (2.4)	**52** (2.1)	**20** (0.8)	**29** (1.1)
Total	**436** (17.2)	**464** (18.3)	**432** (17.0)	**-28** (-1.1)	**4** (0.2)

[1] Data obtained from the NOAA - National Climate Data Center.
[2] Value calculated using NOAA – National Climate Data Center temperature data.

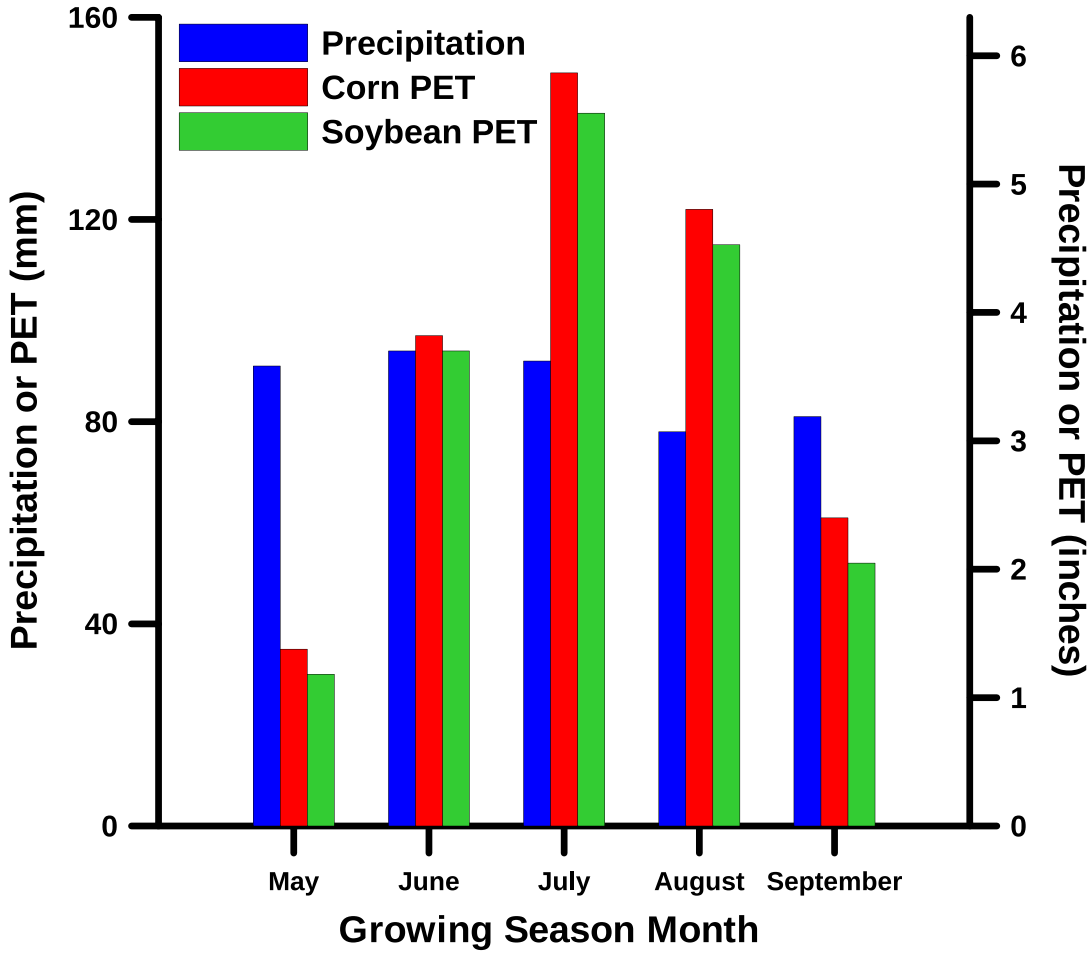

Figure 6. Average WRSIS precipitation and potential evapotranspiration (PET) data. As shown, even in an average year with regard to precipitation, there is still a substantial crop water deficit, based on PET, in the crucial growing season months of July and August.

Table 2: Total Growing Season (May 1 – Sept. 30) WRSIS Climate Data: 1996-2006

County	Year	Deviation from Average Precip.[1] **mm** (inches)	Precip. - PET_{Corn}[2] **mm** (inches)	Precip. - $PET_{Soybeans}$[2] **mm** (inches)
Defiance (Weather station is in city of Defiance, OH.)	**1997**	**250** (9.8)	**234** (9.2)	**265** (10.4)
	1998	**3** (0.1)	**-56** (-2.2)	**-21** (-0.8)
	1999	**-130** (-5.1)	**-195** (-7.7)	**-161** (-6.3)
	2000	**70**[3] (2.8[3])	**32**[3] (1.3[3])	**65**[3] (2.6[3])
	2001	**2** (0.1)	**-39** (-1.5)	**-6** (-0.2)
	2002	**-28** (-1.1)	**-98** (-3.9)	**-63** (-2.5)
	2003	**239** (9.4)	**217** (8.5)	**248** (9.8)
	2004	**176** (6.9)	**156** (6.1)	**188** (7.4)
	2005	**-88** (-3.5)	**-166** (-6.5)	**-131** (-5.2)
	2006	**69** (2.7)	**24** (0.9)	**56** (2.2)
Fulton (Weather station is in city of Wauseon, OH.)	**1996**	**-45** (-1.8)	**-48** (-1.9)	**-18** (-0.7)
	1997	**213** (8.4)	**219** (8.6)	**247** (9.7)
	1998	**63** (2.5)	**39** (1.5)	**71** (2.8)
	1999	**-41** (-1.6)	**-79** (-3.1)	**-47** (-1.9)
	2000	**203** (8.0)	**195** (7.7)	**226** (8.9)
	2001	**42** (1.7)	**14** (0.6)	**45** (1.8)
	2002	**-153** (-6.0)	**-215** (-8.5)	**-182** (-7.2)
	2003	**151** (5.9)	**142** (5.6)	**172** (6.8)
	2004	**57** (2.2)	**66** (2.6)	**96** (3.8)
	2005	**-51** (-2.0)	**-100** (-3.9)	**-67** (-2.6)
	2006	**208** (8.2)	**183** (7.2)	**214** (8.4)
Van Wert (Weather station is in city of Van Wert, OH.)	**1997**	**225** (8.9)	**220** (8.7)	**250** (9.8)
	1998	**68** (2.7)	**5** (0.2)	**41** (1.6)
	1999	**-108** (-4.3)	**-176** (-6.9)	**-141** (-5.6)
	2000	**174** (6.9)	**147** (5.8)	**179** (7.1)
	2001	**59**[3] (2.3[3])	**18**[3] (0.7[3])	**51**[3] (2.0[3])
	2002	**-78** (-3.1)	**-148** (-5.8)	**-113** (-4.5)
	2003	**390** (15.4)	**374** (14.7)	**405** (15.9)
	2004	**299** (11.8)	**302** (11.9)	**334** (13.2)
	2005	**-49** (-1.9)	**-117** (-4.6)	**-82** (-3.2)
	2006	**71** (2.8)	**39** (1.5)	**71** (2.8)

[1] Equals the growing season precipitation for a particular year minus the average growing season precipitation. Data obtained from the NOAA - National Climate Data Center.
[2] Equals the growing season precipitation for a particular year minus that year's calculated growing season potential crop evapotranspiration. Data obtained from the NOAA - National Climate Data Center.
[3] This value may be significantly underestimated due to missing data.

Note: Total growing season evapotranspiration was determined by adding May through September monthly values calculated using the following equation:

$$PET_{Crop} = k_C k_L PET_{Thornthwaite} \quad ,$$

where $\boldsymbol{PET_{Crop}}$ is the monthly potential evapotranspiration of a particular crop such as corn or soybeans, $\boldsymbol{k_C}$ is a crop adjustment coefficient, $\boldsymbol{k_L}$ is a latitude adjustment coefficient and

PET_{Thornthwaite} is the monthly potential evapotranspiration of grass based on Thornthwaite's method.

The following scale, based on deviation from average precipitation (**DAP**), was used as a gauge for overall growing season wetness/dryness:

extremely dry [**DAP** < **-114 mm** (-4.5 in.)]
dry [**-114 mm** (-4.5 in.) ≤ **DAP** < **-76 mm** (-3.0 in.)]
marginally dry [**-76 mm** (-3.0 in.) ≤ **DAP** < **-38 mm** (-1.5 in.)]
near average [**-38 mm** (-1.5 in.) ≤ **DAP** ≤ **38 mm** (1.5 in.)]
marginally wet [**38 mm** (1.5 in.) < **DAP** ≤ **76 mm** (3.0 in.)]
wet [**76 mm** (3.0 in.) < **DAP** ≤ **114 mm** (4.5 in.)]
extremely wet [**DAP** > **114 mm** (4.5 in.)]

The average growing season precipitation for Defiance, Fulton, and Van Wert Counties are 434 mm (17.08 in.), 431 mm (16.96 in.), and 445 mm (17.50 in.), respectively. The year 1996 was marginally dry in Fulton County. The 1999 growing season in the three counties ranged from marginally dry to extremely dry. The Fulton and Van Wert County sites were, respectively, extremely dry and dry in 2002. During the 2005 growing season the Defiance County site was dry, while the Fulton and Van Wert County sites were marginally dry. The Defiance County site in 2002 had a near average growing season in regard to precipitation. All three locations were either near average or marginally wet in 1998 and 2001; and wet or extremely wet in 1997, 2000, and 2003. For 2004, The Defiance and Van Wert County sites were extremely wet, while the Fulton County site was only marginally wet. In the 2006 growing season, the Fulton County site was extremely wet, while the Defiance and Van Wert County sites were marginally wet.

Table 3. WRSIS Growing Season Precipitation Classification

Year	Defiance County	Fulton County	Van Wert County
1996	-	marginally dry	-
1997	extremely wet	extremely wet	extremely wet
1998	near average	marginally wet	marginally wet
1999	extremely dry	marginally dry	dry
2000	marginally wet[1]	extremely wet	extremely wet
2001	near average	marginally wet	marginally wet[1]
2002	near average	extremely dry	dry
2003	extremely wet	extremely wet	extremely wet
2004	extremely wet	marginally wet	extremely wet
2005	dry	marginally dry	marginally dry
2006	marginally wet	extremely wet	marginally wet

1 Due to missing precipitation data, growing season may be wetter than indicated.

5) WRSIS Crop Yield Data (1996 - 2006)

Note: For the purpose of converting crop yield values between bushels/acre and kg/ha, the following values are used:

Field Corn - 1 bushels/acre = 62.86 kg/ha, and
Soybeans – 1 bushels/acre = 67.43 kg/ha.

Table 4a: Field Corn and Soybean Crop Yields (kg/ha): 1996-2006

WRSIS Site	Year	Corn (kg/ha)			Soybeans (kg/ha)		
		Subirrigated[1]	Control[2]	Difference[3]	Subirrigated[1]	Control[2]	Difference[3]
Defiance County	1997	9970	8373	1597	-	-	-
	1998	8140	-	-	3621	-	-
	1999	8738	7732	1006	2374	1497	877
	2000	4557	4513	44	526	681	-155
	2001	4803	5180	-377	1062	728	334
	2002	6393	6776	-383	1585	1416	169
	2003	6864	7763	-899	2434	2232	202
	2004	6676	4740	1936	2003	1996	7
	2005	5796	6236	-440	1537	2320	-783
	2006	5129	4991	138	-	-	-
	Avg.	**6707**	**6255**	**289**	**1895**	**1551**	**94**
Fulton County	1996	11711	6839	4872	4552	3102	1450
	1997	11962	10705	1257	4248	4073	175
	1998	13232	11711	1521	4464	4248	216
	1999	12025	8536	3489	4639	3675	964
	2000	11409	10328	1081	3695	3392	303
	2001	12063	4570	7493	4902	3247	1655
	2002	12214	5393	6821	4005	2724	1281
	2003	14615	14552	63	2562	2630	-67
	2004	12698	8172	4526	4349	4045	304
	2005	11610	9171	2439	-	-	-
	2006	11566	10309	1257	-	-	-
	Avg.	**12283**	**9115**	**3168**	**4066**	**3459**	**607**
Van Wert County	1997	9052	9322	-270	3129	3183	-54
	1998	9498	10171	-673	2765	2778	-13
	1999	11918	9844	2074	3506	2643	863
	2000	10912	9687	1225	3581	3216	365
	2001	12911	11855	1056	3634	3608	26
	2002	-	-	-	4187	3007	1180
	2003	-	-	-	2690	2522	169
	2004	12069	11038	1031	3365	3641	-276
	2005	11793	11849	-56	5064	4740	324
	2006	8455	7229	1226	3270	3109	162
	Avg.	**10824**	**10127**	**698**	**3520**	**3243**	**276**

[1] Average subirrigated field crop yield.
[2] Average control plot crop yield.
[3] Difference equals subirrigated field crop yield minus control plot crop yield.

Table 4b: Field Corn and Soybean Crop Yields (bushels/acre): 1996-2006

WRSIS Site	Year	Corn (bushels/acre)			Soybeans (bushels/acre)		
		Subirrigated[1]	Control[2]	Difference[3]	Subirrigated[1]	Control[2]	Difference[3]
Defiance County	1997	158.6	133.2	25.4	-	-	-
	1998	129.5	-	-	53.7	-	-
	1999	139.0	123.0	16.0	35.2	22.2	13.0
	2000	72.5	71.8	0.7	7.9	10.1	-2.2
	2001	76.4	82.4	-6.0	15.8	10.8	5.0
	2002	101.7	107.8	-6.1	23.5	21.0	2.5
	2003	109.2	123.5	-14.3	36.1	33.1	3.0
	2004	106.2	75.4	30.8	29.7	29.6	0.1
	2005	92.2	99.2	-7.0	22.8	34.4	-11.6
	2006	81.6	79.4	2.2	-	-	-
	Avg.	**106.7**	**99.5**	**4.6**	**28.1**	**23.0**	**1.4**
Fulton County	1996	186.3	108.8	77.5	67.5	46.0	21.5
	1997	190.3	170.3	20.0	63.0	60.4	2.6
	1998	210.5	186.3	24.2	66.2	63.0	3.2
	1999	191.3	135.8	55.5	68.8	54.5	14.2
	2000	181.5	164.3	17.2	54.8	50.3	4.5
	2001	191.9	72.7	119.2	61.2	48.2	13.0
	2002	194.3	85.8	108.5	59.4	40.4	19.0
	2003	232.5	231.5	1.0	38.0	39.0	-1.0
	2004	202.0	130.0	72.0	64.5	60.0	4.5
	2005	184.7	145.9	38.8	-	-	-
	2006	184.0	164.0	20.0	-	-	-
	Avg.	**195.4**	**145.0**	**50.4**	**60.4**	**51.3**	**9.1**
Van Wert County	1997	144.0	148.3	-4.3	46.4	47.2	-0.8
	1998	151.1	161.8	-10.7	41.0	41.2	-0.2
	1999	189.6	156.6	33.0	52.0	39.2	12.8
	2000	173.6	154.1	19.5	53.1	47.7	5.4
	2001	205.4	188.6	16.8	53.9	53.5	0.4
	2002	-	-	-	62.1	44.6	17.5
	2003	-	-	-	39.9	37.4	2.5
	2004	192.0	175.6	16.4	49.9	54.0	-4.1
	2005	187.6	188.5	-0.9	75.1	70.3	4.8
	2006	134.5	115.0	19.5	48.5	46.1	2.4
	Avg.	**172.2**	**161.1**	**11.1**	**52.2**	**48.1**	**4.1**

[1] Average subirrigated field crop yield.
[2] Average control plot crop yield.
[3] Difference equals subirrigated field crop yield minus control plot crop yield.

Table 5: Defiance County WRSIS Site Subirrigated Crop Yield Comparison Between 2.4 m (8 ft) and 4.9 m (16 ft) Drain Line Spacings

Year	Corn - kg/ha (bushels/acre)			Soybeans - kg/ha (bushels/acre)		
	2.4 m Spacing	4.9 m Spacing	Difference[1]	2.4 m Spacing	4.9 m Spacing	Difference[1]
1997	**10366** (164.9)	**9574** (152.3)	**792** (12.6)	-	-	-
1998	**8423** (134.0)	**7858** (125.0)	**566** (9.0)	**3466** (51.4)	**3769** (55.9)	**-303** (-4.5)
1999	**9177** (146.0)	**8298** (132.0)	**880** (14)	**2158** (32.0)	**2583** (38.3)	**-425** (-6.3)
2000	**4752** (75.6)	**4356** (69.3)	**396** (6.3)	**506** (7.5)	**553** (8.2)	**-47** (-0.7)
2001	**5205** (82.8)	**4400** (70.0)	**805** (12.8)	**1281** (19.0)	**843**[2] (12.5)[2]	**438** (6.5)
2002	**6757** (107.5)	**6022** (95.8)	**735** (11.7)	**1524** (22.6)	**1645** (24.4)	**-121** (-1.8)
2003	**7229** (115.0)	**6493** (103.3)	**735** (11.7)	**2380** (35.3)	**2488** (36.9)	**-108** (-1.6)
2004	**6349** (101.0)	**7072** (112.5)	**-723** (-11.5)	**2245** (33.3)	**1780** (26.4)	**465** (6.9)
2005	**5796** (92.2)	**5796** (92.2)	**0** (0.0)	**1463** (21.7)	**1605** (23.8)	**-142** (-2.1)
2006	**5475** (87.1)	**4777** (76.0)	**698** (11.1)	-	-	-
Average	**6952** (110.6)	**6462** (102.8)	**490** (7.8)	**1881** (27.9)	**1915** (28.4)	**-34** (-0.5)

[1] Difference equals 2.4 m drain line spacing crop yield minus 4.9 m drain line spacing crop yield.
[2] Foraging groundhogs from adjacent woodland significantly reduced yield.

Note: Subirrigated corn yields are better with a 2.4 m (8 ft) spacing between drain lines as compared to a 4.9 m (16 ft) spacing between drain lines. Conversely, subirrigated soybean yields are slightly better with a 4.9 m (16 ft) spacing between drain lines as compared to a 2.4 m (8 ft) spacing between drain lines.

Table 6: Statistics on Crop Yield Differences (Subirrigated Field Minus Control Plot) in Relation to Growing Season Wetness/Dryness.

	-Corn- Near Average to Extremely Wet Growing Seasons	-Corn- Marginally Dry to Extremely Dry Growing Seasons	-Soybeans- Near Average to Extremely Wet Growing Seasons	-Soybeans- Marginally Dry to Extremely Dry Growing Seasons
Mean **kg/ha** (bu/ac)	**1142** (18.2)	**2526** (40.2)	**196** (2.9)	**770** (11.4)
Std. Dev. **kg/ha** (bu/ac)	**1923** (30.6)	**2475** (39.4)	**405** (6.0)	**713** (10.6)
P[1]	**P < 2.5 %**	**P < 2.5 %**	**P < 10 %**	**P < 2.5 %**

	-Corn- All Growing Seasons Combined	-Soybeans- All Growing Seasons Combined
Mean **kg/ha** (bu/ac)	**1538** (24.5)	**372** (5.5)
Std. Dev. **kg/ha** (bu/ac)	**2144** (34.1)	**572** (8.5)
P[1]	**P < 0.1 %**	**P < 0.5 %**

[1] P equals the probability that the mean value is not significantly different than zero. In the case of the data presented in this table, a low value of P indicates a high likelihood that the mean value of the subirrigated field minus control plot crop yield difference is substantially greater than zero.

Note: As of 2006, WRSIS subirrigated field crop yield increases for corn and soybeans, respectively, were 30.8 % and 26.0 % during drier growing seasons, 13.3 % and 6.9 % during near average to wetter growing seasons, and 18.1 % and 13.0 % overall.