Technical Report TR09-12 December 2009

Agricultural Experiment Station

College of Agricultural Sciences
Department of Horticulture and Landscape Architecture
Arkansas Valley Research Center
Extension

Arkansas Valley Research Center 2007 Reports

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Funding Provided by the Colorado Agricultural Experiment Station

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Cover: Photo of the pepper variety "Mosco" that was developed at the Arkansas Valley Research Center.

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FIELD CROPS

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Results of the 2007 Field Crop Variety Performance Trials[1]

Abdel Berrada and Jerry Johnson

The variety trials were conducted at the Arkansas Valley Research Center near Rocky Ford, Colorado in collaboration with Colorado State University's Crop Testing Team. The Nuňa bean trial was coordinated by Calvin Pearson of Western Colorado Research Center and Mark Brick and Barry Ogg of Colorado State University's Bean Breeding Program. The predominant soil type at the center is Rocky Ford silty clay (fine-silty, mixed, calcareous, mesic Ustic Torriorthents). Soil pH ranges from 7.5 to 8.0 and ECe from 1.0 to 3.0 dS/m. The elevation is 4180 ft. above sea level. The first fall frost typically occurs in early (32 °F) to mid-October (28 °F) and the last spring frost in late April to early May. The average length of the growing season is 156 (32 °F) to 179 (28 °F) days (http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?corock).

Table 1. Monthly precipitation at the Arkansas Valley Research Center.

Month	1918-2006	2005	2006	2007
	----------------	inches	----------------	
January	0.31	0.45	0.61	0.35
February	0.28	0.24	0.00	0.13
March	0.72	1.55	0.91	0.11
April	1.23	0.75	0.31	2.21
May	1.81	0.49	1.58	1.48
June	1.44	1.05	0.28	3.27
July	1.97	0.45	3.25	0.39
August	1.61	2.17	3.81	2.08
September	0.92	1.38	2.84	0.85
October	0.78	2.04	2.30	0.48
November	0.48	0.04	0.15	0.04
December	0.30	0.25	1.64	0.40
Total	**11.85**	**10.86**	**17.68**	**11.79**

Total precipitation was about average in 2007 (Table 1). Higher average air temperatures were recorded in August through mid-October of 2007 compared to the same period in 2006 (Fig. 1). The experimental design of all the trials was randomized complete block with four replications, except where indicated. All the trials were furrow-irrigated.

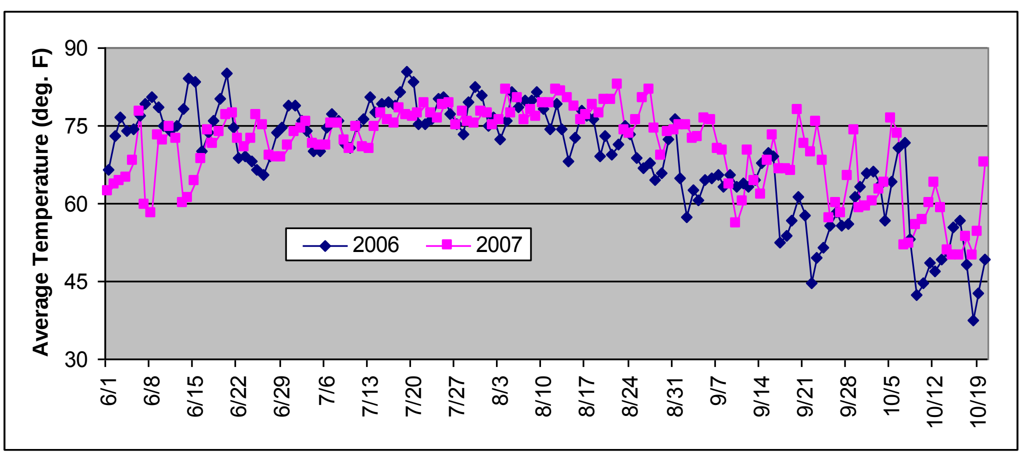

Figure 1. Average daily air temperature in June through 20 October 2006 and 2007.

[1] Some of the results are published in: http://www.colostate.edu/Depts/SoilCrop/extension/CropVar/index.html

Winter canola:

There is growing interest in biofuels in Colorado and nationwide. Oil crops that have been tested at AVRC are soybean, canola, and to a lesser extent, sunflowers. Winter canola is better suited to the climatic conditions of the Arkansas Valley than spring canola. In earlier tests, spring canola did poorly, probably due to warm weather (Maximum temperature ≥ 86 ^{o}F) during flowering and seed formation. Winter canola can be rotated with winter wheat since both crops have a similar growth cycle, i.e., fall planting and late June to early July harvest. Studies elsewhere have shown that winter wheat following canola produces better seed yield than wheat after wheat. The meal (byproduct of oil extraction) from canola is a good source of protein in animal diets and marketing it should not be difficult due to the existence of several feeding operations in the Arkansas Valley. Other advantages of canola include high salt tolerance and lower water requirement compared to alfalfa and corn. Canola can also be used to mine selenium from the soil (phytoremediation). Relatively high selenium concentrations have been found in the Arkansas River and its aquifers.

Canola seed yield averaged 2233 lb/acre in 2007 (Table 2). Canola's fall stand was generally good to excellent and the 2007 crop benefited from above average snowfall and few weed and disease problems. Winter survival averaged 81% in 2007. The canola trials at Rocky Ford were part of the National Winter Canola Variety Trial.

Winter wheat:

Winter wheat had less lodging than 2006 and good winter moisture boosted wheat yields in 2007 (Table 3).

Nuňa beans:

Nuňa beans (*Phaseolus vulgaris*) are hard-shelled beans that burst open when subjected to heat, thus the name "popping beans". They originate from the Andes where they are grown at elevations in excess of 8000 ft.

Low yields were obtained in 2007 (data not shown) due to a number of factors such as substantial damage from Mexican beetles, above-average air temperature during flowering, poor field condition (heavy field bindweed infestation), and less than optimal irrigation scheduling. The top performing entry was „49979' with 1111 lb/acre and the lowest performing was '49956' with 222 lb/acre.

Soybeans: Seed yields were negatively impacted by a severe woolly bear caterpillar infestation in August and September (Tables 4 & 5). There was also substantial seed shattering for the early-maturity entries which was exacerbated by a late harvest.

Table 2. Irrigated Winter Canola Variety Performance Trial at Rocky Ford[1] in 2007.

Entry	Seed Yield lb/acre	Fall Stand (1-10)	Winter Survival (%)	Date 50% Bloom	Plant Height (in.)	Lodging %	Shattering %
DSV06201	3528	9	80	1-May	45	0	1
DSV05101	3184	7	68	29-Apr	50	4	1
DSV06200	2768	7	70	27-Apr	47	0	1
DSV05102	2736	8	78	30-Apr	52	0	1
DSV05100	2475	8	90	29-Apr	51	0	1
Plainsman	2401	8	73	2-May	50	5	1
X01W692C	2247	8	90	28-Apr	46	0	3
Jetton	2225	8	88	29-Apr	50	0	4
NPZ0391RR	2216	8	93	1-May	53	0	1
SLM0402	2151	8	78	27-Apr	50	2	1
DSV06202	2142	8	83	30-Apr	49	0	1
KS4085	2116	8	75	2-May	50	1	2
Satori	2096	7	75	30-Apr	47	0	9
X01W522C	2095	8	85	27-Apr	47	0	8
Hybristar	2025	8	85	27-Apr	47	3	1
Wichita	1944	8	75	2-May	50	4	1
TCI.06.M1	1921	8	80	2-May	50	5	2
DKW13-62	1827	9	90	3-May	55	1	2
Virginia	1751	8	73	2-May	51	0	0
TCI.06.M2	1654	8	78	3-May	52	0	1
EXP3269	1399	8	95	1-May	53	0	5
Average	**2233**	**8**	**81**		**50**	**1**	**2**
$LSD_{(.13)}$	880						

[1]Trial conducted at the Arkansas Valley Research Center; seeded on 9/27/06 and harvested on 7/24/07.

Fertilizer: 100 lb of 11-52-0/acre was broadcast in August.

Weed control: Treflan at 1.5 pt/acre

Planting date: 9/27/06

Previous crop: Winter wheat

Irrigation dates: 9/28/06, 11/3/06, 4/18/07, 5/9/07, and 6/7/07

Total precipitation (from rain & snow) from October 2006 through July 15, 2007: 11.6 in.

Table 3. Irrigated Wheat Variety Performance Trial at Rocky Ford[1] in 2007.

Origin & Year of Release	Variety	Grain Yield	Grain Moisture	Test Weight	Plant Height	Lodging
		bu/ac	%	lb/bu	in	1-9
TX 2005	TAM 112	104.8	12.4	61.6	37	5
AP 2005	NuDakota	101.3	11.1	59.3	36	5
AP 2001	Jagalene	101.2	12.3	60.7	38	4
CSU Exp	CO01385-A1	101.1	12.8	60.8	37	3
WB 2006	Aspen	100.2	11.3	59.9	36	1
CSU Exp	CO03W239	98.2	11.9	59.9	37	3
CSU 1991	Yuma	98.2	11.4	58.9	38	4
CSU 2004	Hatcher	97.6	12.5	60.8	37	6
TX 2002	TAM 111	97.1	13.1	61.7	37	3
CSU 2004	Bond CL	96.6	11.2	59.8	39	3
CSU Exp	CO03W054	96.3	11.9	60.3	39	3
CSU Exp	CO03W238	94.5	10.4	59.3	36	5
CSU 2002	Ankor	94.3	12.8	61.1	39	4
CSU Exp	CO03W139	93.5	12.1	59.8	37	4
AP 2006	Hawken	91.8	11.9	61.1	36	3
CSU Exp	CO03W108	91.5	12.5	61.8	39	4
AP 2005	Postrock	90.8	12.3	61.9	37	2
CSU Exp	CO02W280	89.9	13.0	62.4	40	5
CSU Exp	CO03443	89.5	12.3	61.5	40	4
CSU Exp	CO03W033	89.3	12.9	62.4	38	4
CSU Exp	CO03064	88.9	12.1	60.9	39	6
CSU 1998	Prairie Red	88.5	11.4	60.9	37	2
CSU Exp	CO02W237	88.5	12.8	61.2	38	6
CSU Exp	CO03W043	88.1	11.4	60.2	37	7
AP 2005	NuGrain	87.8	12.9	62.2	36	2
CSU Exp	CO03W269	87.5	11.1	60.3	37	4
WB 2005	Keota	87.2	12.1	60.8	40	5
CSU Exp	CO03W146	86.7	12.8	61.3	38	7
KSU 2005	Danby	85.6	11.9	62.0	38	3
CSU Exp	CO03W127	85.4	12.0	60.0	37	5
AP 1995	Platte	84.2	13.2	63.0	33	1
CSU Exp	CO02W214	84.2	12.5	60.4	37	4
	Average	92.5	12.1	60.9	37	4
	$LSD_{(0.30)}$	7.6		1.0		

[1]Trial conducted at the Arkansas Valley Research Center; seeded 9/28/06 and harvested 7/5/07.
Previous crop: Winter canola
Lodging score: 1=no lodging, 9=completely lodged.
Variety origin code:
CSU=Colorado State University, CSU Exp=Colorado State University Experimental Line
WB=WestBred, LLC, AP=AgriPro® COKER®
KSU=Kansas State University, TX=Texas A&M University

Table 4. Irrigated* Early Maturity Soybean Variety Performance at Rocky Ford[1] in 2007.

Variety	Yield	Moisture	Test Weight	Shattering²
	bu/ac	%	lb/bu	(1-10)
NK Brand 508C3	48.9	10.7	59.1	0.8
Dyna-Gro 33X19	48.1	11.7	56.8	2.0
Dyna-Gro 39D11	43.2	12.5	57.2	0.7
Rough Rider Genetics RG604RR	42.3	11.8	58.2	2.3
NK Brand 514A7	39.9	12.3	57.2	1.2
NK Brand 502M9	39.5	12.4	57.5	2.0
Dyna-Gro 36P10	38.9	12.9	58.1	4.0
Dyna-Gro 32K16	38.1	12.1	54.9	2.7
NK Brand 512V7	35.0	10.3	60.8	3.0
Rough Rider Genetics RG607RR	32.0	10.5	57.9	4.0
Rough Rider Genetics RG200RR	29.4	11.9	58.9	4.0
Rough Rider Genetics RG405RR	27.8	11.7	58.3	4.7
Rough Rider Genetics RG600RR	27.4	12.1	56.5	3.3
Rough Rider Genetics RG601NRR	26.5	11.2	58.8	3.7
Dyna-Gro 33T06	24.6	14.0	55.8	5.0
Rough Rider Genetics RG603RR	24.1	12.7	57.5	8.0
Rough Rider Genetics RG6008RR	20.6	11.9	57.3	5.0
Average	**34.5**	**11.9**	**57.7**	**3.3**
$LSD_{(0.30)}$	3.8			

Table 5. Irrigated* Medium Maturity Soybean Variety Performance at Rocky Ford[1] in 2007.

Variety	Yield	Moisture	Test Weight	Shattering²
	bu/ac	%	lb/bu	(1-10)
Dyna-Gro 36F22	44.9	9.1	57.4	0.7
Dyna-Gro 37Y21	43.5	10.0	57.8	0.8
Dyna-Gro 35F25	41.4	8.9	58.8	2.8
Dyna-Gro 31D20	40.9	9.5	57.7	0.7
Dyna-Gro 36C28	38.2	9.7	58.4	0.7
Dyna-Gro 37T26	37.3	9.6	58.5	1.5
Dyna-Gro 33D27	36.5	9.0	58.3	0.8
Average	**40.4**	**9.4**	**58.1**	**1.1**
$LSD_{(0.30)}$	4.2			

[1]Both soybean trials were conducted at the Arkansas Valley Research Center; planted on 5/14 at 130,000 seeds/ac and harvested on 9/24.

[2]Rating scale 1-10, with 1 = no shatter and 10 = completely shattered.

*Limited furrow-irrigation total water received = 11 inches in four applications.

Season rainfall = 7 inches

Previous Crop: Soybean

Fertilizer: None

Herbicide: Dual Magnum/Roundup

Insecticide: None

Effects of Two Years of Manure and Nitrogen Fertilizer Application on Corn Yield, N and P Uptake, and Soil N and P Tests under Drip and Furrow Irrigation[2]

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ABSTRACT

A field experiment was conducted at the Arkansas Valley Research Center in 2007 to test the residual effects of two years (2005 and 2006) of manure application (10, 20, and 30 tons/acre) and N fertilizer (60, 120, and 180 lb N/acre) on corn yield, N and P uptake, and soil $N0_3$-N and P concentrations under subsurface drip irrigation (SDI) and furrow irrigation (FrI). There were no significant differences in corn yield between SDI and FrI in 2005, 2006, and 2007, even though, on average, 43% more water was applied with FrI than with SDI. The highest corn yields were obtained with 180 lb N/acre in 2005 and with as little as 60 lb N/acre or 10 tons of manure/acre in 2006. With no N fertilizer or manure applied in 2007, the residual manure and high N rate treatments produced an average of 224 bu/acre of corn. At the end of 2007, there was enough residual soil N left in the high manure treatment to produce top corn yields for two years. Applying manure in excess of crop nutrient requirements can lead to N and P buildup in the soil and associated water pollution hazards, as demonstrated in this study.

INTRODUCTION

Nitrate-N levels exceeding the Water Drinking Standard of 10 mg/L (ppm) were reported in 14% of domestic wells tested in the Arkansas Valley in 1994 (Yegert et al., 1997). Contamination sources were not determined but could be due in part to excessive N fertilizer application. Research indicates that N fertilizer rate in corn following alfalfa or vegetable crops such as melons can be reduced substantially without a significant drop in corn yield (Halvorson et al., 2005). Excessive N fertilizer application can lead to leaching of NO_3-N below the root zone, which is exacerbated by inefficient irrigation. Over 90% of the cropland in the Arkansas Valley is furrow-irrigated. Manure application in excess of crop requirements can cause a substantial buildup of N, P, and salts in the soil and their potential loss through leaching and runoff, which could adversely impact the environment (Eghball and Power, 1999).

Water quality issues, coupled with diminishing water supplies have led to increased interest in drip irrigation in the Arkansas Valley. The majority of current drip acreage is used for growing high-value crops such as onions, cantaloupes, and watermelons. Research elsewhere has demonstrated the feasibility of SDI for corn and other field crops (Lamm et al., 1995). A well designed and managed SDI system can save water by eliminating runoff losses and minimizing evaporation and deep percolation losses (Berrada, 2005). SDI also has the potential to minimize the leaching of salts and NO_3-N, but little is known about their movement under drip irrigation in the Arkansas Valley.

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[2] A similar article was published in the proceedings of the 2008 Great Plains Soil Fertility Conference.

The main objective of this research in 2007 was to assess the residual effects of two consecutive years of N fertilizer and manure application under SDI and FRI on corn yield, N and P uptake, and soil NO_3-N and P concentrations.

MATERIALS AND METHODS

This research was conducted in 2005, 2006, and 2007 near Rocky Ford, CO. The soil at the study site was Rocky Ford silty clay (fine-silty, mixed, calcareous, mesic Ustic Torriorthents). The plot area was the same each year. Composite soil samples were taken from each replication and from selected treatments prior to fertilizer application in 2005. The soil had a pH of 8.1 and SOM of 1.5%. It averaged 36 ppm of P and 298 ppm of K in the top foot and 153 lb NO_3-N/acre in 0 to 6 ft. The recommended N fertilizer rate was 120 lb N/acre, based on a 250 bu/acre yield goal.

The experiment design was as a randomized complete block split plot with four replications. Irrigation type (SDI vs. FrI) was assigned to the main plots and fertilizer rate to the subplots. Plot size was 20 ft x 60 ft. The SDI system consisted of 0.875-in. diameter drip tapes with 0.45 gpm/100 ft. flow rate and 12-in. emitter spacing, buried 8 in. below ground, and spaced 60 in. apart. Water was pumped from the Rocky Ford Canal and filtered before it reached the drip tapes. Two flow meters were used to monitor irrigation amount. Furrow irrigation consisted of dispensing water from the irrigation ditch, with siphon tubes, to every other furrow. Water flow at the top and bottom of selected furrows was measured with a v-shaped furrow flume. All the plots were furrow-irrigated shortly after the corn was planted to ensure adequate corn germination and emergence. Total FrI irrigation amounts were 47 in. in 2005 and 30 in. in 2006 and 2007. Total SDI irrigation amounts, including the first furrow irrigation, were 26, 19, and 16 inches, respectively. Furrow-irrigation efficiencies were 40 to 50% in 2005 and 50 to 60% in 2006 and 2007. The higher efficiencies in 2006 and 2007 were due to improved management e.g., by switching to lower-diameter siphons after water reached the tail end. SDI efficiency (around 90%) was not as high as it could be (≥95%) because of evaporative water losses due to subbing, which was caused by shallow drip tape placement depth, high flow rate, and long irrigation runs (12 hours on average). Total season rainfall was 6, 11, and 8 inches in 2005, 2006, and 2007 respectively.

Fertilizer rates were: No N added (0N), no N or P added (0NP), 60 lb N/acre (60N), 120 lb N/acre (120N), and 180 lb/acre (180N). Manure rates were 10 tons (10T), 20 tons (20T), and 30 tons (30T) per acre. Phosphorus fertilizer 0-46-0 was added to 0N, 60N, 120N, and 180N at 100 lb/acre in 2005 and 2006. The N source was a polymer-coated urea with a release time of 30 days. Nitrogen and P fertilizers were broadcast by hand on 10 March 2005 and 10 April 2006. Feedlot beef manure was applied with a manure spreader on 18 March 2005 and 14 November 2005. Manure analysis is shown in Table 1. The recommended rate was 11 tons manure/acre for a yield goal of 250 bu/acre. There are several feedlots in the area, which makes manure application economical within a certain radius. An informal survey revealed that manure application rates in the Arkansas Valley varied from 10 t/acre or less to over 40 t/acre, with 20 t/acre being common. The plot area was disked after the first manure application and plowed after the second manure application. *No N or P fertilizer and no manure were applied after corn harvest in 2006.*

Table 1. Selected characteristics of beef feedlot manure applied in the spring and fall of 2005.

Sampling date	Total N lb/ton	Organic N lb/ton	NH_4-N lb/ton	NO_3-N lb/ton	P_2O_5 lb/ton	Water %	Ash %	C:N ratio	EC dS/m	pH
March'05	35.6	28.5	7.1	<0.1	18.3	40.8	18.0	13:1	24.8	7.6
Nov.'05	35.8	28.7	7.1	<0.1	23.6	35.0	28.4	11:1	23.4	8.6

Soil samples were taken in the spring and fall (after corn harvest) of each year to determine NO_3-N and NH_4-N concentrations. Sampling depths were: 0-1 ft, 1-2 ft, 2-3ft, and 3-4 ft in the spring and down to 6 ft in the fall. In addition, available soil P in the top foot was determined with the sodium bicarbonate method in 0NP, 10T, 20T, and 30T in 2005 and 2006 and 0NP, 120N, 10T, 20T, and 30T in 2007.

Corn hybrid Asgrow RX752RR/YG was planted in 30-in rows on 27 April 2005, 21 April 2006, and 3 May 2007 at approximately 33,000 seeds/acre. The preceding crop was soybean. Timely herbicide applications kept the plot area weed-free throughout most of the growing season. Hot and dry conditions in July 2005 led to a substantial infestation of spider mite which was suppressed later by aerial spraying of labeled insecticides. Preventive spraying was done on 27 June 2006 and no treatment was needed in 2007. The two middle rows (5 ft x 50 ft) in each plot were harvested on 18 Oct. 2005, 20 Oct. 2006, and 16 Oct. 2007 to determine grain yield, which was adjusted to 15.5 % water content and 56 lb/bu test weight. Grain samples were dried in the oven at 60 to 65 ^{0}C, ground, and analyzed for total N (all treatments) and P (0NP, 120N, 10T, 20T, and 30T). The soil and plant data were analyzed using the PROC MIXED procedure (SAS 9.1 Software, 2002-2003).

RESULTS

Grain yield

Table 2. Corn yield as affected by irrigation type and fertilizer rate in 2005.

Fertilizer Treatment	*FrI (bu/acre)*	*SDI (bu/acre)*
0N	169	202
0NP	187	214
60N	209	212
120N	207	227
180N	232	231
10T	200	210
20T	206	202
30T	205	183
Mean	**202**	**210**
LSD$_{(0.05)}$	25	

Analysis of variance (PROC MIXED)

Effect	DF	F value	Pr > F
Irr. Type	1	1.05	0.382
Fert. Trt.	7	6.40	<0.00
I x F	7	2.83	0.017

There were no significant differences in corn yield between FrI and SDI in all three years, despite the fact that an average of 43 % less water was applied with SDI than with FrI. In 2005, corn yields in 0N and 0NP were much higher in SDI than in FrI due to higher initial soil NO_3-N levels (Table 2). There was a significant yield reduction in 30T with SDI compared to most of the other treatments. Corn plant population in 2005 was markedly lower in the high manure treatment, particularly with SDI, which may have been caused by high salt concentration in the seedbed early in the season (data not shown). The highest yield in 2005 was achieved with 180N in both FrI and SDI, but was not statistically different than that of 60N and 120N with FrI and 0NP, 60N, 120N, and 10T with SDI (Table 2). There was no significant irrigation type by fertilizer rate effect in 2006 and 2007. The highest yield in 2006 was obtained with 60 to 180 lb N/acre and 10 to 20 t manure/acre (Table 3).

Table 3. Corn yield as affected by fertilizer rate in 2006 and 2007.

Fertilizer Treatment	*2006 (bu/acre)*	*2007 (bu/acre)*	*Analysis of variance (PROC MIXED)*	DF	F Value	Pr > F
0N	197	139				
0NP	195	127	Year: 2006			
60N	231	144	Irr. Type	1	0.03	0.869
120N	242	197	Fert. Trt.	7	8.49	<0.00
180N	247	224	I x F	7	1.67	0.144
10T	253	213	Year: 2007			
20T	245	233	Irr. Type	1	2.52	0.210
30T	223	224	Fert. Trt.	7	15.27	<0.00
Mean	229	187	I x F	7	0.77	0.617
$LSD_{(0.05)}$	22	33				

Corn yields averaged187 bu/acre in 2007 compared to 229 bu/acre in 2006 and 206 bu/acre in 2005. There was a large decrease in the yield of 0N, 0NP, and particularly 60N in 2007 compared to 2006. Treatments 180N, 10T, 20T, and 30T averaged 224 bu/acre in 2007 compared to 197 bu/acre with 120N.

Soil N

Table 4. Soil NO_3-N in the fall of 2005, 2006 and 2007, and the spring of 2007, as affected by fertilizer treatment.

Fertilizer Treatment	Fall 2005 (0- to 3-ft depth)	Fall 2006 (0- to 3-ft depth)	Spring 2007 (0- to 3-ft depth)	Fall 2007 (0- to 3-ft depth)	Fall 2005 (3- to 6-ft depth)	Fall 2006 (3- to 6-ft depth)	Fall 2007 (3- to 6-ft depth)
	lb NO_3-N/acre						
0N	26	33	24	10	99	68	67
0NP	30	25	17	12	94	40	45
60N	25	46	41	18	47	43	74
120N	63	88	115	26	145	54	81
180N	155	121	114	24	51	102	105
10T	93	95	71	45	184	74	136
20T	166	176	247	136	87	125	307
30T	189	354	283	372	62	209	409
Mean	**93**	**117**	**114**	**80**	**96**	**89**	**153**
$LSD_{(0.1)}$	102	100	82	186	NS	57	150

There was more residual NO_3-N in the top three feet of soil in the fall of 2005, in 180N, 20T and 30T compared to the other treatments (Table 4). The fall 2005 and fall 2006 NO_3-N levels were similar, except for 30T which increased from 189 to 354 lb N/acre in 0-3 ft. Obviously, N released by the high manure treatment exceeded N uptake by the second corn crop. There was a slight or no increase in NO_3-N levels in the spring of 2007 in the 0- to 3-ft depth compared to the fall of 2006. However, twice as much NH_4-N (60 vs. 30 lb N/acre) was present in the spring than in the fall (data not shown). Not much NO_3-N was left in the top three feet of soil in the fall of 2007 in all the treatments except 20T and 30T (Table 4). Assuming a total N requirement of 1.1 lb N per bushel of corn

(Halvorson et al., 2005), there was enough residual N to produce around 100 bu/acre in 20T and over 300 bu/acre in 30T in 2008. Additional N will be released from the manure treatments, but not all the residual N may be available for the next crop. There were generally higher NO_3-N levels in the bottom than in the top three feet of soil in the fall of 2007, which reflects N uptake by corn, and may indicate a downward movement of NO_3-N, particularly in 20T and 30T where NO_3-N levels in the 3- to 6-ft depth increased every year. When averaged over all treatments and depths, there was significantly more NO_3-N ($P = 0.086$) in SDI than in FrI in the fall of 2007, primarily due to much higher residual N in the manure treatments with SDI. The same trend was observed in 2005, although the effects of irrigation type and irrigation by fertilizer treatment interaction were not significant (data not shown).

Soil P

Table 5. Soil P concentration in the top foot of soil in selected treatments in the fall 2005, 2006 and 2007, and the spring of 2007.

Fertilizer Treatment	Fall 2005	Fall 2006	Spring 2007	Fall 2007
	ppm (mg/kg)			
0NP	9.3	4.7	6.9	7.3
120N	NA	NA	10.4	6.1
10T	19.0	18.0	26.0	18.1
20T	41.1	25.5	49.5	39.3
30T	37.1	67.0	80.4	44.0
Average	**26.6**	**28.8**	**34.6**	**23.0**
$LSD_{(0.05)}$	13.8	20.8	30.7	20.5

Soil $NaHCO_3$-P concentration in 0- to 1-ft depth was highly affected by fertilizer treatment as would be expected (Table 5). There was significantly more P in the manure treatments than in the check (0NP) or in 120N in the fall or spring (2007) of each year. Irrigation type did not have a significant impact on soil P. However, the potential for losing P e.g., through runoff is much higher with FrI than with SDI. Available P in 20T and 30T was well above the sufficiency level for irrigated corn production (Mortvedt et al., 2006) in all three years.

Grain N and P uptake

Table 6. Corn grain N and P uptake in 2005, 2006, and 2007 as affected by fertilizer treatment.

Fertilizer	2005	2006	2007	2005	2006	2007
Treatment	lb N/acre			lb P/acre		
0N	143	125	92	-	-	-
0NP	152	114	80	30	29	19
60N	158	141	94	-	-	-
120N	168	159	143	31	35	31
180N	181	171	173	-	-	-
10T	169	170	164	32	34	27
20T	159	169	192	33	35	35
30T	157	161	188	30	32	34
Average	**161**	**151**	**141**	**31**	**33**	**30**
$LSD_{(.05)}$	16	25	33	NS	4	4

Nitrogen uptake by corn grain was highest with 180N in 2005 and with the manure and high N rate treatments in 2006 and 2007, in accordance with soil NO_3-N levels (Table 6). There were no significant irrigation type or irrigation type by fertilizer treatment effects in any of the three years. Phosphorus uptake was significantly higher with 120N, 10T, and 20T in 2006, and with 120N and all three manure rates in 2007 compared to the check. The increase (or lack of) in P uptake in 2005 and 2006 in the manure treatments is less than what would be expected based on soil P test levels (Table 5), or indicates the amount of P needed by the corn plants was adequately supplied with no luxury consumption of available soil P by the corn.

CONCLUSIONS

There were no significant differences in corn yield between SDI and FrI in all three years, which indicates that SDI may be a feasible alternative to FrI for corn production in the Arkansas Valley. Growing more crops with SDI will save substantial amounts of water in an area where water resources are declining due to the sale and transfer of irrigation water to municipalities along the Front Range of Colorado. Concerns with SDI include high installation cost, salt accumulation, and how to ensure uniform crop germination and emergence in years with low spring precipitation.

Corn yields at or near the maximum were produced with 60 lb N/acre in 2005 and 2006 and with 10 tons of manure/acre in all three years. This confirms the results of Halvorson et al. (2005) and shows that fertilizer rates can be greatly reduced by taking into account residual N. The high manure rates of 20 and 30 t/acre resulted in high NO_3-N concentrations in the spring and fall of 2007. There was enough residual N in 30T after corn harvest in 2007 to produce an additional 300+ bu/acre of corn. Similarly, soil P tests in the manure treatments exceeded P sufficiency levels. Nitrogen and P buildup in the soil can impair water quality through leaching and runoff. The elevated NO_3-N and P levels in the soil led to increased N and P uptake by the corn grain in 2006 and 2007. This study did not show clear differences between SDI and FrI in soil N and P distribution. Part of the reason may be the way SDI was managed (long-duration water applications).

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ACKNOWLEDGMENT

This study was funded by the Colorado Department of Public Health and Environment, USDA-NRCS, USDA-ARS, and Colorado State University Agricultural Experiment Station.

Corn Glyphostate Antagonism Trial

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Corn used for grain or silage is an important crop in the Arkansas Valley and other regions of the state. The majority of the corn grown in the Arkansas Valley is genetically-modified and can contain a number of attributes; most notably, resistance to the herbicide glyphostate. Glyphostate-resistant or "Round-up Ready" corn has proven to be an invaluable component of a successful weed control program. Although glyphosate is an important tool in corn production, there has been some concern that, under certain circumstances, glyphostate applications may depress yields. Because of this potential, this study was conducted to determine the effect of glyphostate applications on corn grain yield. In addition, the effects of commercially available spray adjuvants, sprayed in conjunction with glyphosate, were also assessed.

Overall, there was a significant (p=0.1) decrease in grain yield by the late application (V10) of glyphosate compared to an unsprayed control. The addition of commercially available adjuvants significantly reduced the aforementioned yield depression.

METHODS

This study was conducted with conventional tilled, furrow-irrigated corn on a calcareous Rocky Ford silty clay loam soil at Colorado State University's Arkansas Valley Research Center (AVRC) in 2007. The Center is located near Rocky Ford, Colorado. The plot area had previously been in soybeans during 2006. Corn (var. Asgrow RX752 -RR/YG) was planted on April 30, 2007 at a seeding rate of about 32,000 seeds per acre. A single line of corn was planted on top of the bed with a 30 inch row spacing (furrow to furrow). Conventional corn production practices were used throughout the course of the season. Irrigation was by gravity-flow furrows with water being applied to every other furrow (every 60 inches). Four spray treatments were applied on July 3 at about the V10 stage of corn development. The treatments were:

1. Unsprayed Control
2. Glyphostate at 1 lb A.I. per acre plus Ammonium Sulfate (AMS) at 1 pint per acre.

3. Glyphostate at 1 lb A.I. per acre plus Ammonium Sulfate (AMS) at 1 pint per acre plus the adjuvant AGMO 7027 at 3 pints per acre.
4. Glyphostate at 1 lb A.I. per acre plus Ammonium Sulfate (AMS) at 1 pint per acre plus the adjuvant AGMO 4038 at 3 pints per acre.

All materials were applied with a hand-held sprayer (2 gal. capacity) in water (30 gal per acre). All foliage was thoroughly and uniformly wetted with the spray material.
A randomized complete block design with 4 replications was used. Each plot was 4 beds wide (10 feet) and 36 feet long. The corn was harvested at full black layer maturity and near 15% grain moisture on October 16.

RESULTS

Treatment	Rate Per Acre	% Grain Moisture	Test Wt Lb/bu	Yield bu/acre
Unsprayed Control	-	15.6	56.2	233.9 a
Glyphosate AMS	1 lb A.I. 1 pint	15.6	56.2	194.7 d
Glyphosate AMS AGMO 7027	1 lb A.I. 1 pints 3 pints	15.6	56.2	221.4 b
Glyphosate AMS AGMO 4038	1 lb A.I. 1 pints 3 pints	15.6	56.2	207.5 c
lsd(0.1)				12.4

This work was generously supported by Agriliance LLC under the direction of Mr. Joe Bush.

Corn Starter Fertilizer Trial

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Corn used for grain or silage is an important crop in the Arkansas Valley and other regions of the state. In 2007, a study was conducted to characterize the response of corn to commercially available forms of starter fertilizers and seed treatments containing zinc and other nutrients. Applications were applied below the seed row at the planting. Overall, the seed treatments and applications of fertilizers did not significantly increase yield compared to an unfertilized control. An additional corn variety (Croplan 6831TS) used as a control, had significantly higher yields than the other treatments.

MATERIALS AND METHODS

This study was conducted with conventional tilled, furrow-irrigated corn on a calcareous Rocky Ford silty clay loam soil at Colorado State University's Arkansas Valley Research Center (AVRC) in 2007. The Center is located near Rocky Ford, Colorado. The plot area had previously been in soybeans during 2006. Nine treatments, including controls, were applied just prior to planting. After marking out the seed lines with an empty plot planter, fertilizer materials were applied in a small trench. Each fertilizer material was uniformly placed at the bottom of a 1-2" deep trench and after the application, the trench was carefully re-filled. Corn (varieties, Croplan 6818TS and 6831TS) were planted on April 30, 2007 at a seeding rate of about 32,000 seeds per acre using a fabricated plot planter. A single line of corn was planted on top of the bed with a 30 inch row spacing (furrow to furrow). Conventional corn production practices were used throughout the course of the season. Irrigation was by gravity-flow furrows with water being applied to every other furrow (every 60 inches).

RESULTS

Corn Seed Treatment Trial – 2007

Treatment	Croplan Variety	Rate Per Acre	Application Method	Yield bu/acre
1. Control	6818 TS	-	-	228.8 ab
2. Advance Zinc AGO 4021	6818 TS	4 oz/100 lb 3.2 oz/ 100 lb	seed treatment	242.5 ab
3. Origin 10% Zinc	6818 TS	2 qts/A	at planting in seed furrow	227.9 ab
4. Origin 10% Zinc AGO 4021	6818 TS	2 qts/A 3.2 oz/A	at planting in seed furrow	222.1 b
5. AGO 4021	6818 TS	3.2 oz/A	at planting in seed furrow	224.5 ab
6. AGO 4035	6818 TS	2 oz/A	at planting in seed furrow	227.1 ab
7. 10-34-0	6818 TS	10 gal/A	at planting in seed furrow	227.3 ab
8. Advance Zinc AGO 4021 10-34-0	6818 TS	4 oz/100 lb 3.2 oz/ 100 lb 10 gal/A	seed treatment at planting in seed furrow	226.1 ab
9. Control – Variety 2	6831 TS	-		249.3 a
lsd(0.1)				26.7

All yields adjusted to 15.5% moisture

Corn planted on and in furrow treatments made May 4, 2007.

Corn harvested on October 15, 2007.

This work was generously supported by Agriliance LLC under the direction of Mr. Joe Bush.

Nitrogen Effects on Onion Yield Under Drip and Furrow Irrigation

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ABSTRACT

Onion (*Allium cepa* L.) is a high cash value crop with a very shallow root system that is frequently irrigated and fertilized with high N rates to maximize yield. Converting from furrow-irrigated to drip-irrigated onion production may reduce N fertilizer needs, water inputs, and NO_3-N leaching potential. Onion growth and N uptake, fresh yield, and residual soil NO_3-N were determined under drip and furrow irrigation on a clay loam soil with N fertilizer rates from 0 to 224 kg N ha^{-1}. Onions were sampled bi-weekly from 25 May to 30 August in 2005 and 2006 from each treatment. In 2005, 72% less water was applied with the drip system compared with furrow system, and 57% less in 2006. Onion yields were significantly greater with the drip system. Total marketable fresh onion yield increased with increasing N rate in 2005 only. The drip system had more colossal and jumbo sized onions and less medium sized onions than the furrow system. Biomass production and N accumulation accelerated in mid-June each year with an average total N accumulation (leaves + bulbs) of 121 kg N ha^{-1} at final harvest. Irrigation water use efficiency (IWUE) and N use efficiency (NUE) were higher with the drip system than with the furrow system. Residual soil NO_3-N levels were greater in the drip-irrigated treatments after onion harvest in 2005 than in the furrow-irrigated treatments, but soil NO_3-N levels were similar after harvest in 2006. Adjusted gross economic returns (less cost of N, water and drip system) were greater with drip irrigation than with furrow irrigation. This study demonstrates that fresh onion yields, potential economic returns, IWUE, and NUE can be improved in Colorado by using drip irrigation for onion production rather than furrow irrigation.

Abbreviations: AN, available N [soil N (0-60 cm depth) + fertilizer N added + irrigation water N]; ET, evapotranspiration; IWUE, irrigation water use efficiency; NFUE, N fertilizer use efficiency; NUE_1, nitrogen use efficiency based on N uptake; NUE_2, nitrogen use efficiency based on fresh onion yield.

INTRODUCTION

High NO_3-N and salinity levels have been reported in groundwater in the Arkansas River Valley in Colorado (Austin, 1997; Ceplecha et al., 2004, Gates et al., 2006), which is a major production area for onion and other vegetable crops in rotation with alfalfa (*Medicago sativa* L.), corn (*Zea mays* L.), sorghum (*Sorghum bicolor* L.), winter wheat (*Triticum aestivum* L.), and soybean (*Glycine max* L.). High rates of N fertilizer (>200 kg N ha^{-1}) are usually applied to onion in the Western U.S. to increase overall yield and bulb size, generally without regard to soil testing (Bartolo et al., 1997, Brown, 1997; Brown, 2000; Drost et al., 1997; Stevens, 1997). Halvorson et al. (2002) reported N fertilizer use efficiency (NFUE) by onion to be about 15%.

Sammis (1997) also reported the need for high rates of N on onion to optimize yield in New Mexico, but expressed concern about leaching of NO_3-N from the root zone and the low NFUE (30%) by onion. Onion has a shallow rooting depth (<60 cm) and requires frequent irrigation to maintain market grade and quality (Schwartz and Bartolo, 1995). High N fertilization rates, shallow water tables, and frequent irrigation to establish and maintain an onion crop all contribute to a high NO_3-N leaching potential (Ells et al., 1993).

Sullivan et al. (2001) and Brown (2000) developed nutrient management plans for onion production in the Pacific Northwest to help reduce N application rates, to improve N use efficiency (NUE), and to minimize the detrimental effects of fertilizer N on groundwater. Schwartz and Bartolo (1995) developed similar nutrient management guidelines for Colorado. Bartolo et al. (1997) and Brown (1997) point out that N fertilization costs are generally < 2% of onion production costs, therefore, growers are not very concerned about N application rate, other than insuring that sufficient N is present. Although these N fertilizer management guidelines recommend limiting N application when soil N is high, growers often apply N to ensure high yields and large sized onions. Irrigation, crop, and N management practices need to be developed to reduce NO_3-N leaching potential and improve N use efficiency (NUE) in Colorado (Halvorson et al., 2002, 2005).

Gates et al. (2006) reported the need to use more efficient irrigation methods in the Arkansas River Valley in Colorado to lower the levels of the groundwater table to reduce the impact of salinity on crop yields. They recommended converting to sprinkler and drip irrigations systems that required less water application to avoid excessive water movement below the crop root zone. Converting from furrow to drip irrigation has potential for reducing the amount of irrigation water needed to produce a high yielding onion crop (Sammis, 1980; Shock et al., 2007). A more uniform application of water can be achieved with drip irrigation with little or no water runoff, deep percolation, evaporation, and water contact with onion leaves, which reduces disease potential (Shock, 2006; Shock et al., 2004, 2007).

Following onion planting in the semi-arid Arkansas River Valley in Southeastern Colorado, frequent irrigation is needed to achieve germination and keep the young seedlings alive. Drip irrigation has the potential to apply water frequently and uniformly to the onion seed row on an onion bed without wetting the soil between onion beds (Shock et al., 2007). Furrow irrigation requires that sufficient water be applied to wet the furrow area plus the onion bed, which requires more water than a drip system. With the furrow system and frequent irrigation, there is greater potential for NO_3-N leaching and excess water contribution to the shallow groundwater table which contributes to the soil salinity problems in the Arkansas River Valley in Colorado (Gates et al., 2006). Converting to more efficient irrigation systems, such as drip irrigation for high cash value crops is one way to reduce excess water application above consumptive use of the crop and reduce NO_3-N leaching potential (Trout and Kincaid, 2007; Shock et al, 2004).

The objectives of the research reported here were to: 1) determine N fertilizer requirements of onion under drip and furrow irrigation in the Arkansas River Valley of Colorado to optimize yield and bulb size, and 2) evaluate the influence of N fertilizer rate and irrigation system on residual soil NO_3-N.

METHODS AND MATERIALS

This study was conducted on a Rocky Ford clay loam soil (fine-silty, mixed, calcareous, mesic Ustic Torriorthents) at the Arkansas Valley Research Center (AVRC) (lat. 38° 2’23” N, long. 103° 41'43" W), near Rocky Ford, CO. The soil had a pH of 7.6, soil organic matter content of 21 g kg^{-1}, soil electrical conductivity of 0.7 dS m^{-1}, sodium bicarbonate extractable P content of 17 mg kg^{-1}, ammonium acetate extractable K content of 296 mg kg^{-1}, and a clay and silt content of 410 and 290 g/kg soil in the 0- to 15-cm depth. Depth to water table at the AVRC ranges from 4.5 to 6 m.

In 2000, a N source and rate study was initiated under conventional till (disk, moldboard plow, roller harrow, landplane, etc. for seedbed preparation) and furrow-irrigated corn production practices (Halvorson et al., 2005). The same plot area and established N plots were used for the 2005 onion study, with modified N rates. The plot area had previously been in continuous corn for 4 years (2000 – 2003) and chile pepper in 2004. The 2006 study was located in an adjacent field that had been cropped to soybean the previous year with no N fertilizer applied. Six N rates (0, 45, 90, 134, 179, and 224 kg N ha^{-1} or N1, N2, N3, N4, N5, N6 treatments, respectively) were established on February 22 in 2005 and 2006. Drost et al. (2002) demonstrated the benefit of using a polymer-coated urea for onion production; therefore, a polymer-coated urea was used in this study to reduce NO_3-N leaching during the early growth period when frequent irrigation is required to keep the onions healthy. The N source used in this study was a controlled-release polymer-coated urea (Duration Type III® produced by Agrium Inc., Calgary, AB [3]; cost of \$2.43 kg^{-1} N) with a 90 to 120 day 80% release period in water at 23 °C. The N fertilizer was broadcast on February 22nd and incorporated with a harrow within a few days after application both years.

Two irrigation systems were used, furrow irrigation with 3.2 cm diameter siphon tubes, common practice in the Arkansas Valley, and drip irrigation (T-Tape: TSX-708-30-340, T-Systems, San Diego, CA[1]) with 30 cm between emitters and a flow rate of 1.1 $L \cdot h^{-1}$. The drip tape was located about 5- to 8-cm below the soil surface near the center of the bed between the two onion rows. The experimental design was a split-plot, randomized complete block with N rate as main plots (7.6 m x 15.2 m) and irrigation system as subplots (3.8 m x 15.2 m) in 2005 and 9.1 by 15.2 m main plots and 4.6 by 15.2 m subplots in 2006 with four replications.

Phosphorus fertilizer (0-46-0) was applied over the entire plot area at a rate of 112 kg P ha^{-1} prior to fall plowing. In the spring, the field was roller-harrowed, leveled, and bedded prior to N application. Following N application the field was cultivated to incorporate the N fertilizer and re-bedded for onion planting.

Onion (var. Ranchero, Nunhems USA. Inc.[1]) were planted on March 8 in 2005 and 2006 at a seeding rate of about 320,000 seeds ha^{-1}. At harvest, the plant population was 263,423 plants ha^{-1} in 2005 and 310,763 plants ha^{-1} in 2006 when averaged over all plots. Two rows of onion spaced 25 cm apart were planted in the center of 76 cm wide beds. The onions were harvested on August 30th both years for fresh weight yield and graded for size. Marketable onion sizes (Schwartz and Bartolo, 1995) were colossal (>10.2 cm diameter), jumbo (7.6 to 10.2 cm diameter), and medium (5.1 to 7.6 cm diameter). Final onion harvest yields are expressed as fresh onion weight ha^{-1} with an average water content of 918 g kg^{-1}. Estimated gross return per hectare was calculated based on a harvest price of \$441 Mg^{-1} of colossal, \$353 Mg^{-1} of jumbo, and \$265 Mg^{-1} of medium size onions in 2005 and \$617 Mg^{-1} of colossal, \$529 Mg^{-1} of jumbo, and \$352 Mg^{-1} of medium size onions in 2006. Water cost was estimated at \$0.36 cm^{-1}. The drip irrigation system was estimated to cost \$1853 ha^{-1} (disposable drip tube used plus amortized cost for pump, filter, and set-up material used for more than one year). Labor costs, although

[3] Trade names and company names are included for the benefit of the reader and do not imply any endorsement or preferential treatment of the product by the authors or the USDA, Agricultural Research Service.

different for each irrigation system, were not considered in this simple economic analysis as well as other input costs (seed, herbicides, machinery, cultivation, etc.) which were the same for both irrigation systems. Herbicides were applied for weed control, with the plots being relatively weed free during the study period.

Soil water in the onion row was monitored almost daily during the early part of the onion growing season using Watermark[1] soil moisture sensors (Irrometer Company, Riverside, CA[1]) placed in the seed row at a depth of 20 cm, and by the "feel" method (Klocke and Fischbach, 1998) for each of the irrigation systems. Soil water tension was maintained at about -20 kPa (Shock et al., 2007) in the drip-irrigated plots, but was more variable in the furrow-irrigated plots (-20 to -30 kPa) due to less frequent irrigations. The onions under drip irrigation were irrigated 20 times during the growing season with a total gross water application of 68.6 cm in 2005, and 17 times during the growing season in 2006 with a total gross water application of 87.9 cm. Onions under furrow irrigation received a total gross water application of 243.8 cm using 13 irrigations in 2005, and 202.7 cm in 2006 using 12 irrigations. Under furrow irrigation, water was applied to every furrow (76 cm spacing) to obtain uniform wetting of both onion rows on the bed. The runoff water from the furrow irrigated plots was estimated using a flume placed in the furrow at the lower end of the field. Approximately 82.3 cm of the water applied ran off the end of the field in the furrow irrigated system in 2005 and 62.0 cm in 2006. No water was lost off the end of the field with the drip system. Using the daily evapotranspiration (ET) value for onion obtained from the Colorado State University CoAgMet weather station located at AVRC, a estimated growing season ET was calculated for 2005 and 2006 with respective ET values of 74.2 cm and 78.2 cm. Water lost to deep percolation within the field was estimated by subtracting crop ET from precipitation received plus net irrigation water applied for the growing season. In 2005, an estimated 104 cm of water moved below the onion root zone with furrow irrigation and 11 cm with drip irrigation. In 2006, an estimated 88 cm of water was lost to deep percolation with the furrow irrigation and 36 cm with drip irrigation.

The average NO_3-N level in the irrigation water for the season was 1.4 mg kg^{-1}, with about 9.6 kg NO_3-N ha^{-1} added to the soil with the drip system and 22.6 kg NO_3-N ha^{-1} with the furrow irrigation system in 2005. The average NO_3-N level in the irrigation water for the season was 1.3 mg kg^{-1}, with about 11.4 kg NO_3-N ha^{-1} added to the soil with the drip system and 18.3 kg NO_3-N ha^{-1} with the furrow irrigation system in 2006 based on the net amount of irrigation water that stayed in the field.

Precipitation during the growing season in 2005 was 39.4 mm in March, 19.1 mm in April, 12.4 mm in May, 26.7 mm in June, 11.4 mm in July, and 55.1 mm in August and in 2006, 23.1 mm in March, 7.9 mm in April, 40.1 mm in May, 7.11 mm in June, 82.6 mm in July, and 96.8 mm in August. Total precipitation for the growing season (March – August) was 164 mm in 2005, a rather dry season during April, May, June, and July, and 258 mm in 2006, with March, April, May and June being relatively dry.

Onion samples (six adjacent onions from each treatment) were collected at two week intervals from 25 May until harvest (30 August) both years. At final harvest, two rows 3-m long were hand harvested from each plot. The onions at each sampling were separated into leaves and bulbs for dry matter and N-uptake determination. The onion parts were dried at 60 C to determine dry matter yield. Plant samples collected for N analysis were ground to pass a 150-Φ screen and analyzed for N content using an Elementar vario Macro C-N analyzer (Elementar Americas, Inc., Mt. Laurel, NJ)[1].

Irrigation water use efficiency (IWUE) was calculated for each treatment. IWUE was calculated as the fresh onion yield divided by the cm of net irrigation water applied. Nitrogen use efficiency (NUE) was expressed in two ways: 1) NUE_1 was equal to total N uptake (leaves + bulbs) divided by available N (AN) [soil N (0-60cm) + fertilizer N + irrigation water N] times 100, and 2) NUE_2 was equal to the fresh onion yield divided by AN. A NFUE was calculated for the 2006 onion crop because the whole plot area had been uniformly cropped with no variable N fertilizer treatments for several years prior to initiation of the study and the check (zero fertilizer N) plots represented a true zero fertilizer N treatment. The NFUE was calculated as follows:

NFUE = (N uptake of fertilized treatment – N uptake of check plot)*100/N fertilizer rate.

A NFUE value was not calculated for the 2005 onion crop because the check plots had not received N for more than 5 years, compared to the fertilizer N plots in the study that had received N fertilizer each crop year. Thus the amount of mineralizable soil N was assumed to be less in the check plots (502 kg N ha^{-1} removed by previous crops from 2000 through 2004) than the other plots in the study receiving annual N fertilizer additions, therefore, a NUE was calculated as done by Halvorson et al. (2005) for the 2005 onion N treatments.

Soil NO_3-N levels in the 0- to 180-cm profile were measured before fertilization and after onion harvest. One soil core was collected with a hydraulic soil sampler from near the center of each plot each spring (0- to180-cm profile) prior to fertilization and planting and from the harvested onion row near the center of each plot after harvest each year. The soil core was sectioned into 15-cm increments for the first 30-cm depth, then into 30-cm increments to a depth of 180 cm for determination of NO_3-N content. Soil samples were sieved through a 2 mm screen in preparation for soil NO_3-N content determination. Soil NO_3-N concentrations (cadmium reduction) were determined by using a continuous flow analyzer (Lachat QuickChem FIA+8000 Series[1], Lachat Instruments, Loveland, CO) after extraction with 1 *M* KCl (soil:solution ratio, 1:5). A soil bulk density of 1.44 g cm^{-3} was used to convert soil NO_3-N to a mass basis.

Analyses of variance were performed using Analytical Software Statistix8 program (Analytical Software, Tallahassee, FL[1]) to determine treatment effects. All statistical comparisons were made at $\alpha = 0.05$ probability level unless otherwise stated using the least significant difference method for mean separation. A linear-plateau model was used to describe the yield and economic response of onions to N fertilization in 2005 using PROC NLIN in SAS (SAS Institute, 2002). If the analysis of variance indicated a significant F value for N rate, a linear or quadratic function was fit to the N response data using regression functions present in the graphics program SigmaPlot v.8.0 (SPSS Inc., Chicago, IL[1]).

RESULTS

Onion Yield – Fresh Weight

Excellent marketable onion yields were obtained in 2005 (92.7 Mg ha^{-1}) and in 2006 (79.1 Mg ha^{-1}) with the 2005 marketable onion yield being significantly greater than the 2006 yield. Averaged over N rates and both years, the drip irrigation system produced significantly greater onion yield (91.9 Mg ha^{-1}) than the furrow irrigation system (79.9 Mg ha^{-1}). A significant ($P = 0.088$) N rate by year interaction was present due to an onion yield response to N fertilization in 2005 following chile pepper, but no response to N application in 2006 following soybean (Fig. 1, Table 1). In 2005, onion yields were approaching maximum with an estimated N rate of 131 kg N ha^{-1} (Fig. 1). The response to N fertilization in 2005 probably resulted because of the prior conservative N management used for corn (2001-2003; Halvorson et al.,

2005) and chile pepper (2004) production on the plot area. This probably resulted in removal of a sizeable amount of mineralizable N (502 kg N ha^{-1} from check plot) from the 2005 plots, making this a more responsive site to N fertilizer additions. In 2006, the onion plots were located on a field that had been in soybean in 2005 and well fertilized corn for several years prior to soybean. Thus, the soil mineralizable N pool was probably larger in the 2006 plot area due to past N management, resulting in little response of onion to N fertilization in 2006. The lack of response of onion to N fertilization in 2006 was typical of previous unpublished N studies on onion by the authors at this location. The 2006 results suggest that onion producers can take a conservative approach to N application on onion in the Arkansas River Valley area of Colorado when following soybean or other legume crops in rotation. The 2005 onion study also indicates that N fertilizer rates of less than 150 kg N ha^{-1} can result in optimum onion yields, compared to the usual 200+ kg N ha^{-1} rates used by many producers.

Because of the significant N rate x year interaction for fresh onion yield, each year was analyzed separately when evaluating the influence of N rate on onion size. The quantity of colossal size onions ($P = 0.12$) and jumbo size onions ($P = 0.02$) increased with increasing N rate in 2005, but the quantity of medium size onions ($P = 0.02$) decreased with increasing N rate when averaged over irrigation systems (Table 1). The N rate x irrigation system interactions were not significant ($P > 0.5$) in both years. Nitrogen fertilization had no effect on onion size in 2006 (Table 1).

The drip system had more colossal and jumbo size onions than the furrow system in 2005 and 2006, and generally fewer medium size onions than the furrow system when averaged over N rates (Table 2). The higher established plant population in 2006 (310,763 plants ha^{-1}) versus the lower population in 2005 (263,423 plants ha^{-1}) may have reduced the colossal size onion yield in 2006 due to closer plant spacing. In 2005, the percentage of colossal size onions increased from 5% for the check plot (no N added) to a maximum of 14% of the total marketable onions at the 134 kg N ha^{-1} rate ($P = 0.08$) when averaged over irrigation systems. Increasing N rate did not change the percentage of jumbo size onion as a percentage of the total marketable onion yield, averaging 80% over all N rates and irrigation systems in 2005. Increasing N rate decreased the percentage of medium sized onions from 14.4% at the lowest N rate to 5.4% at the highest N rate ($P = 0.01$) when averaged over irrigation systems in 2005. This demonstrates the need to have adequate N available to maximize bulb size. These results also demonstrate the value of the drip system in producing larger size onions with more market value compared to the furrow irrigation system.

An adjusted gross dollar return per hectare (gross return *minus* N fertilizer, water, and drip system costs) was calculated for each treatment. Adjusted gross returns (Fig. 2) were increased with increasing N rate in 2005 for both irrigation systems with no significant N rate by irrigation system interaction ($P = 0.21$). Adjusted gross returns were significantly greater with the drip system (\$32,985 ha^{-1}) than with the furrow system (\$30,328 ha^{-1}) when averaged over N rates in 2005. Adjusted gross returns were significantly greater with the drip system (\$40,777 ha^{-1}) than with the furrow system (\$33,285 ha^{-1}) when averaged over N rates in 2006. Adjusted gross returns were significantly greater with the drip system (\$36,881 ha^{-1}) than with the furrow system (\$31,807 ha^{-1}) when averaged over N rates and years. A significant irrigation system by year interaction resulted from the drip irrigation having a greater adjusted gross return than furrow irrigation; however, the difference was greater in 2006 (\$7,492 ha^{-1}) than in 2005 (\$2,657 ha^{-1}).

Onion Yield – Dry Weight

Onion leaf biomass (oven dry basis) averaged over irrigation systems and years did not vary significantly with N rate, nor were the N rate by irrigation system and N rate by year interactions significant. Onion leaf biomass was significantly greater in 2005 (1669 kg ha^{-1}) than in 2006 (1431 kg ha^{-1}) when averaged over N rates, irrigation systems, and harvest dates. Leaf biomass varied with irrigation system and harvest date (Table 3), with a significant irrigation system by harvest date interaction. Onion leaf development started increasing rapidly in mid-June, then leveled off in late-July and decreased slightly during August as older leaves began to senesce and drop off within both irrigation systems. The interaction occurred because leaf biomass was similar between irrigation systems in May, June, and early-July, but the drip system attained greater leaf yields than the furrow system during the latter part of the growing season (Table 3). The dry matter accumulations observed in 2005 and 2006 are similar to the onion growth curves reported by Schwartz and Bartolo (1995) and Halvorson et al. (2002).

Onion bulb yields were influenced by irrigation system and harvest date as shown in Table 3. The irrigation system by harvest date interaction resulted from both irrigation systems having similar yields from May through early August, then the drip system having greater yields from mid-August to harvest (Table 3). During May, June, and July there was no difference in bulb yield between irrigation systems, however in August, bulb yield was greater with the drip than furrow irrigation system. Onion bulb initiation began in early June both years. Onion bulb development was very slow until early-July, then developing very rapidly until maturity in late August. Onion bulb yields (oven dry basis) varied significantly with N rate when averaged over irrigation systems and years, with a significant N rate by year interaction (Table 4). The interaction occurred due to a greater bulb response to N fertilization in 2005 than in 2006, similar to the fresh bulb yield. A significant N rate by harvest date (Table 4) interaction was also present for onion bulb dry weight yields. There were no differences in dry matter bulb yields among N rates until the first sampling date in August. The higher N rates began achieving greater dry matter yields than the lower N rates starting in mid-August. Bulb dry matter yields were near maximum with the application of 90 kg N ha^{-1} at the August 30th harvest date in 2005, with no significant differences between N rates in 2006.

Nitrogen Uptake

Nitrogen accumulation by the onion leaves averaged over irrigation system, years, and harvest date was increased by N fertilization with the 224 kg ha^{-1} N rate having significantly higher N accumulation (32.1 kg N ha^{-1}) than the 0 and 45 kg ha^{-1} N rates (27.6 and 29.4 kg N ha^{-1}, respectively). The significant ($P = 0.069$) N rate by harvest date interaction is shown in Table 5. During May and early-June, N fertilization rate had little influence on the N accumulation by onion leaves. Starting in late-June through July, the higher N rates (>45 kg N ha^{-1}) had the greatest amount of leaf N accumulation. In August, N levels in the onion leaves declined until harvest, with no significant differences in N accumulation with N rate. The N accumulated by the onion leaves was apparently being translocated to the onion bulbs. Irrigation system significantly influenced N accumulation by onion leaves, with the drip system having significantly more N accumulated (32.8 kg N ha^{-1}) than the furrow system (28.0 kg N ha^{-1}) when averaged over N rates, years, and harvest dates. The N rate by irrigation system interaction was not significant. The significant irrigation system by harvest date interaction for leaf N accumulation is shown in Table 3. During May and June, there were no significant differences in leaf N accumulation between irrigation systems; however, leaf N accumulation was greater for the drip system than the furrow system from July through final harvest. In both irrigation systems, N uptake increased from May through July, then declined until harvest. Nitrogen accumulation by onion leaves was significantly greater in 2005 (32.2 kg N ha^{-1}) than in 2006 (28.6 kg N ha^{-1}) when averaged over all variables. This reflects the greater fresh onion yield in 2005 than in 2006. The N accumulation patterns for onion leaves reported for this study are similar to the N accumulation patterns reported by Halvorson et al. (2002). At final harvest, N accumulation in the leaves was significantly greater with the drip system (25.7 kg N ha^{-1}) than with the furrow system (21.2 kg N ha^{-1}). The C:N ratio of the onion leaves returned to the soil at harvest was 31 when averaged over years.

Nitrogen accumulation by the onion bulbs increased with increasing N rate, with a significant N rate by harvest date interaction (Table 5). During May, June, and early-July, N rate had no affect on the N accumulation by onion bulbs. From mid-July through harvest, N accumulation in the onion bulbs increased with increasing N rates with N accumulation leveling off above the 134 kg ha^{-1} N rate. Nitrogen accumulation increased in the onion bulbs with each sequential harvest date. At final harvest, N accumulation in the bulbs was greater with the drip system (105.2 kg N ha^{-1}) than with the furrow system (89.7 kg N ha^{-1}) when averaged over N rates and years (Table 3).

The significant irrigation system by harvest date interaction is shown in Table 3 for onion bulb N accumulation. From May through early August, there were no significant differences in N accumulation by the onion bulbs between irrigation systems; however, at the 16 and 30 August sampling dates, the drip system had greater N accumulation by onion bulbs than the furrow system. The N rate by irrigation system interaction was not significant for onion bulb N accumulation. In contrast to onion leaves, N uptake by onion bulbs was greater in 2006 (35.3 kg N ha^{-1}) than in 2005 (31.2 kg N ha^{-1}), with significant N rate by year and irrigation system by year interactions. The significant N rate by year interaction occurred as a result of greater N accumulation by onion bulbs in 2006 than in 2005 at the lower N rates with similar N accumulation levels at the higher N rates (data not shown). The significant irrigation by year interaction resulted from a larger difference in onion bulb N accumulation (data not shown) between the drip and furrow systems in 2005 (drip 21% greater than furrow) than in 2006 (drip 3% greater than furrow).

Total N accumulation (leaves + bulbs) varied significantly with N rate, irrigation system, and harvest date when averaged over years with significant N rate by harvest date (Table 5) and irrigation system by harvest date interactions (Table 3). The irrigation system by harvest date interaction resulted from no differences in total N accumulation from May through early-July, then greater total N accumulation with the drip system than with the furrow system until harvest (Table 3). The N rate by harvest date interaction resulted from little difference in total N accumulation among N rates in May and June, with the higher N rates tending to have greater N accumulation than the 0 and 45 kg ha^{-1} N rates during mid-July until harvest (Table 5). A N rate by year interaction occurred due to lower total N accumulation at the low N rates in 2005 than in 2006, but greater N accumulation in 2005 than in 2006 at the two highest N rates (data not shown). This reflects the greater response of onion to N application in 2005 than in 2006. The greater N response in 2005 probably reflects a lower level of mineralizable soil N in the 2005 plots due to the previous 4 years of corn and one year of chile pepper production with conservative N application rates compared to the 2006 onion plots where soybean was grown the previous year and relatively high rates of N application to previous crops. A significant irrigation by year interaction resulted from a larger difference in total N accumulation (data not shown) between the drip and furrow systems in 2005 (drip 21% greater than furrow) than in

2006 (drip 8% greater than furrow). At final harvest, total N accumulation (leaves + bulbs) was significantly greater with the drip system (130.9 kg N ha^{-1}) than with the furrow system (110.9 kg N ha^{-1}) when averaged over N rates and years.

Irrigation Water Use Efficiency

Irrigation water use efficiency (IWUE) based on gross water applied was not affected by N fertilization when averaged over irrigation systems and years. IWUE was significantly greater for the drip system (1216 kg yield cm^{-1} H_2O) than for the furrow irrigation system (534 kg yield cm^{-1} H_2O) when averaged over N rates and years. IWUE was greater for 2005 (993 kg yield cm^{-1} H_2O) than for 2006 (757 kg yield cm^{-1} H_2O) when averaged over N and irrigation treatments. The only interaction that was significant was the irrigation by year interaction. This resulted from IWUE being greater in 2005 (1441 kg yield cm^{-1} H_2O) than in 2006 (990 kg yield cm^{-1} H_2O) for the drip irrigation system and not significantly different between years for the furrow irrigation system (545 kg yield cm^{-1} H_2O in 2005 and 524 kg yield cm^{-1} H_2O in 2006).

Nitrogen Use Efficiency

Nitrogen use efficiency (NUE_1) decreased significantly with increasing N rate when expressed as a function of total N uptake and AN. A significant N rate by year interaction was present with NUE_1's of 238, 98, 80, 59, 45, and 47% in 2005 and 154, 90, 62, 54, 45, and 39% in 2006 for the 0, 45, 90, 134, 179, and 224 kg ha^{-1} N rates, respectively. The interaction resulted from greater NUE_1 differences between years at the lower N rates than at the higher N rates. This probably reflects a lower level of mineralizable N in the lower N rate plots of the 2005 study compared to a potentially higher level of readily available mineralizable N following soybean in the 2006 study. The high NUE_1 values for the zero N rates suggest that mineralizable N became available to the onion crop during the growing season and was not accounted for in the AN value used to calculate NUE_1. A reliable mineralizable N value was not available to use in this calculation. The drip irrigation system resulted in a greater NUE_1 (92%) than for the furrow irrigation system (76%) when averaged over N rates and years. Average NUE_1 was greater in 2005 (94%) than in 2006 (74%) due to a greater total N uptake with the higher onion yield in 2005.

Nitrogen fertilizer use efficiency (NFUE) for the 2006 onion crop (4.1%) was not significantly affected by N fertilization rate (P=0.81), but was significantly different between irrigation systems (P=0.02). In 2006, NFUE was 7.1% for drip and 1.0% for furrow irrigation systems. These NFUE values are lower that the NFUE values of 30% reported by Simmis (1997) and 15% by Halvorson et al. (2002). This demonstrates the N management concern when growing irrigated onions which are very shallow rooted, yet require considerable N application to attain high yield and large size onions.

Expressing NUE_2 on a fresh yield basis as a function of AN, NUE_2 decreased with increasing N rate with a significant N rate by year interaction. NUE_2's were 1637, 717, 560, 409, 312, and 306 kg yield kg^{-1} AN in 2005 and 1199, 693, 473, 395, 332, and 290 kg yield kg^{-1} AN in 2006 for the 0, 45, 90, 134, 179, and 224 kg ha^{-1} N rates, respectively. The interaction resulted from greater NUE_2 differences between years at the lower N rates than at the higher N rates. The drip irrigation system resulted in a greater NUE_2 (654 kg yield kg^{-1} AN) than with the furrow irrigation system (566 kg yield kg^{-1} AN). Average NUE_2 was greater in 2005 (657 kg yield kg^{-1} AN) than in 2006 (564 kg yield kg^{-1} AN) as a result of the greater onion yield in 2005.

Residual Soil Nitrate-N

Residual soil NO_3-N levels at study initiation, after onion harvest, and prior to planting a corn crop the following year are reported in Table 6. Initial soil NO_3-N levels in the 0- to 60-cm soil depth were slightly higher in the furrow plots than the drip irrigation plots in 2005, but similar in 2006. After onion harvest, residual soil NO_3-N levels were not different between irrigation systems in the 0- to 60-cm soil depth both years. In 2005, residual soil NO_3-N levels were significantly greater with the drip system than with the furrow system in the 0- to 180-cm soil depth, reflecting less water lost to deep percolation with drip (11 cm) compared with furrow (104 cm). In April 2006, residual soil NO_3-N levels were significantly greater in the plots of the 2005 drip system than in the 2005 furrow system plots. For the 2006 onion crop, there was no significant difference in residual soil NO_3-N levels between the drip and furrow systems at planting or after harvest in the 0- to 180-cm soil depth; however, residual soil NO_3-N levels were slightly greater in the drip than furrow irrigation plots in April 2007, reflecting the loss of 88 cm of irrigation water to deep percolation with the furrow system compared to 36 cm for the drip system. Residual soil NO_3-N levels were greater following the onion crop in 2005 than in 2006, particularly with the drip system. More rainfall during the latter part of the growing season in 2006 plus a greater loss of irrigation water with drip irrigation in 2005 than in 2006 may have resulted in more leaching of the N applied to the onion crop than occurred with the drier growing season in 2005. Residual soil NO_3-N generally increased with increasing N rate in both systems with no significant N rate by irrigation system interaction, except for the 0- to 180-cm soil depth in April of 2006 following the 2005 onion crop (Fig. 3). The data in Fig. 3 suggest that the drip system reduced soil NO_3-N leaching compared with the furrow system in 2005.

SUMMARY

This study demonstrates that potential economic returns can be maintained or improved by using the lower water requirement, but more costly drip irrigation system for onion production rather than the normal furrow irrigation production system. Fresh onion yield response to N fertilization was similar for both irrigation systems in 2005, with no significant response to N fertilization in 2006. Onion yields were near maximum with the application of 132 kg N ha^{-1} in 2005. Nitrogen fertilization increased onion size in 2005. Onion response to N fertilization was significant following chile pepper but not following soybean in rotation. The results suggest that onion producers can take a conservative approach to N application on onion in the Arkansas River Valley area of Colorado unless the amount of potentially mineralizable N in the soil profile has been reduced by previous crops, such as several years of continuous corn, prior to onion production. The drip system produced greater onion yields with more large sized onions, greater estimated economic returns, and used 64% less irrigation water than with the furrow irrigation system averaged over 2 years. The drip irrigation resulted in greater IWUE, NFUE, and NUE than with furrow irrigation. Less NO_3-N appears to have been lost from the soil 0- to 180-cm profile with the drip system compared with the furrow irrigation system. Visually, soil erosion was also less with the drip system than with the furrow irrigation system. Converting from furrow irrigation to drip irrigation for onion production appears to have economical and environmental advantages in the Arkansas River Valley of Colorado.

ACKNOWLEDGMENT

The authors wish to thank Patti Norris, Brad Floyd, Robert D'Adamo, and Kevin Tanabe for their field assistance and analytical support in processing the soil and plant samples and collecting the data reported herein, and Dr. Alan Blaylock with Agrium, Inc. for providing the Duration Type III® polymer-coated urea for the study.

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List of Figures

Table 1. Colossal, jumbo, and medium sized and total marketable fresh onion yield as a function of N rate each year averaged over irrigation systems.

	Year							
N rate	2005				2006			
	Fresh onion market size class and total marketable yield†							
kg N ha^{-1}	Colossal	Jumbo	Medium	Total	Colossal	Jumbo	Medium	Total
	Mg ha^{-1}							
0	5.07c	67.13c	11.26a	83.46b	0.82a	51.40a	26.03a	77.52a
45	6.16bc	70.31bc	8.43abc	84.90b	0.62a	57.32a	21.77a	79.18a
90	11.20ab	74.27abc	8.80ab	94.27a	0.00a	55.01a	21.33a	76.42a
134	14.22a	77.64a	7.05bc	98.91a	0.85a	52.77a	25.96a	78.82a
179	13.74a	76.87a	6.17bc	96.78a	0.64a	59.46a	21.00a	80.54a
224	14.11a	78.74a	5.25c	98.10a	0.31a	59.53a	22.53a	82.16a
P>F	0.12	0.02	0.02	0.01	0.66	0.59	0.43	0.66
α	0.20	0.05	0.05	0.05	n.s.	n.s.	n.s.	n.s.

†Yield values within a column followed by the same letter are not significantly different at α shown.

Table 2. Colossal, jumbo and medium sized fresh onion yields as a function of irrigation system each year averaged over N rate.				
Irrigation system	Year	Colossal†	Jumbo†	Medium†
		Mg ha^{-1}		
Drip	2005	12.48a	78.59a	7.26a
Furrow	2005	9.02b	69.73b	8.39a
Drip	2006	1.00a	67.60a	17.86b
Furrow	2006	0.09b	44.22b	28.35a

†Yield values within a year and size class followed by the same letter are not significantly different at α = 0.05.

Table 3. Onion leaf and bulb yields (oven dry) and N accumulation as a function of sample harvest date and irrigation system (significant irrigation system by harvest date interaction) averaged over N rates and years.				
	Yield		N accumulation	
Sample Date	Drip	Furrow	Drip	Furrow
	kg dry matter ha^{-1}		kg N ha^{-1}	
Onion leaves				
24 May	44	42	1.4	1.4
7 June	195	226	6.8	8.1
21 June	708	691	20.9	20.0
5 July	1685	1653	40.7	37.3
20 July	3049	2532	66.8	51.0
2 August	2784	2648	52.9	49.5
16 August	2643	2198	47.0	35.8
30 August	2016	1688	25.7	21.2
$LSD_{0.05}$	139 within irrig. system 159 between irrig. system		3.0 within irrig. system 3.3 between irrig. system	
Onion bulbs				
24 May	7	6	0.2	0.2
7 June	24	28	0.8	1.0
21 June	118	131	2.9	3.0
5 July	531	649	7.7	7.8
20 July	1933	2055	25.6	25.2
2 August	4808	4699	51.1	49.5
16 August	7504	6699	84.4	73.6
30 August	7685	6626	105.2	89.7
$LSD_{0.05}$	232 within irrig. system 247 between irrig. system		2.9 within irrig. system 2.8 between irrig. system	

Onion leaves + bulbs				
24 May	51	48	1.6	1.6
7 June	218	253	7.6	9.0
21 June	826	822	23.7	23.0
5 July	2215	2303	48.5	45.1
20 July	4981	4587	92.4	76.2
2 August	7592	7347	104.1	99.0
16 August	10146	8897	131.4	109.5
30 August	9701	8314	130.9	110.9
$LSD_{0.05}$	306 within irrig. system 347 between irrig. system		4.7 within irrig. system 5.1 between irrig. system	

Table 4. Oven dry onion bulb yield as a function of N rate and sample harvest date (significant N rate by harvest date interaction) averaged over irrigation systems and years, and N rate and years (significant N rate by year interaction) averaged over irrigation system and harvest dates.

	Fertilizer N rate (kg N ha^{-1})					
Sample Date	0	45	90	134	179	224
	Onion bulb yield, kg ha^{-1}					
24 May	7	6	7	8	6	7
7 June	22	28	28	28	22	28
21 June	101	135	125	128	126	131
5 July	558	602	570	607	577	625
20 July	1533	2014	2069	2305	1994	2048
2 August	4140	4443	5201	5070	4687	4981
16 August	6764	7322	7008	6946	7297	7271
30 August	6793	6865	7100	7403	7282	7492
$LSD_{0.05}$	402 within N rate; 416 among N rates					
Year						
2005	2320	2660	2895	2878	2893	2984
2006	2659	2694	2632	2746	2605	2662
$LSD_{0.05}$	259 within N rate; 265 among N rates					

Table 5. Onion leaf and bulb N accumulation as a function of N rate and sample harvest date averaged over irrigation systems and years (significant N rate by harvest date interaction).

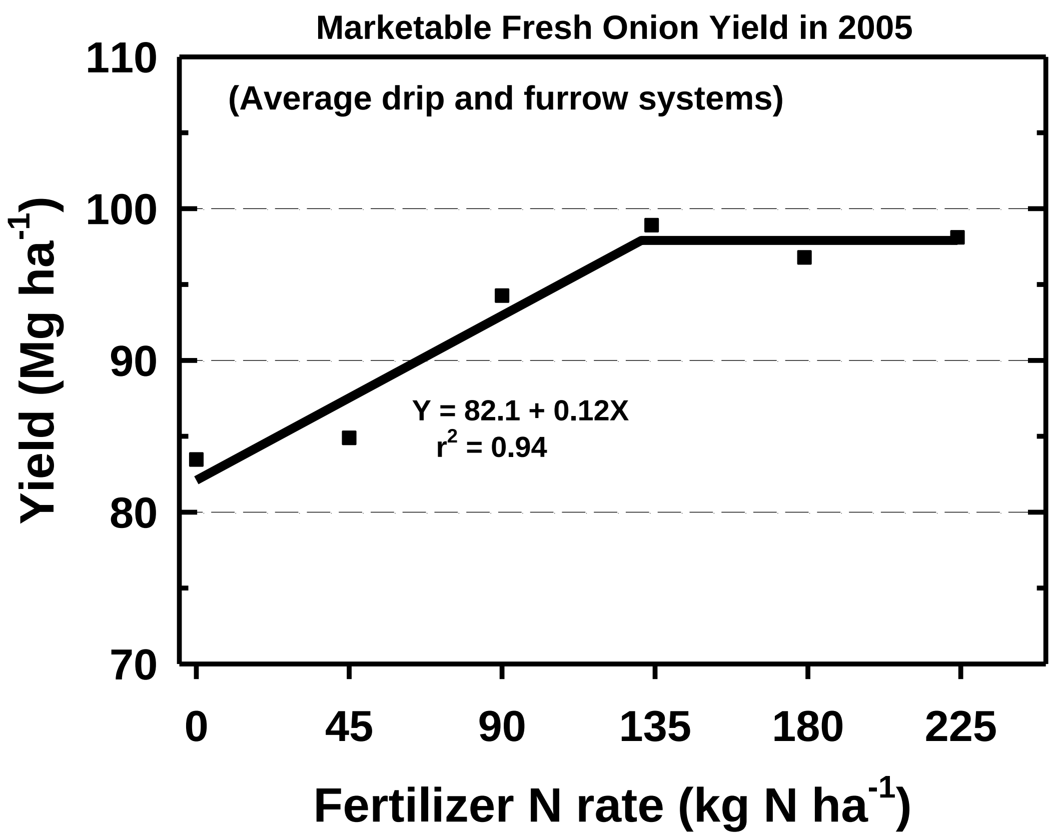
	Fertilizer N rate (kg N ha^{-1})					
Sample Date	0	45	90	134	179	224
	N accumulation, kg N ha^{-1}					
Onion leaves						
24 May	1.2	1.3	1.3	1.5	1.6	1.5
7 June	6.2	7.5	7.7	7.7	7.3	8.1
21 June	15.4	20.0	20.3	20.7	23.1	23.0
5 July	30.5	37.7	40.5	42.7	40.0	42.7
20 July	53.4	53.7	63.8	60.6	59.2	62.4
2 August	49.8	49.3	51.7	51.2	50.2	55.2
16 August	40.0	43.3	41.3	39.9	43.7	40.1
30 August	24.2	22.7	24.6	22.9	22.4	23.8
$LSD_{0.10}$	4.4 within N rate; 4.7 among N rates					
Onion bulb						
24 May	0.1	0.1	0.2	0.2	0.2	0.2
7 June	0.7	1.0	1.0	0.9	0.8	1.0
21 June	2.1	2.9	3.0	3.1	3.3	3.3
5 July	6.0	7.6	8.0	8.0	8.2	8.7
20 July	18.3	24.1	27.7	28.1	26.6	27.6
2 August	41.7	45.3	55.3	55.4	50.8	53.4
16 August	71.9	79.0	74.5	80.7	82.3	85.7
30 August	88.3	88.2	93.0	105.7	103.3	106.2
$LSD_{0.05}$	5.0 within N rate; 5.1 among N rates					
Onion leaves + bulbs						
22 May	1.3	1.5	1.5	1.7	1.7	1.7
7 June	6.9	8.5	8.7	8.6	8.1	9.0
21 June	17.5	22.9	23.4	23.8	26.4	26.3
5 July	36.5	45.3	48.5	50.7	48.2	51.3
19 July	71.7	77.8	91.5	88.8	85.8	90.0
2 August	91.5	94.5	107.0	106.6	101.0	108.6
16 August	111.9	122.3	115.8	120.7	126.1	125.9
30 August	112.5	110.9	117.6	128.6	125.7	130.0
$LSD_{0.05}$	8.2 within N rate; 8.8 among N rates					

Table 6. Soil NO_3-N levels in the 0- to 60-cm and 0- to 180-cm depths before onion planting in the spring, after onion harvest in the fall, and before planting a corn crop in April of 2006 or 2007 following onion in rotation.

N rate	Before planting		After harvest		April of next year	
	0 – 60 cm	0 – 180 cm	0 – 60 cm	0 – 180 cm	0 – 60 cm	0 – 180 cm
kg N ha^{-1}	Soil NO_3-N, kg N ha^{-1}					
	February 2005		September 2005		April 2006	
0	45c†	80bc§	41c	93c	72c	107e
45	48c	79c	72bc	140bc	109bc	159de
90	56bc	87bc	70bc	132c	145b	213cd
134	56bc	74c	114ab	223ab	159b	231bc
179	69b	111ab	141a	249a	250a	329a
224	91a	125a	87abc	180abc	215a	289ab
	February 2006		September 2006		April 2007	
0	52a	77a	25c	50c	48c	94c
45	58a	81a	41c	70c	51bc	119bc
90	58a	79a	77bc	126bc	73ab	169b
134	55a	78a	82bc	125bc	75a	173b
179	53a	76a	133ab	204ab	77a	167b
224	47a	67a	212a	286a	81a	233a
Irrigation	February 2005		September 2005		April 2006	
Drip	56b	84b	96a	211a	200a	293a
Furrow	66a	101a	79a	128b	117b	150b
	February 2006		September 2006		April 2007	
Drip	56a	79a	92a	137a	71a	178a§
Furrow	52a	74a	99a	150a	64a	140b

†Soil NO_3-N values within a sampling depth for each year followed by the same letter are not significant at $\alpha = 0.05$ unless otherwise indicated.
§ Soil NO_3-N values within the 0-180 cm depth for February 2005 followed by the same letter are not significant at $\alpha = 0.10$

Figure 1.



Marketable Fresh Onion Yield in 2005
(Average drip and furrow systems)
Y = 82.1 + 0.12X
r2 = 0.94
Yield (Mg ha-1)
110
100
90
80
70
0
45
90
135
180
225
Fertilizer N rate (kg N ha-1)

Figure 2

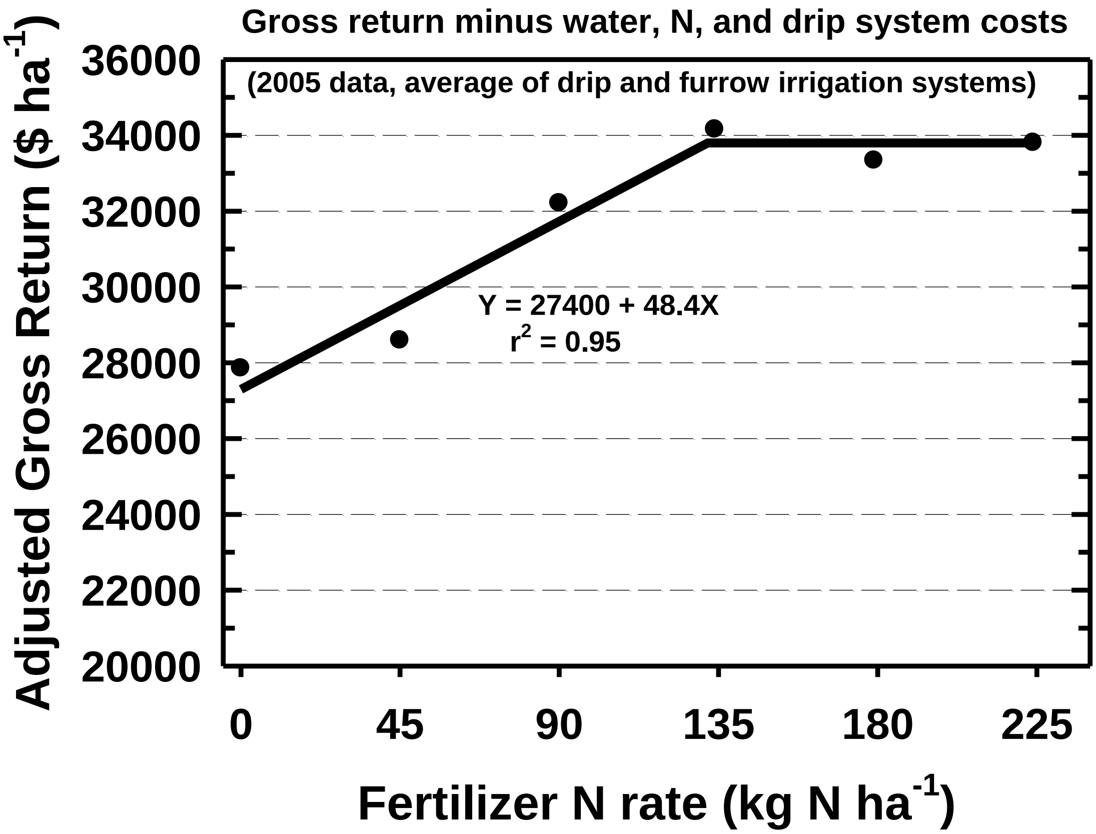
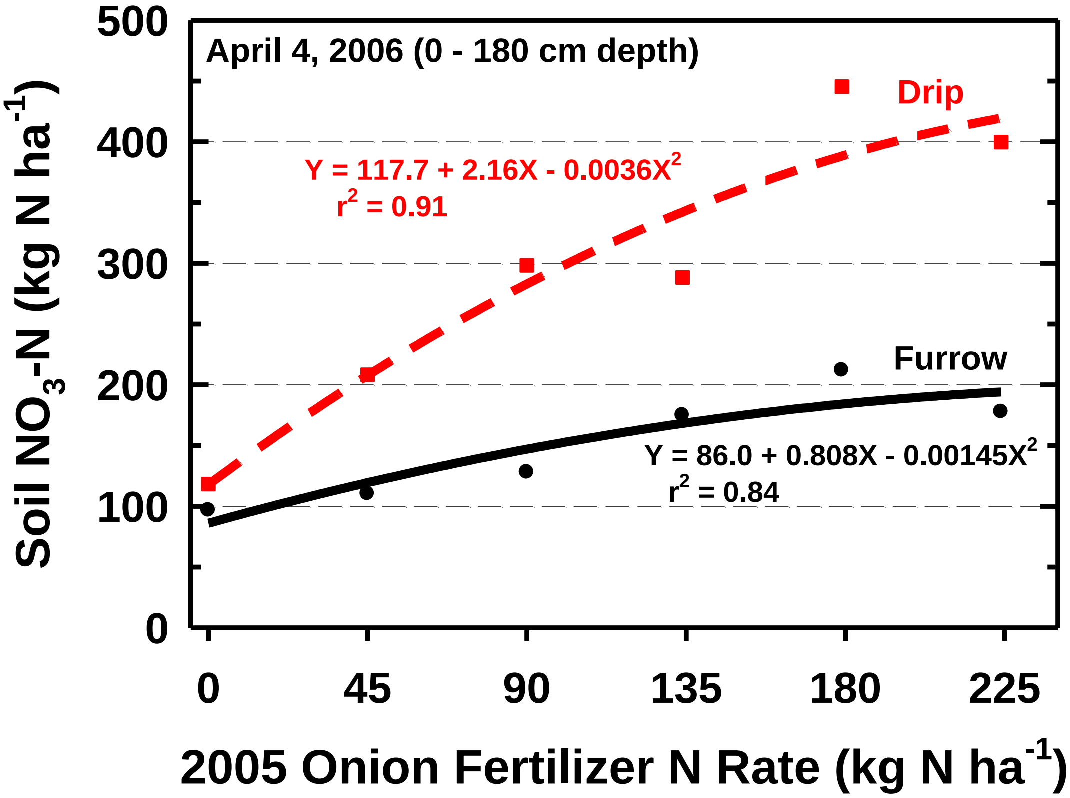

Gross return minus water, N, and drip system costs
(2005 data, average of drip and furrow irrigation systems)
Y = 27400 + 48.4X
r2 = 0.95
Adjusted Gross Return ($ ha-1)
36000
34000
32000
30000
28000
26000
24000
22000
20000
0
45
90
135
180
225
Fertilizer N rate (kg N ha-1)

Figure 3.


April 4, 2006 (0 - 180 cm depth)
Drip
Y = 117.7 + 2.16X - 0.0036X^2
r^2 = 0.91
Furrow
Y = 86.0 + 0.808X - 0.00145X^2
r^2 = 0.84
Soil NO_3-N (kg N ha^{-1})
2005 Onion Fertilizer N Rate (kg N ha^{-1})
0
100
200
300
400
500
0
45
90
135
180
225

2007 VEGETABLE CROP REPORTS

Onion Variety Trial

Mike Bartolo
Arkansas Valley Research Center
Colorado State University

PRODUCTION INFORMATION

Plots - *Planted 20' long X4 rows on beds spaced 60" on centers. Rows were spaced 12" apart on top of the bed with an in-row spacing between plants of ~3". Harvested 8 bed feet (8' X 2 rows) for yield determination. Water was supplied via drip irrigation. Each plot was replicated four times in the trial.*

Planted *- March 20th, 2007*

Fertilizer *- 104 lbs. P_2O_5/A and 22 lbs N/A as 11-52-0 - preplant. ~ 100 lbs. N/A residual and 12 lbs N supplied via drip system.*

Weed Control *- Roundup Ultra on April 9th*
-Goal 2 and Starane on May18th
- Prowl and Outlook on May 21st
- Goal 2 + Dual II + Select on June 19th ,
- Dual and Trigger and Goaltender on July 7th ** all ground applications*
- Hand weeded 2 times

Insect Control *– Lannate on June 20th, Warrior and Lannate on July 7th* ** all ground applications*

Disease Control *– Dithane + Top Cop on July 7th (ground application), Dithane and NuCop July 14th and July 23rd* ** all ground applications*

Irrigation *– The plots were irrigated multiple times via drip. The amount of irrigation water applied was approximately 26 inches and seasonal precipitation was 9.4 inches.*

Harvest *– September 6th* ***Grade*** *– November 15-20th*

Comments

The 2007 season was good for onion production with no disease problems and only slight damage from storms. Thrips populations were fairly high and control measures were relatively ineffective. High population of thrips and severe leaf scarring may have contributed to some yield losses. There was no Iris Yellow Spot Virus detected in the plots. Please contact Mike Bartolo at the Arkansas Valley Research Center (719-254-6312) for additional information.

ONION VARIETY TRIAL - Arkansas Valley Research Center - 2007

Variety	*Source*	*Maturity (% tops down) 8-27*	*Colossals ∃ 4" %*	*Jumbos 3"-4" %*	*Medium 2ℨ"-3" %*	*Pre-Pack 1 :"-2ℨ" %*	***Total Market. Weight CWT/A***	*Culls %*	*Total Weight CWT/A*
X-Y201	Waldow	22	5.3	78.9	13.0	2.0	**764.4**	0.7	770.8
X-Y202	Waldow	12	0.0	72.6	23.0	4.3	**758.1**	0.0	758.1
Vaquero	Nunhems	72	0.0	63.3	32.4	4.3	**749.5**	0.0	749.5
Tequilla	D. Palmer	20	1.8	64.4	29.0	4.3	**718.2**	0.5	722.4
Ranchero	Nunhems	62	1.4	55.3	39.7	3.5	**716.6**	0.0	716.6
Generation X	D. Palmer	20	0.0	59.3	37.0	3.7	**693.7**	0.0	693.7
Evolution	D. Palmer	17	0.0	69.6	28.5	1.8	**688.4**	0.0	688.4
Cinch	Bejo	15	0.0	76.9	18.9	3.1	**668.1**	1.1	677.2
Peso	Bejo	22	0.0	63.5	32.8	3.7	**635.2**	0.0	635.2
OLYS03-222 (W)	Crookham	87	0.0	58.9	37.4	3.1	**622.4**	0.6	626.1
Mesquite	D. Palmer	12	5.4	69.0	22.5	1.5	**614.4**	1.5	622.9
OLYS03-207	Crookham	17	0.0	57.5	36.5	6.0	**601.6**	0.0	601.6
T-433	Takii	27	0.0	69.7	26.3	3.9	**601.6**	0.0	601.6
OLYS05N5	Crookham	10	1.1	78.1	17.7	3.0	**597.9**	0.0	597.9
Cometa	Nunhems	27	0.0	50.8	43.8	5.4	**596.9**	0.0	596.9
OLYS03-207	Crookham	12	0.0	77.1	20.7	2.2	**586.2**	0.0	586.2
NUN8000ON	Nunhems	22	1.0	53.2	40.7	5.1	**582.5**	0.0	582.5
Delgado	Bejo	20	0.0	39.2	53.6	7.1	**581.4**	0.0	581.4
Affirmed	Seminis	77	0.0	70.7	25.9	3.4	**572.9**	0.0	572.9
Charismatic	Seminis	55	0.0	60.0	33.9	6.1	**563.9**	0.0	563.9
Desparado	Bejo	42	0.0	52.8	40.7	6.5	**551.6**	0.0	551.7
Harmony	Crookham	12	1.1	65.0	29.0	3.4	**551.1**	1.4	560.2
Colorado 6	Burrell's	12	0.0	67.8	27.3	3.3	**544.2**	1.6	552.7

XP7106 (W)	Seminis	20	0.0	43.2	52.5	4.3	**539.9**	0.0	539.9
Joaquin	Nunhems	17	0.0	68.5	29.9	1.5	**535.1**	0.0	535.1
Calibra	Bejo	62	0.0	42.5	50.2	6.8	**534.6**	0.5	537.8
NUN7606ON	Nunhems	42	0.0	47.1	44.4	8.5	**530.4**	0.0	530.4
Toluca (W)	Seminis	35	0.0	46.8	48.0	4.6	**526.1**	0.5	528.8
Arcero	Nunhems	27	1.7	48.5	46.2	3.6	**504.8**	0.0	504.8
Sedona	Bejo	22	0.0	30.5	62.6	6.4	**503.8**	0.5	506.4
BGS231	Bejo	15	0.0	38.9	53.0	5.8	**473.4**	2.2	484.1
Granero	Nunhems	47	0.0	29.7	63.5	6.8	**468.6**	0.0	468.6
Pandero	Nunhems	22	0.0	35.4	59.8	4.8	**465.5**	0.0	465.5
Gunnison	Bejo	52	0.0	11.7	71.0	17.3	**450.0**	0.0	450.0
Crockett	Bejo	10	0.0	21.9	68.0	10.1	**445.2**	0.0	445.2
Talon	Bejo	45	0.0	13.6	78.0	8.4	**429.3**	0.0	429.3
DPS 1417	D. Palmer	47	0.0	34.3	58.6	6.3	**397.9**	0.8	401.1
Salsa (R)	Nunhems	50	0.0	28.6	67.8	3.6	**390.4**	0.0	390.4
DPS 1423	D. Palmer	90	0.0	20.6	71.1	8.2	**380.3**	0.0	380.3
DPS 3052 (R)	D. Palmer	15	0.0	9.8	71.5	15.6	**333.0**	3.0	343.6
DPS 1418	D. Palmer	67	0.0	2.5	82.5	14.9	**327.1**	0.0	327.1
DPS 3055 (R)	D. Palmer	15	0.0	3.9	69.3	23.7	**309.0**	3.0	320.2
DPS 1424	D. Palmer	85	0.0	9.3	72.9	17.8	**300.5**	0.0	300.5
DPS 3058 (R)	D. Palmer	12	0.0	6.1	65.9	23.8	**293.6**	4.2	306.4
DPS 1413	D. Palmer	57	0.0	1.1	82.1	16.8	**279.3**	0.0	279.3
DPS 3062 (R)	D. Palmer	7	0.0	5.6	76.9	12.3	**275.5**	5.1	289.9
DPS 1415	D. Palmer	50	0.0	1.6	66.0	32.4	**270.7**	0.0	270.7
DPS 1416	D. Palmer	67	0.0	10.4	69.2	18.4	**258.5**	2.1	263.8
DPS 1414	D. Palmer	47	0.0	1.2	65.7	33.1	**253.2**	0.0	253.2
DPS 1419	D. Palmer	47	0.0	4.6	71.5	23.9	**233.0**	0.0	233.0
Lsd (0.1)=							108.5		109.1

Onion Response to Different Water Qualities

Mike Bartolo
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ABSTRACT

Onions are one of the highest value and most-widely grown vegetable crops in Colorado. Onions are also one of the most salt-sensitive crops and are susceptible to water deficits due to the shallow nature of their root system. In Colorado and other rapidly urbanizing western states, the competition for water resources is dramatically increasing. As a result, growers are using alternative water sources that often have lower quality than sources originating directly from streams and rivers.

In 2007, a study was conducted to characterize the response of commonly-grown onion cultivars (Ranchero, X-202, Cometa, and Red Bull) to irrigation waters having an average electrical conductivity (EC) of about 1.0 $dS.m^{-1}$ (low EC river water) or 2.8 $dS.m^{-1}$ (high EC groundwater). The timings and amounts of irrigations were the same for both water treatments throughout the growing season and all irrigations were delivered via a drip system.

Overall, onion yields were high regardless of irrigation water source. However, total marketable yield was significantly less for all varieties when irrigated with high EC water compared to low EC. The red variety (Red Bull) had the greatest decrease in total marketable yield (23.9 %) when irrigated with the high EC water. The proportion of jumbo class onions (>3" in diameter) was also significantly reduced. As a result, economic losses were realized for all onion varieties when irrigated with the high EC water.

INTRODUCTION

Growers in the Arkansas Valley of Colorado face increasing pressure to conserve water along with other natural resources. Recent droughts and heightened competition for water from rapidly growing urban areas have compelled many growers to adopt more efficient irrigation methods like drip.

In Colorado, irrigation water derived from the Arkansas River and its shallow alluvial aquifer can be of poor quality. The Arkansas River, for example, is one of the most saline rivers for its size in the country (Miles, 1977). Furrow irrigation can aggravate salt accumulation in the root zone and can lessen the quality of water that is returned to the river (Bartolo et al., 1995; Halvorson et al., 2002). Applied properly, drip irrigation can successfully manage water that is high in salt content (Hartz, 1994).

Many Colorado growers adopting drip irrigation rely on systems that are designed to use groundwater rather than surface water. In contrast to surface water, groundwater is free of sediment and is available on a more timely and reliable basis, making it ideal for drip irrigation. Unfortunately, groundwater often contains 2-3 times the amount of salt than surface water.

Onions are one of the more salt-sensitive crops. Yield reductions can occur when the electrical conductivity (EC) of the saturated soil paste extract reaches 1.2 dS.m-1 or the EC of irrigation water reaches 0.8 dS.m-1. Yield reductions of 50% can be realized when the EC of irrigation waters are as little as 2.9 dS.m-1 (Ayers, 1977). Some research, however, suggests that yield reductions due to salinity may vary with onion cultivar and may not be as severe if salinity is due to calcium and sulfur-containing salts rather than sodium-containing salts (Doss et al, 2003)

This study was conducted to characterize the response of four commonly-grown onion cultivars to irrigation waters having an EC of 1.0 $dS.m^{-1}$ (river/surface water) or $2.8 dS.m^{-1}$ (groundwater). The derived information will help growers manage their diminishing water resources more efficiently and economically.

MATERIALS AND METHODS

This field study was conducted on a Rocky Ford silty clay loam soil at Colorado State University's Arkansas Valley Research Center (AVRC) in Rocky Ford, Colorado. The plot area had been fallow in 2006. Two irrigation water sources were examined as the main plots: surface water diverted from the Arkansas River and groundwater derived from a shallow (25-30 feet deep) alluvial aquifer on the AVRC site. The surface water varied slightly in salinity during the course of the season but had an average electrical conductivity (EC) of approximately 1.0 $dS.m^{-1}$. The groundwater had an EC of 2.8 $dS.m^{-1}$. Other characteristics of the water sources are noted in Table 1.

Component	Groundwater*	Surface**
Calcium	283 ppm	111 ppm
Sodium	133 ppm	64 ppm
Hardness - CaCO3	1022 ppm	420 ppm
Sulfate	1053 ppm	365 ppm
Specific Conductance	2.77 ds/m	1.00 ds/m
TDS	1764 ppm	720 ppm

Table 1: Chemical characteristics of ground and surface waters.* Analysis at AVRC, ** EPA analysis at Arkansas River

Four commonly-grown onion varieties were selected as the subplots. The varieties were „Ranchero' (Nunhems) and X-202 (Waldow), yellow-skinned types, „Cometa' (Nunhems), a white-skinned type, and Red Bull (Bejo), a red-skinned type. Onions were direct-seeded on March 12, 2007 at a seeding rate of about 130,000 seeds per acre. Four rows of onion were planted on beds with 60 inches between centers. Onion rows were spaced 12 inches apart and in-row spacing between onions seeds was approximately 3.1 inches. Each sub-plot was 25 feet long and one bed

(5 feet) wide. Borders beds were placed on each side of the sampling areas to avoid any cross contamination from irrigation treatments.

Irrigation water was delivered via drip lines (Netafim-8 mil,12" emitter-.22 gph). There were two drip lines per bed, spaced 12 inches apart and at a depth of 4 inches. Each drip line was equidistance from two onion rows (Figure 1). Throughout the season, both water sources were delivered in the same quantity and at the same time.

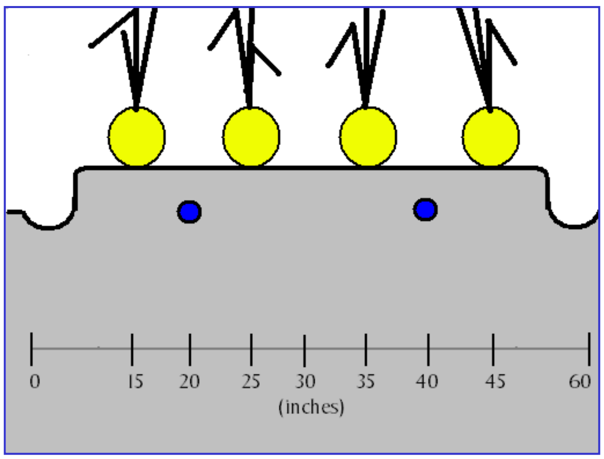

Figure 1: Planting and drip line configuration

Irrigation timing and duration was based on weather data collected from a nearby electronic weather station, the need to enter fields for cultural operations, and estimated soil moisture content from *Watermark Sensors*. All cultural practices were consistent with others used in Colorado (Schwartz and Bartolo, 1998).

Soil samples were taken prior to planting, near bulbing and after harvest. Each time, samples were taken at two locations in the bed: below the inside seed-row and in the middle of the furrow between the raised beds. Samples were taken at depths of 0-6", 6-12", 1-2', and 2-3'. Soil salinity was estimated by developing a curve comparing the saturated pasted extract with a 1:1 soil-water extract.

Onions were harvested September 7th and held in storage until grading in October. Marketable onion sizes were colossal (<4" diameter), jumbo (3 to 4" diameter), and medium (2 to 3" diameter). Onion yields were expressed as bags (one bag = 50 lbs) of fresh onion weight per acre.

RESULTS

Total marketable yield was lowered significantly in all varieties when irrigated with the high EC water. The red variety (Red Bull) had a 23.9% decrease in yield when irrigated with the high EC water (Figure 2).

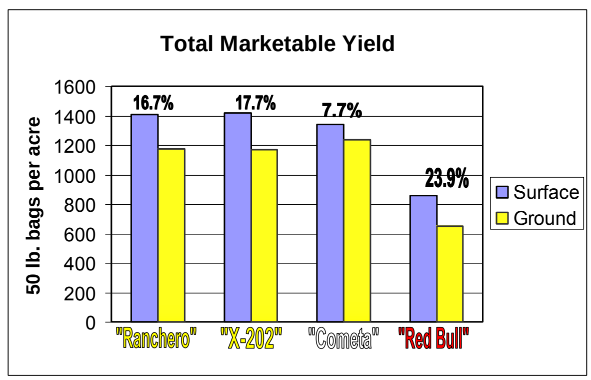

Figure 2: Total market yield of onion varieties grown with surface and well water. (DMRT: p<0.1)

Soil salinity was measured after harvest (September 21st) at different locations in the production bed. Salinity levels generally reflected the salt content of the water sources (Figure 3). The highest salinity levels were detected at the surface layers and at outside of the production bed (furrow), near the edge of the wetting front.

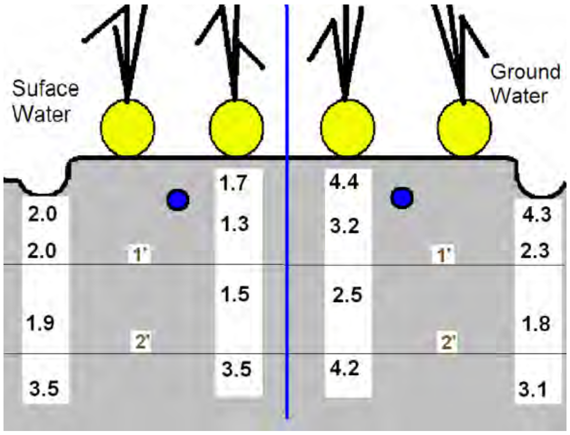

Figure 3: Electrical conductivity (in $dS.m^{-1}$) of the soil measured at depths of 0-6", 6-12", 1-2', and 2-3" below the seed row and bed furrow. Samples were taken on September 21, 2007.

CONCLUSIONS

As seen in past studies, onion response to high salinity in the Arkansas Valley of Colorado may not be as severe as those predicted by other studies; studies conducted with soils and waters more influenced by the presence of sodium salts. As a result, growers using groundwater may be able to manage salinity by choosing varieties that are more tolerant of salinity and irrigating with a sufficient volume of water to prevent excessive build-up of salt in the soil profile.

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Sweet Onion Production from Transplants

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In 2007, a study was conducted to determine the yield and quality of onion varieties grown from containerized transplants. The onions were evaluated for their potential to be used in a specialized market for low pungency (sweet) onions.

Overall, the variety *NuMex Arthur* had significantly larger bulbs and lower pungency (as measured by pyruvic acid content) compared to other varieties including the currently used industry standard, *Candy*.

MATERIALS AND METHODS

This field study was conducted on a Rocky Ford silty clay loam soil at Colorado State University's Arkansas Valley Research Center (AVRC) in Rocky Ford, Colorado. Onions were seeded into 200 cell plastic flats containing commercial potting soil on March 23rd. All of the varieties were yellow-skinned and intermediate-day types. On April 27th, the transplants were set into the field at the 4-5 leaf stage. Onion rows were spaced 12 inches apart and in-row spacing between onions plants was 4 inches. Each plot was 10 feet long and one bed (5 feet) wide. Irrigation water was delivered via drip lines. There were two drip lines per bed, spaced 12 inches apart and at a depth of 4 inches. Each drip line was equidistance from two onion rows. Standard production and pest management practices were employed during the course of the season.

Onions were harvested August 22nd when all of the onion tops had fallen over. The onions were held in storage until weighing on October 2nd. Five representative bulbs from each variety were sent to the Vegetable and Fruit Improvement Center at Texas A&M University for chemical analysis. On October 5th, the bulbs were analyzed for soluble solid (% Brix) and pyruvic acid content.

Acknowledgemnts: We would like to sincerely thank Dr. Chris Cramer at New Mexico State University for providing some of the seed used in this trial.

Results

Bulb weight, soluble solids content (% Brix) and pungency as measured by pyruvic acid content of three onion cultivars.

Variety	Bulb Weight (g)	Brix (%)	Pyruvic Acid (μmole/ml)
Candy	243.84 b	6.58 a	6.42 a
NuMex 06-80-4	247.19 b	6.10 b	5.56 a
Numex Arthur	270.36 a	5.88 b	3.22 a
Lsd (0.1)	15.39	0.32	0.89

Note: Onion bulbs having a pyruvic acid concentration of 5.5 or less are considered sweet according to Vidalia Labs sweet onion certification specifications.

Tomato Virus Control Trial

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Arkansas Valley Research Center
Colorado State University

In the Arkansas Valley and other parts of Colorado, tomatoes often face pest pressure that can severely reduce fruit yield and quality. In recent years, extremely high incidences of viral diseases have severely reduced tomato stands. Some growers have reported over 50% stand losses. Several viral diseases have been known to infect tomatoes in the state. Probably the most common is *Curly Top,* with the curly top virus (CTV) as the causal agent. The CTV is vectored by the beet leafhopper which has numerous hosts in addition to tomato. In other parts of the country, conventional insecticide applications have not been effective in controlling the beet leaf hopper and subsequently, the spread of the CTV.

This study was conducted to determine the effect of alternative measures for the control of CTV. The percentage of plants showing disease infection was recorded at prior to fruit maturity.

During the 2007 season, insect infestation and disease pressure were extremely low. Overall, there were no significant differences in treatments. Nonetheless, application of the systemic insecticide, *Admire*, via the transplant plug tray proved to be a relatively easy and low cost way to provide in-field protection to the tomato seedlings. The plant defense activator, *Actigard*, did not cause plant injury when applied to plants 14 days after transplanting. In previous studies, *Actigard*, caused moderate phytotoxic effects when applied to the foliage of transplants while still in the plug tray. Straw and a reflective silverized mulch (ReflecTec) did not have any negative effects on plant growth and development relative to a conventional black plastic mulch.

Methods

This study was conducted at the Arkansas Valley Research Center in Rocky Ford. Beds, 45 inches wide and 60 inches between centers, were shaped in early April. Drip lines were placed down the center of the bed at a depth of 2 inches. The beds were covered with black embossed plastic mulch (Mechanical Transplanter) or a silverized-reflective mulch (ReflecTec) on May 8th using a one-bed mulch layer.

Six-week-old transplants (cv. *Shady Lady*) were set through holes in the plastic mulch in a single row down the center of the bed on May 16th. The distance between plants was 18 inches. Each plot was three beds wide (15 feet) and 33 feet long and was replicated four times. There were 66 plants in each plot.

The experiment was designed as a randomized complete block with the following eight treatments:

1. Untreated control tomatoes grown in black plastic mulch.
2. Tomatoes grown in "Repelgro" silverized reflective mulch (Reflec Tec).
3. Tomatoes treated with Admire (Bayer Corp.) insecticide. Insecticide was drenched around the base of the transplants 3 days prior to transplanting (in the plastic flat) at a rate of 2 fluid ounces per acre. Plants were grown in black mulch.
4. Tomatoes treated with Admire (Bayer Corp.) insecticide. Insecticide was drenched around the base of the transplant on May 29th at a rate of 24 fluid ounces per acre. Each plant received 100 ml of drench solution. Plants were grown in black mulch.
5. Tomatoes treated with Admire (Bayer Corp.) insecticide. Insecticide was drenched around the base of the transplant on May 29th at a rate of 24 fluid ounces per acre. Each plant received 100 ml of drench solution. Plants were grown in silver mulch.
6. Tomatoes treated three times with Actigard 50WG (Syngenta Crop Protection). At each application, each treated plant was thoroughly wetted with a 38 ml solution containing 0.5 oz/acre Actigard. Applications were made June 5th and June 15th and July 6th .
7. Tomatoes grown in black mulch covered with straw mulch.
8. Conventional applications of *Provado* insecticide applied June 5th and June 15th and July 6th.

Disease symptoms were evaluated on July 11th. Plant infection was categorized as having slight infection (some leaf curling but still somewhat healthy plant) or obvious infection (severe leaf curling, plant yellowing, and stunting). It should be noted that the symptoms of "slight infection" are similar to those caused by other environmental stresses.

Percent tomato plants exhibiting signs of infection with Curly Top Virus on July 11th observation date.

Treatment	% Plants Showing Slight Infection	% Plants Showing Obvious Infection
1. Control	1	0
2. Silver Mulch	1	0
3. Admire: Transplant Drench	0	0
4. Admire: In-Field Drench	0	0
5. Admire + Silver Mulch	0	0
6. Actigard	0	0
7. Straw Mulch	0	0
8. Provado	1	0

Paper Mulches for Vegetable Production

Mike Bartolo – CSU Arkansas Valley Research Center
Mike Gallager – Sunshine Paper Company

Plastic mulches have become increasingly popular for the production of melons and other vegetable crops in the Arkansas Valley. Plastic mulches provide good weed control and improve water use efficiency, yield, and quality. One major drawback of the use of plastic mulches is the need for disposal at the end of the season. Plastic mulch disposal can be tedious and expensive since it requires significant hand labor.

The purpose of this observation trial was to evaluate a paper-based mulch for its applicability in both home and commercial production. Different mulch properties including ease of application, durability, and biodegradability were monitored.

Materials and Methods

This study was conducted at Colorado State University's Arkansas Valley Research Center in Rocky Ford. Beds, 45 inches wide and 60 inches between centers, were shaped in early April. Drip lines were placed 1-2 inches from the center of the bed at a depth of 3 inches. All beds used in this trial were reshaped with a commercial bed shaper just prior to laying the mulch down. The observation trial consisted of two treatments; one without mulch (bare ground) and one with black paper mulch provided by Sunshine Paper Company. The paper mulch was black in color, 24 inches wide and had a thickness of 3 mils. Each treatment was replicated four times in plots that were one bed (5') wide and 25' long. The paper mulch was applied by hand (Figure 1). Approximately 4-5 inches of material was buried on each side of the mulch.

Figure 1: Applying paper mulch by hand in May 2007 by (l-r) Emery Crump, Alisha Golden, and Jeremy Muth.

Acknowledgement: We would like to thank Sunshine Paper Co. for their generous support of this project.

After the mulch edges of the mulch were secured with soil , 2.5 inch diameter holes were cut in the center of the mulch using a hole (wood) bit. The holes were spaced 3 feet apart. In each hole, 2 seeds of pumpkin (var. Magic Lantern) were placed at a depth of 1-2 inches. During the course of the season, all standard production practices were conducted on the pumpkin crop. Both treatments, mulch and bare ground, were treated identical.

Observations

Ease of application	Paper was somewhat rigid and would be difficult to apply like plastic much with a mechanical layer. Tearing would be a problem. A modified mechanical layer, without press wheels, might work. Hand application would not be economically feasible on a commercial basis.
Mulch Characteristics	The mulch was somewhat rigid and prone to tearing if care was not taken. Nonetheless, the paper had very good conformation and contact to the soil. The width of the roll that was tested was a bit too narrow. A wider surface area would have provided more weed control.
Mulch Durability	The mulch was extremely durable. Over the course of the season, the mulch was subjected to numerousl cycles of wetting and drying, small hail, and high winds. Throughout the season, the much held in place and maintained its integrity. Near the end of the season, the portion of the mulch that was buried in the soil degraded and lost its integrity. However, by that time, the crop had covered the surface and helped hold the above ground portion in place (Figure 2)
Mulch Disposal	Easily incorporated into the soil at the end of the season. No disposal issues.
Crop and Production Characteristics	Crop growth was similar to other plastic mulches. Good weed control in covered portions. The mulch responded well to wetting and drying cycles associated with irrigations and precipitation.

Figure 2: Paper mulch at the end of the growing season after harvest and removal of crop residue.

Popcorn Variety Trial

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Frontier Wholesome Seeds

Despite the closure of the last remaining processing facility in the area several years ago, popcorn production has a long and successful history in the Arkansas Valley. Unique climatic conditions, specifically the large degree of separation between day and night temperatures, give rise to popcorn of superior quality. In an effort to support the reestablishment of the industry, this trial was conducted to compare the yield and quality attributes of new and standard popcorn varieties.

METHODS

This study was conducted at Colorado State University's Arkansas Valley Research Center (AVRC) in 2007. The Center is located near Rocky Ford, Colorado. The plot area had previously been in soybeans during 2006. The soil was type was a Rocky Ford silty clay loam soil. Popcorn varieties in the replicated yield trial were planted on May 4, 2007 with a fabricated plot planter at a seeding rate of about 32,000 seeds per acre. A single line of corn was planted on top of the bed with a 30-inch row spacing (furrow to furrow). Conventional corn production practices were used throughout the course of the season. Weeds were controlled by a pre-plant application of *Dual* and cultivation. Irrigation was by gravity-flow furrows with water being applied to every other furrow (every 60 inches). The yield trial was replicated four times in plots that were four rows (10 ft wide and 30 ft long). In addition to the yield trial, an observation trial was planted on May 5, 2007. The observation trial contained 20 entries planted into unreplicated plots. The observation trial was seeded by hand (Earthway push type planter) and later thinned to a population of over 31,000 plants per acre.

Several agronomic characteristics were measured and monitored during the course of the season. The yield trial was harvested on October 18 with a CSU-fabricated plot combine. Other quality characteristics will be reported in a later report.

Acknowledgemnts: We would like to sincerely thank Dr. Abdel Berrada for assistance with analyzing the data from this trial.

2007 Popcorn Yield Trial

Hybrid	Adjyld lb/acre	Moisture %	Test Weight lb/bu	Standability Stalk %	Standability Root %	Mid-Silk Date From July 1st	Ear Height ft
R997	4974	11.0	69.3	13.8	9.5	15.5	4.1
R128YH	4730	11.3	68.9	12.3	11.5	16.3	4.6
3751	4351	12.9	68.3	7.5	2.3	16.5	4.6
R501	4125	11.0	68.1	22.5	49.0	16.3	3.8
ME453	3675	11.8	68.7	9.3	48.5	22.0	5.1
VYP330	3597	11.6	68.6	10.3	11.0	17.8	4.6
R96566	2391	11.1	67.2	86.0	40.8	17.0	3.7
VEXP990198	2264	11.8	68.6	12.0	13.0	20.8	4.8
Means	**3763**	**11.6**	**68.5**	**21.7**	**23.2**	**17.8**	**4.4**
CV (%)	27	1.6	0.6	31.0	73.5	2.0	3.1
$LSD_{.05}$	1469	0.3	0.6	9.9	25.0	0.5	0.2

Qualitative characteristics

Hybrid	Silk color	Notes
R997	RED	Brown husk & green stalk
R501	WHITE	Heat stress & lots of tillers
R96566	WHITE	Heat stress
R128YH	WHITE	Green-snap
3751	RED	
VYP330	RED	
VEXP990198	RED	
ME453	RED	

2007 Popcorn Observation Trial

Hybrid	Entry	Adj. Yld lb/acre	Moisture %	Test Wt lb/bu	Standability %S	%R	Mid-silk date	Ear Ht ft	Silk COLOR	Notes
55 x 17	5	7192.3	12.2	67	0	0	17	3.75	W+R	
R128YH	14	4718.9	11.5	68.1	13	0	18	4	W	Green-Snap
61 x 17	6	4625.5	12.8	67.6	0	0	18	4	R	
12 x 17	3	4622.9	15	66	0	0	17	3.75	W	
55 x 27	7	4551.2	13.1	68	5	17	19	4.75	R	
11 x 17	2	4278.0	13.9	66.2	0	0	19	4	W	
12 x 53	9	3775.2	13.5	65.8	2	2	17	5	R	Few Tillers Heat-Stress
ME453 ARG	19	3744.9	11.8	68.1	2	3	22	4.75	R	
30 x 17	4	3709.8	12.3	67.9	6	19	16	4.5	R	Broken Stalks
58 x 27	8	3697.1	12.6	67.7	9	7	19	5	R	
R997	11	3603.1	11	68.7	0	0	15	3.75	R	
ME453 IOWA	20	3578.8	11.6	67.2	0	1	22	4.5	R	
BKH 3751	15	3530.2	12.8	67.9	2	4	16	4.25	R	
10 x 17	1	3016.7	13.6	65.5	0	0	20	3.75	W	
VYP330	16	2957.7	11.9	68.4	13	9	20	4	R	
R501	12	2705.9	11.6	67.5	22	18	17	3.5	W	
ME453	18	2612.7	11.8	68	0	0	22	4.75	R	Green-Snap
30 x 53	10	2428.1	11.8	67.1	0	12	19	5.25	R	
R96566	13	1924.7	11.4	66.8	93	11	18	3.5	W	Heat-Stress
VEXP990198	17	1309.3	11.6	68.1	5	25	21	4.5	R	
Means		**3629.1**	**12.4**	**67.4**	**8.6**	**6.4**	**18.6**	**4.3**		

White Corn Variety Trial

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White corn hybrids are dent types with specific starch traits and often referred to as hard endosperm types. Domestic demand for white corn has been strong in recent years with increased usage in cereals, tortillas, corn chips, snack foods, and corn meal. Production-wise, white corn will freely cross-pollinate with other corn types and therefore, isolation is necessary to ensure the highest quality. This trial was conducted to compare the yield and quality attributes of several commercially available white corn varieties and see how well they are adapted to the Arkansas Valley.

METHODS

This study was conducted at Colorado State University's Arkansas Valley Research Center (AVRC) in 2007. The Center is located near Rocky Ford, Colorado. The plot area had previously been in soybeans during 2006. The soil was type was a Rocky Ford silty clay loam soil. White corn varieties in the trial were planted on May 4, 2007 with a fabricated plot planter at a seeding rate of about 32,000 seeds per acre. On each side of the trial, eight rows of border were planted to reduce the amount of cross-pollination from nearby yellow corn. Border ranges were planted at the top of the plot area as well. A single line of corn was planted on top of the bed with a 30-inch row spacing (furrow to furrow). Conventional corn production practices were used throughout the course of the season. Irrigation was by gravity-flow furrows with water being applied to every other furrow (every 60 inches). The trial was replicated four times in plots that were four rows (10 ft) wide and 30 ft long.

A variety of agronomic characteristics were measured during the course of the season. The trial was harvested on October 17 with a CSU-fabricated plot combine. Other quality characteristics will be reported at a later time.

Acknowledgements: We would like to sincerely thank Dr. Abdel Berrada for assistance with analyzing the data from this trial.

2007 White Food Corn Yield Experiment

Entry no.	Hybrid	Adj yield bu/acre	Moisture %	Test Weight lb/bu	Standability Stalk %	Standability Root %	Mid-Silk Date From July 1st	Ear Height ft
4	Asgrow RX818W	185.1	15.8	60.2	8.5	0.0	19.5	3.7
11	Pioneer 32B10	169.1	13.9	60.3	14.8	0.8	20.5	4.5
10	Pioneer 33V62	167.6	13.1	61.0	22.5	8.0	20.3	4.6
9	Garst 1717W	160.6	14.7	62.2	9.8	0.8	20.8	4.3
8	Agrigold 6637W	155.5	15.5	61.7	16.0	1.8	19.8	4.4
5	Agrigold 6537W	153.6	14.8	61.3	21.5	1.3	21.0	4.5
6	Agrigold 6567W	147.5	13.9	63.5	11.8	2.0	17.8	4.1
3	NC+ 5774W	144.2	14.9	62.1	10.3	1.3	21.8	4.2
7	Agrigold 6587W	143.6	14.9	61.7	16.0	0.0	21.3	4.3
2	Hoegmeyer 1128W	142.7	14.5	62.3	9.0	0.0	19.0	4.3
1	Hoegmeyer 1080W	141.5	14.3	63.2	9.8	0.0	19.8	4.2
	Means	**155.5**	**14.6**	**61.8**	**13.6**	**1.4**	**20.1**	**4.3**
	CV (%)	9.1	2.6	0.5	41.5	183.5	3.3	3.3
	$LSD_{.05}$	20.5	0.5	0.4	8.2	3.8	1.0	0.2

The Lysimeter Project in Rocky Ford: Objectives and Accomplishments.

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Rationale and objectives:

One of the recommendations that came out of the Kansas v. Colorado Arkansas River Compact litigation is for Colorado to use the ASCE (American Society of Civil Engineers) Standardized Penman-Monteith equation to estimate crop consumptive use in the Arkansas River Valley. The Penman-Monteith equation (PME) calculates the evapotranspiration (ET) of a reference crop, which in Colorado is alfalfa, using meteorological data such as maximum and minimum temperature, relative humidity, solar radiation, and wind speed (Allen et al., 1998). The ET of other crops (ETc) is derived from reference ET (ETr) with the equation:

ETc = ETr x Kc for well-watered crops.

Kc or crop coefficient varies with crop type, growth stage, crop condition (plant density, health, etc.), and soil wetness, among other things. When the crop is water-stressed,

ETc = ETr x Kc x Ks

The coefficient Ks is derived from the water balance (water inputs minus water outputs) in the root zone.

ETr is defined as the evapotranspiration of a non-stressed, well watered alfalfa crop, 50 cm in height, covering the ground fully. In other states, the reference ET is that of a non-stressed grass or similar short crop that is 12 cm in height at full canopy and is usually denoted ETo.

Direct measurement of ET is best achieved with weighing lysimeters. Precision weighing lysimeters measure water loss from a control volume by the change in mass with an accuracy of a few hundredths of a millimeter. Non-weighing lysimeters are more common but they “are not considered suitable for reference ET equation verification and crop coefficient research. They may, however, be very suitable low cost alternatives for studying the effects of varying water salinity levels and high water table conditions on crop ET up and down the Arkansas River Valley.” (Ley, 2003).

In the absence of locally generated algorithms for calculating ETr with PME and Kc, the Colorado Division of Water Resources (DWR) has been using estimates from Kimberly, ID and Bushland, TX. However, the crop growing conditions (soil, elevation, climate, etc.) in the Arkansas Valley vary greatly from the prevailing conditions in Kimberly or Bushland. In his findings relating to the Arkansas River Compact compliance litigation initiated by Kansas, Special Master Arthur Littleworth accepted that the method used for calculating crop consumptive use in the Arkansas Valley be changed from Blaney-Criddle to PME. Consequently, Colorado’s Attorney General requested that the Colorado Water Conservation Board (CWCB) fund the “design, installation, and operation of weighing lysimeters at the Colorado State University Agricultural Experiment Station at Rocky Ford, Colorado”. The requested funds also cover the enhancement of CoAgMet weather stations, the investigation of irrigation water management in the Arkansas Valley, and the review of the changes made to the Hydrological-Institutional (H-I) Model by experts. The H-I Model has been used by the State Engineer’s Office (DWR) to determine depletions to usable water flows to Kansas.

Colorado State University (CSU) has a network of twelve automated weather stations along the Arkansas Valley. Temperature, solar radiation, humidity, and wind speed data from these stations will be used to validate ETr and Kc estimates for the whole Valley.

The lysimeter project at the Arkansas Valley Research Center (AVRC) consists of one large weighing lysimeter and one reference lysimeter. The large or *test* lysimeter was installed in 2006 and the reference lysimeter will be installed in 2008.

The project objectives, according to Thomas Ley of DWR (2003), are to:

1. Evaluate the performance and predictive accuracy of the ASCE Standardized PME for computing alfalfa reference crop ET for the growing conditions in southeastern Colorado,
2. Determine crop coefficients (for use with PME) for the various crops grown in the Arkansas River Valley under well-watered conditions, and,
3. Determine the effects of typical local growing conditions (which may include limited irrigation, high water table conditions and irrigation with water of high salinity contents) on crop water use.

The latter objective may require additional lysimeters e.g., non-weighing ones to achieve. It is worth noting that the effects of limited irrigation, high water table, and salinity on crop growth and water use in the Arkansas Valley have been studied by CSU scientists for several years using traditional (water balance estimates) and non traditional (remote sensing) methods. However, the impact of salinity for example on crop water use can be determined more accurately with a weighing lysimeter. Relatively high salt levels have been reported in the soils and waters of the Arkansas Valley (Gates et al., 2006).

The installation of the test lysimeter was completed in the fall of 2006, but some of the meteorological sensors were put in place in 2007. Consequently, it will be two to three years before achieving objective no. 1 and several more years before having usable Kc values and formulas for the major crops grown in the Arkansas Valley.

In the remainder of article, we will describe the main characteristics of the test lysimeter and its location and briefly review land preparation, crop establishment, and future plans.

Site characteristics:

The lysimeter is located at the Arkansas Valley Research Center, approximately two miles east of Rocky Ford in Otero County, Colorado (NW1/4 Sec 21, T23S, R 56W). The elevation at the site is approximately 1,274 m, latitude: 38° 2′ 17.30″, and longitude: 103° 41′ 17.60″. The soil type is Rocky Ford; coarse-loamy, mixed, superactive, mesic Ardic Argiustoll. Selected soil properties are shown in Tables 1 and 2.

Table 1. Soil characteristics of the test lysimeter site courtesy of Dr. Lorenz Sutherland USDA-NRCS

Horizon	Depth (cm)	Textural class	pH water (1:1)	CEC (meq/100 g)	ECe (dS/m)	Total C g/kg	SAR
Ap	0-23	Clay loam	8.1	17.2	0.82	15.5	1.70
Bt	23-36	Clay	8.0	16.9	0.90	14.8	2.08
Btk	36-100	Loam	8.3	10.0	0.58	9.0	2.46
Bk1	100-170	Loam	8.3	10.9	0.72	9.5	2.40
Bk2	170-230	Clay loam	8.3	13.5	0.88	10.8	2.18
2C	> 230	Course sand	8.7	1.5	-	1.7	-

Table 2. Soil bulk density and hydraulic properties (calculated) courtesy of Dr. Lorenz Sutherland USDA- NRCS

Horizon	Depth (cm)	Bulk density (g/cm^3)	Matric suction in J/kg						Hydraulic conductivity (cm/hr)
			1500	1000	500	100	33	10	
Ap	0-23	1.36	123	131	144	182	214	254	0.34
Bt	23-36	1.36	124	132	145	182	213	252	0.33
Btk	36-100	1.45	77	84	97	134	167	213	1.25
Bk1	100-170	1.43	82	89	103	141	176	224	1.06
Bk2	170-230	1.35	118	126	141	183	219	266	0.42
2C	> 230	1.86	19	22	26	40	53	73	16.9

The long-term average annual precipitation at the site is 11.8 inches, with May through August having the highest rainfall. The total average annual snowfall is 23.2 inches. The average minimum temperature is 36.3 ^{o}F and the average maximum temperature 70.0 ^{o}F. The last spring frost (32.5 ^{o}F) occurs on or before May 1 and the first fall frost on or before October 5 in 50% of the years; thus the average length of the growing season for warm-season crops like corn is 158 days.

Lysimeter characteristics:

The test lysimeter consists of an inner tank of 10 ft x 10 ft x 8 ft and an outer containment tank. The chamber between the two tanks houses the weighing mechanism, the drainage tanks, data loggers and has standing room for a half-dozen people (Fig. 3). The inner tank was filled with undisturbed soil (soil monolith) from the same field where the lysimeter is located (Fig. 1). Figure 2 shows the tank being lowered into its permanent location. The soil tank moves freely within the outer tank and the two are separated at the top by a fraction of an inch.

Figure 1. The inner tank being pushed into the ground to acquire the soil monolith. Photo taken by Dale Straw of DWR.

Figure 2. The inner tank plus soil being lowered inside the containment tank. Photo taken by Michael Bartolo.

The weighing mechanism consists of a mechanical lever scale-load cell combination. The load cells are connected to Campbell Scientific CR-7 data logger which records the weight of the inner tank plus soil every 10 seconds. The readings are given in millivolts per volt (mV/V). A thorough calibration procedure was performed in 2006 to convert the load cell output in mV/V to the weight of water in kilograms. The standard deviation of the weight measurements (accuracy) was less than 0.02%. The change in total weight of the soil tank represents the amount of consumptive water use (transpiration plus evaporation from the surface of the soil monolith) by the crop. An example of load cell reading is shown in Figure 4.

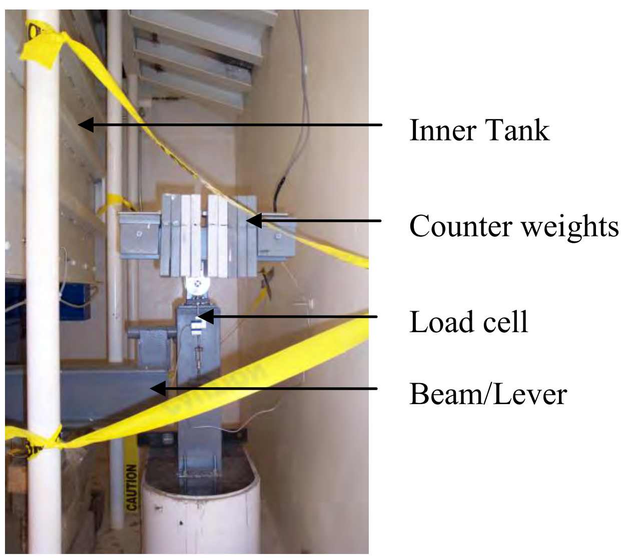

Figure 3. Inside the containment tank (west side). Photo taken by Dale Straw of DWR.

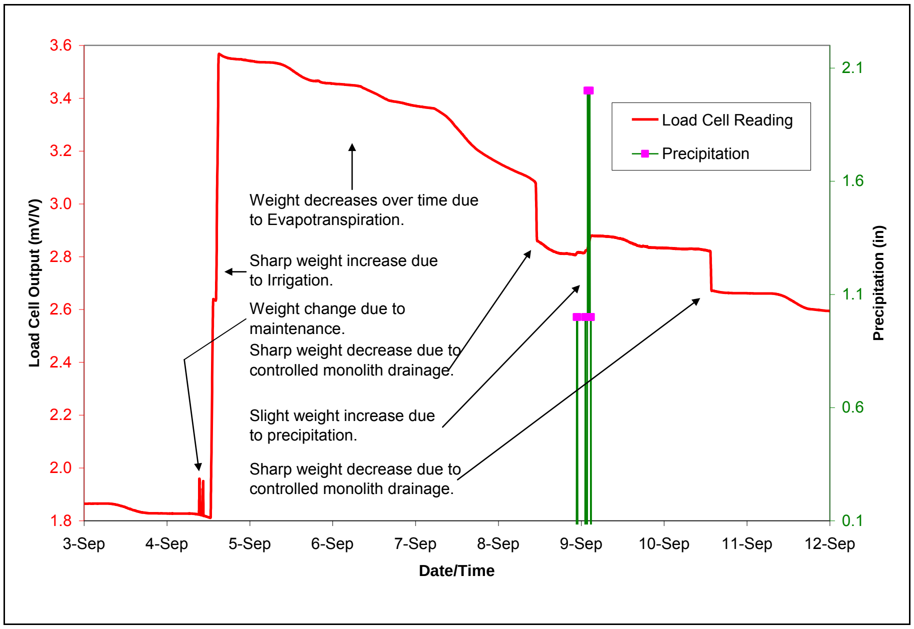

Figure 4. Load cell output for 3-12 Sept. 2006. Graph by Lane Simmons

Water that percolates through the soil monolith is collected in two drainage tanks suspended from the scale frame that supports the soil tank, so that there is no overall weight change as water drains into the tanks. One tank collects water from the internal portion of the monolith and the other tank collects water from the perimeter of the monolith.

Instrumentation:

Several instruments are located in, above, or outside the monolith. They are used to measure:

- Precipitation, wind speed and direction, minimum and maximum air temperature, barometric pressure, dew point temperature, relative humidity, and net radiation.
- Incoming (from the sun) and reflected (from the ground or plants) radiation, and incoming and reflected photosynthetic active radiation (PAR)
- Crop canopy temperature
- Soil temperature at various depths and heat flux in or out of root zone
- Soil moisture at 0- to 2.0 m in 20-cm increments with the CPN 503DR neutron probe. A calibration was performed to convert the probe readings into volumetric water content. The calibration procedure and results will be published elsewhere. Comparison of the soil water content inside and outside the soil monolith will be used to adjust the amount of water applied to the monolith and the amount of drainage.

Soil preparation

Shortly after the installation of the test lysimeter in 2006, the ground around it was flooded to settle the soil. Later, the ground was ripped with a Big Ox chisel plow to alleviate compaction, then plowed, disked, leveled, furrowed, and rolled. The distance between furrows is 30 inches, as is common in the Arkansas Valley. The top eight inches of the monolith were tilled with a roto tiller and the beds and furrows were prepared with shovels and spades. There are three full beds in the middle and a half bed against the eastern and western edges of the monolith, and four furrows. They are aligned with the beds and furrows outside the monolith and run north-south.

The total area designated for the test lysimeter to ensure a good fetch is 10 acres (520 ft x 840 ft), of which 6 acres were fallowed since 2005 and an adjacent 4 acres was in alfalfa since 2003. It was paramount to get all 10 acres managed uniformly, thus in early spring 2007, the area in alfalfa was sprayed with Roundup and the whole field was planted to oats on 5 April 2007 at 140 lb/acre. The oat crop inside and outside the monolith was irrigated four times and cut for hay on 25 June. Figure 5 shows the lysimeter after the oat was cut.

Figure 5. View of the lysimeter and meteorological instrumentation in late June 2007. Photo taken by Michael Bartolo.

The hay was baled on 2 July and the bales removed shortly after that. Oat was chosen as the first crop to be planted after the installation of the test lysimeter because it is easy to grow and could be planted and harvested early, allowing enough time for soil preparation and the seeding and establishment of the next crop (alfalfa) before fall dormancy.

In the latter part of July, the soil in the lysimeter field was again ripped, disked, and leveled. Alfalfa variety'Genoa' was seeded on 9 August at 19 lb/acre and the field was then furrowed and rolled. The soil inside the monolith was prepared and seeded by hand. The number and arrangement of beds and furrows was the same as with the oat crop. Two hundred pounds of 11-52-0 per acre were broadcast on top of the hay crop on 6 December.

Alfalfa establishment inside and outside the monolith was good to excellent, with the exception of a couple acres approximately 100 ft west of the lysimeter. In this area, alfalfa stand was spotty due to a heavy infestation of morning glory. The whole field was mowed with a brush hog on 27-28 September above the hay crop to suppress the taller weeds. That is when it became clear that approximately half of the area west of the lysimeter will have to be reseeded in the spring of 2008 to achieve a more uniform stand with the rest of the field. Alfalfa was irrigated on 17 August, 4 September, and 4 October. Water from the irrigation canal was dispensed to each furrow with a siphon.

Irrigation of the soil monolith:

The monolith was irrigated each time the surrounding area was. The amount of water applied was determined by subtracting the amount that flows (flow x duration) in and out of adjacent furrows, as measured by v-shaped furrow flumes. Water was pumped from the irrigation canal and applied to the monolith through a hose fitted with a flow meter and a valve. The furrows on the monolith were filled with water to simulate normal flood irrigation (Fig. 6).

Figure 6. Water being applied to the soil monolith. Photo taken by Michael Bartolo.

Future plans:

The reference lysimeter (5 ft x 5 ft x 8 ft) will be installed in 2008 in an adjacent field and seeded to alfalfa. The area of the test lysimeter field that has a poor alfalfa stand will be reseeded in the spring of 2008. Alfalfa in the test lysimeter field will be maintained for at least three more years to calibrate the PME. After that, the field will be planted to corn and other major crops in the Arkansas Valley (corn, wheat, sorghum, onions, etc.) to determine their crop coefficients. It will take at least two years of data per crop to generate reliable Kc estimates. Reference ET will be measured with the reference lysimeter after the results are tested and validated.

The lysimeter project is a joint effort between CWCB, DWR, and CSU. Support has also been provided by USDA-ARS engineers and scientists in Fort Collins, CO and Bushland, TX.

For more information about the lysimeter project at AVRC, please contact Lane Simmons at lane.simmons@colostate.edu or (719) 469-5559.

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