Final Report for Drip Irrigation Field Trial for Sustainable Potato Cropping in the San Luis Valley

In 2013 the Colorado Potato Administrative Committee applied to the Rio Grande Basin Roundtable to undertake a drip irrigation project that would serve as a pilot surface drip irrigation demonstration with three goals:

- **Would a drip irrigation system be practical in a potato – small grain rotation scheme that most growers use? Potato production requires a great deal of tillage and harvest involves handling and moving great amounts of soil? While drip irrigation has been shown to work in many crops would it work in this production situation?**
- **Would drip irrigation prove to be effective in meeting the consumptive needs of potato and small grain crops? Would yields be equivalent to center pivot irrigation systems currently in use? Would there be any water savings and if so how much?**
- **Would drip irrigation prove to be cost effective and affordable for growers in the San Luis valley?**

CPAC partnered with two potato growers to establish these demonstration plots, Beiriger Farms near Hooper and Christensen Farms close to Center. Both growers were willing to invest a great deal of their own time and money into the project. They agreed to allow other growers to personally visit their farms during the summer and to participate in a field day for Rio Grande Basin Roundtable members held in August of 2013.

The two sites were designed, engineered, and installed by Diversity D out of Dalhart, Texas. Diversity D was selected because there were no local drip irrigation companies in the San Luis valley, and they had years of experience with drip irrigation in crops like corn, cotton, and wheat in the southern high plains. They also had worked with melon growers in the Arkansas Valley on successful drip irrigation projects, and were recommended by Colorado State University researchers from the agricultural experiment station in Rocky Ford.

At both locations two distinct drip layouts were set up. The first set, meant to be a permanent installation, involved drip tape buried at a twelve inch depth and a width of sixty eight inches. Because the potato growers planted on thirty four inch rows this design allowed a buried tape to supply water to two rows of potatoes with a dry row in between. This design is successfully used in other rows crops like corn at thirty inch rows. This installation occurred prior to planting potatoes. The twelve inch depth was chosen because the growers believed this was deep enough to prevent tillage and harvest operations from damaging the buried tape. Approximately twelve acres were installed at Beiriger Farms, and nearly forty on Christensen Farms.

The second set, meant to be a retrievable installation, involved drip tape laid out on the soil surface at a width of sixty eight inches. This tape would be covered by a few inches of soil during normal potato hilling operations after planting the potatoes. Approximately twenty acres were installed at Beiriger Farms, and nearly forty on Christensen Farms.

Two agricultural consulting firms agreed to monitor the project throughout the growing season on a weekly basis. Cactus Hill Ag Consulting worked with Beiriger's and Agro Engineering monitored the Christensen site. The monitoring program was designed to monitor moisture at three different levels in the soil, determine plant nutrition progress through petiole sampling during the growing season, and scout for pest and disease issue as the crop grew.

In April both sites had their systems installed with relatively few problems. Minor adjustments were made in the layouts as the design was being put in place. Weather delayed the Christensen site installation for over a week but it was still ready at planting time. Both systems were tested prior to planting and some adjustments were made at both sites after the irrigation wells were on line and system testing verified the quantity of water available to irrigate with. Additional zones were added to the north field (#7) at the Beiriger site, and additional filtration equipment was added to the Christensen site because of the larger volume of water from the irrigation well after verifying the water flow.

Figure 1 Installation at Beiriger farm

Planting went well and was completed by mid-May at both locations. Beiriger's were finished first on May 11th with Christensen's to follow on May 15th. From the beginning the Beiriger site had extreme difficulty wetting the soil profile in the buried drip installation on the north field. This site has primarily very coarse sandy loam soil and it was impossible to get the needed capillary movement of water without extreme deep percolation losses. The Christensen site has sandy loam soil too but with a higher degree of clay. So the deep percolation loss wasn't nearly as severe at this site.

As the growing season progressed the potatoes grew and the systems were constantly being tweaked to determine the best operating method to use. Since different soil types were purposely selected the operating methods were expected to be different at each site and they were. The Christensen site was able to achieve the necessary capillary movement of water in the root zone while the Beiriger site struggled, especially with the buried drip system.

Both locations had unforeseen problems arise that had major impacts on the results of the project. At both locations severe weed pressure developed in the surface drip test sites. The normal pre-plant application of herbicide was not done because it requires incorporation, usually accomplished with center pivot irrigation. In this case that was not a possibility. As a result once the soil was saturated numerous weeds began to grow and compete with the crop. Crews had to be hired to manually weed the sites in a rescue operation. The Christensen site had two additional issues that had major impacts on the success of the project. During cultivation of the buried drip system the tillage operation was not precise enough to prevent damage to the buried drip lines. The buried drip line installation had not been done carefully enough that the lines were at the exact depth they were supposed to be, and the cultivator operator was not careful and diligent in checking before damaging the lines. This resulted in the need to find the damage and repair it without damaging the potato crop, which was impossible. This repair work also delayed irrigation which we believe impacted the final yield of the crop. Later when attempting fertigation at the site major filtration issues developed because of attempting to use a fertilizer mixture incompatible with the drip system filtration capabilities. This resulted in clogged filters and emitters that had to be found, flushed, and some emitters had to be replaced.

Despite these setbacks the crop grew and was harvested successfully. Prior to harvest the Rio Grande Basin Roundtable held a field day for all interested parties to view the demonstration fields and ask questions of the potato growers. Over seventy people attended the field day which included Ross Roberts form Diversity D and the representatives from Neta-fim who supplied the drip irrigation tape at cost for the project.

Figure 2 Field Day for Rio Grande Roundtable

Yields were below average for both sites in comparison to what the growers normally produce. The quality of the potatoes was surprising good considering the difficulty both sites had with maintaining the needed soil moisture levels in the root zone because of the problems already mentioned. Because of the nature of the experiment and the unforeseen obstacles that occurred it was difficult to determine if the expected water saving was achieved. In this case the water savings will only result from limited surface evaporation because a high yielding, healthy crop will still consume the same amount of water under drip or center pivot irrigation.

One major issue that was not anticipated was the lack of drip irrigation expertise locally and the impact of Diversity D being so far away geographically from the region. As problems developed in the project it was difficult at times to get timely responses and as a result for the producers and consultants to understand what to do to manage the project problems. While technology is capable of keeping the world connected 24-7 today, there is still a need for hands on service at critical times.
This project has continued and evolved with some success as both producers firmly believe that drip irrigation is feasible for their operations. Diversity D and Neta-fim continue to serve the San Luis valley and have undertaken another major project with Mountain King Farms that includes consultants from Israel.

What did we learn and did we answer the objectives:

- **Would a drip irrigation system be practical in a potato – small grain rotation scheme that most growers use?**

The producers involved believe it is feasible to use surface drip irrigation in potato production in the valley successfully. They do not think that sub-surface permanent systems will work because of the tillage needed to successfully grow potatoes.

- **Would drip irrigation prove to be effective in meeting the consumptive needs of potato and small grain crops?**

Surface drip irrigation can provide the consumptive water needs to potato crops but the jury is still out on small grains. While this project was focused on potatoes the growers involved have experimented with growing barley. The project at Mountain King Farms that resulted because of this pilot project has confirmed that using surface drip irrigation can successfully produce a healthy, high yielding potato crop with some water savings. The water savings only result from the prevention of surface evaporative losses.

- **Would drip irrigation prove to be cost effective and affordable for growers in the San Luis valley?**

Colorado State University never completed the economic analyses that they volunteered to do for this project. I am as much to blame for that as anyone because I did not insist it be completed. In my opinion the initial results of the project did not provide the needed information to conduct such an analysis and it would have been inadequate.

I would like to thank all involved in the project including the producers, Beiriger Farms and Roger Christensen. They spent many hours and a great deal of their own money on this project and dealt with the problems they experienced with a cheerful attitude at all times. The consultants involved, Maya ter Kuile of Cactus Hill Ag, and Jason Lorenz of Agro Engineering were instrumental in keeping the project moving in the right direction and in assessing critical problems that occurred with the project. Lastly the many donors that helped fund the project: Farm Fresh Direct LLC, Monte Vista Co-op, San Luis Valley Irrigation District, Wilbur Ellis, Diversity D, Neta-fim, CPAC, and the Rio Grande Basin Roundtable.

AGRONOMIC MONITORING REPORT FOR DRIP IRRIGATION TRIAL 2013

Beiriger Farm, San Luis Valley of Colorado

ABSTRACT

In 2013, 2 different types of drip installations were set up on Beiriger Fields 6 and 7 near Hooper, in order to compare Drip Irrigation to Center Pivot Irrigation (Standard practice) in the production of potatoes in the San Luis Valley of Colorado. The purpose of the trial was to determine if drip irrigation would be more efficient in terms of reduced water use in potato production given 10 years of drought conditions and impairment to well productivity in the Closed Basin of the San Luis Valley. This report summarizes agronomic monitoring data from this trial.

Sub-surface (buried) Drip lines (a more permanent installation) were unsuccessful in potatoes in 2013 and in barley in 2014 due to the coarse texture of the aridisol soils that prevail within the Closed Basin. These coarse textures reduce capillary movement of water upward into the root zone and result in downward movement of water, causing severe drought stress in the crop. In addition, the endemic pocket gophers in the area resulted in major line damage.

Surface Drip holds potential for future applications but will require a shift in practices. Row planting will need to switch to bed planting if drip lines are set every other row. Fertilizer banded applications will need to be different as will cultivation and weed control.

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Purpose:

The Closed Basin of the San Luis Valley has seen a continuous decline in water availability since 2002 (see figure 1). The year 2011 and 2012 showed continued water supply declines in the aquifer. 2012 in particular had a much lower snowpack for the Rio Grande Basin, therefore lower water supply than average, resulting in continued declines in water table levels. At the planning stage for this trial, the snowpack for 2013 looked no better (see Figure 2).

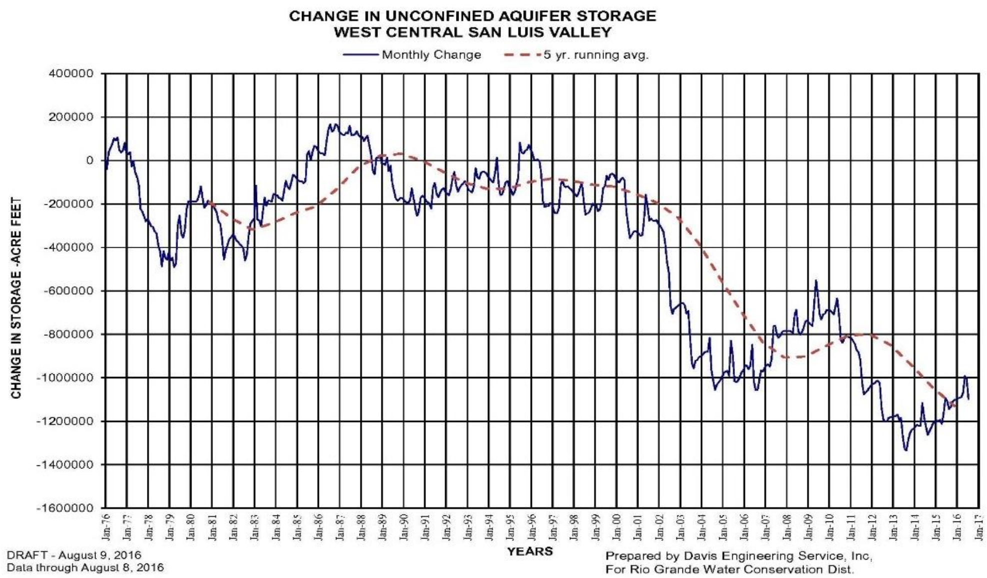


Figure 1: Unconfined aquifer storage in the Closed Basin 1976 through August 2016

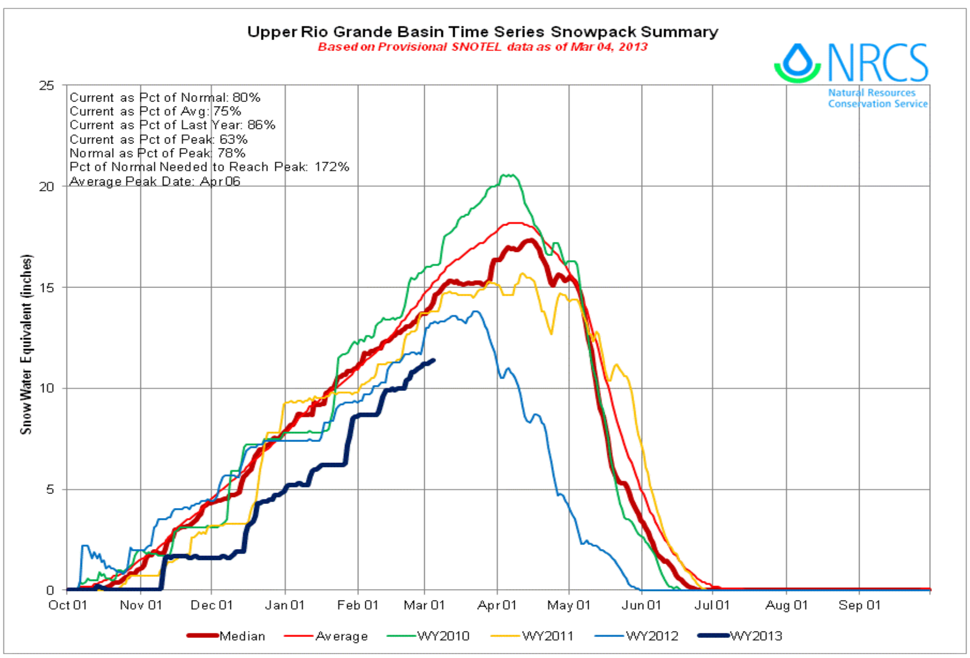


Figure 2: March 4 2013 SNOTEL data for the Rio Grande Basin

Within the Closed Basin Boundaries, certain areas have suffered more than others, and the area around Hooper has shown decreases in well production that are among the worst (field observation and flow measurements by Cactus Hill Ag Consulting, Crane Consulting and others). Beiriger Farm (AMP Operating) is located in Hooper, where this impact is at a crisis to this day, despite slight increases in aquifer storage for 2015 and 2016 as can be seen in Figure 1.

Drip irrigation is considered the most water efficient method of irrigation. It is estimated that irrigation efficiencies can reach 95-98% under good management (Howell, USDA). In the San Luis Valley, Center Pivot irrigation efficiencies average 80-85. Drip irrigation, however, is costly to install and requires a learning period to develop optimum management.

Drip irrigation efficiencies are much higher than Center Pivot Irrigation for two main reasons. Evaporative losses are much lower, and this was felt to be a bonus especially during the windy months of May and June in the San Luis Valley. The water is applied at the soil level or below the soil surface, so evaporation as water leaves the sprinkler and travels to the soil surface is gone, as is evaporation from an open wet soil surface, which can be as high as 0.15 inches per day. In addition, drip irrigation results in lower losses due to deep percolation, since water is applied at root zone level and only in the quantity that is needed to replenish the root zone. Under sprinkler irrigation, root zone diameter adjustments cannot be made for shallow rooted crops like potatoes.

Drip irrigation has potential for added benefits as a method of irrigation in the San Luis Valley because of the more precise placement of water into the root system of the crop being grown, resulting in more accurate fertilizer placement. Fertilizer use in potatoes and other vegetable crops could potentially be reduced. In addition, movement of highly mobile nitrate-nitrogen ions due to deep percolation, with subsequent nitrate contamination of the aquifer, can be reduced if not eliminated. Nitrate contamination of the Closed Basin has been documented as far back as the 1930's and the start of commercial fertilizer use in agriculture. Some areas of the aquifer have very high levels of nitrates (See Figure 3), which are a risk to human health causing methemoglobinemia in infants at levels higher than 10 ppm nitrate-N (EPA Drinking Water MCL, http://water.epa.gov/drink/contaminants/index.cfm#List). Adoption of Drip Irrigation in the San Luis Valley could assist in the mitigation of the nitrate already in the aquifer.

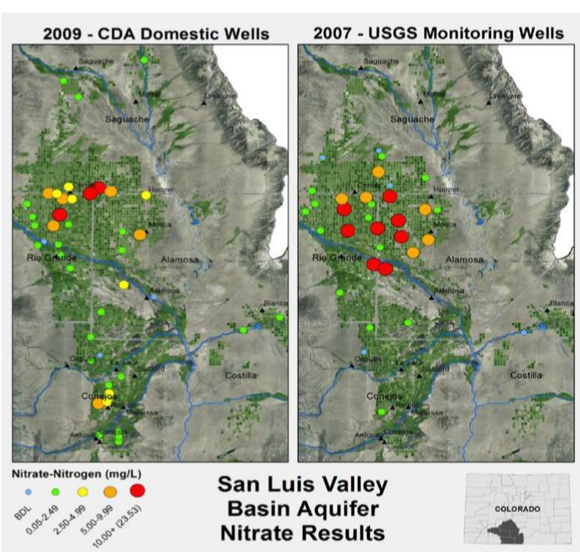


Figure 3: Nitrates found in the Closed Basin 2007 and 2009 (CDA Groundwater Monitoring Report)

Drip irrigation will also reduce the leaching of pesticides, which have been detected in low concentrations in a number of domestic wells during water quality studies conducted by the Colorado Department of Agriculture in 2009 (Fact Sheet, Grounddater Monitoring Report, San Luis Valley, 2009)

Another hoped for advantage to drip irrigation in the San Luis Valley is the reduction in foliar diseases due to the frequent wetting of the crop canopy and the high humidity and cool temperatures that is artificially introduced in the canopy as sprinklers irrigate every 2 to 3 days. In potatoes, this results in a very high incidence of Potato Early Blight (*Alternaria solani*), which requires applications of fungicides from late June until vine kill every 7 days to 2 weeks, depending on weather. In grain like wheat and barley, a high incidence of Net Blotch and Spot Blotch occurs in certain growing seasons. Under Drip irrigation, it may be possible to reduce fungicide applications to no and up to two applications per season, resulting in both economic savings and reduction of pesticide use.

System Setup and Monitoring Methods:

Two different drip layouts were set up in distinct zones on Beiriger fields 6 and 7 (See Figure 4). The north portion of the Beiriger plot (Field 7: 12 Acres) was set up with buried drip tape, to a depth of approximately 12 inches and a width of 68 inches (every other row). The South half (Field 6) and the larger acreage (20 Acres) had drip tape laid out on the surface at 68 inch spacing (every other row). Installation of the system was completed by Diversity D. Two wells (WDID 2005814 (approx 415 gpm peak flow) and 2005815 (approx. 330 gpm peak flow) service the 3 fields. The system was deliberately over-sized in order to send the water across the road to the center-pivot sprinkler system, Field 5 (see figure 4). This was done so that comparisons could be made between the amount of water used by the different systems. However, on June 7th, after 4 weeks of watering the 3 fields from a single combined water source (2 wells), the logistics of watering the Center Pivot on a daily basis was too complex, since the drip system was watered every day to 2 days and the Center Pivot system was watered every 2 or 3 days under normal management schemes. At that decision point, WDID 2005814 was used exclusively on Field 5, and WDID 2005815 was used on the drip system. In addition to the meters already measuring flows out of the two wells, a separate meter measured water volume applied to the drip system.

Field 6 (20 acres) with surface drip was split into 4 zones (7 through 10) and the north field 7, subsurface drip, 12 acres, was split into 6 zones (1 through 6). Irrigation “surges” were programmed in sequences of 3 zones watering at one time.

The east half of each of the drip setup fields (6 and 7) were planted to a shallow rooted, high nutrient demand potato cultivar, the Norkotah Russet (although the line selection 3 is the most resilient of the Norkotah selections). The west halves were planted to a new cultivar being grown in the San Luis Valley called the Tebina, a very low demand cultivar with a deeper rooting system. Two varieties were used to evaluate performance of different cultivars under the same management scheme.

Four continuous moisture monitoring stations (WatchDog 1200 series with Data loggers, and 2 sensors per station A (Root zone) and D (below root zone)) were installed 2 in each of the Drip installations, one in the Norkotah Russets, one in the Tebina Russets. Readings were downloaded weekly for review.

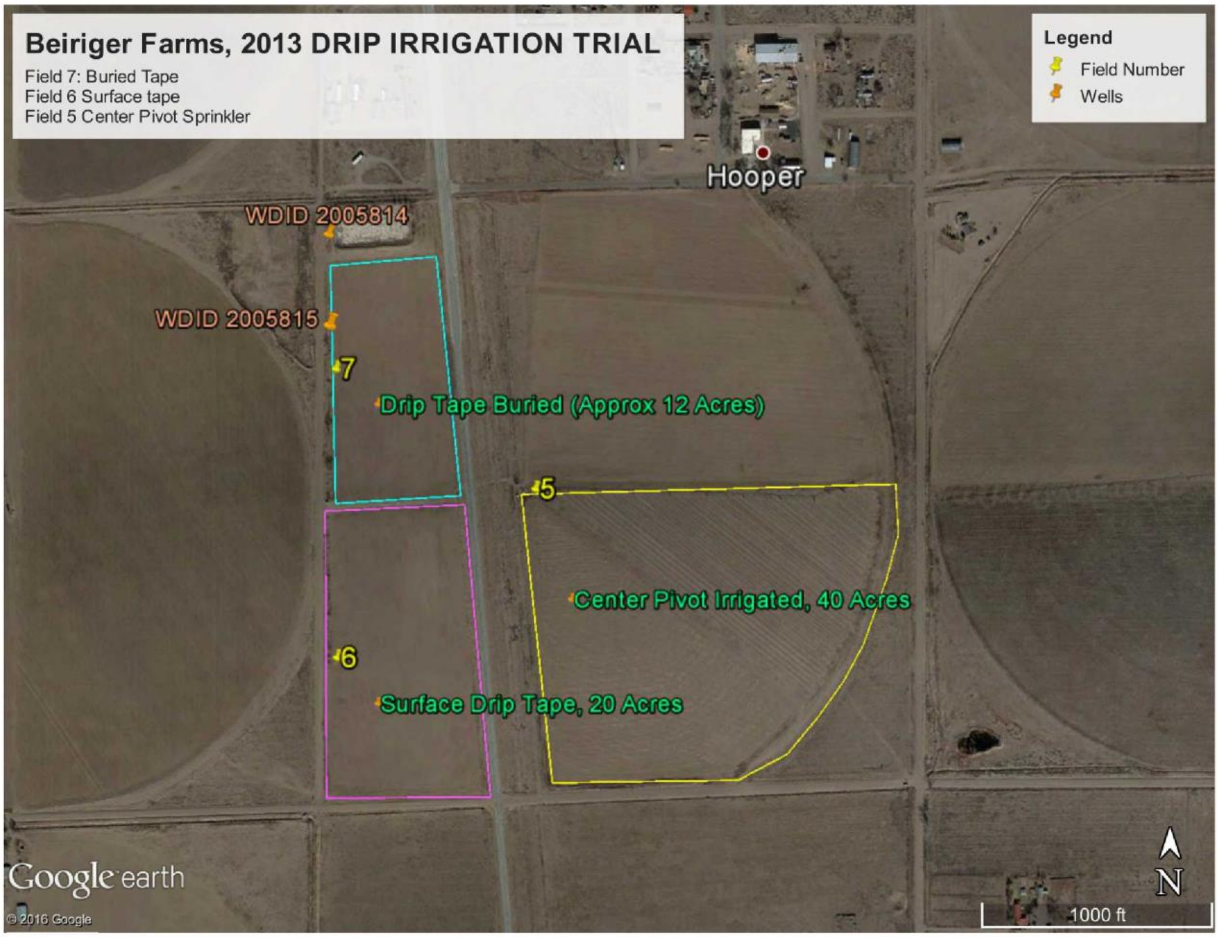


Figure 4: Map of Drip Trial

Plant nutrition monitoring involved the sampling of potato petioles (standard practice) from each of the 4 management scenarios twice during the season. Analysis was conducted by Ward Laboratories Inc. in Kearney, Nebraska, an Agricultural Lab that provides analytical services to Cactus Hill Ag Consulting (CHAC), the crop consultants that were conducting the monitoring for this trial.

Pest monitoring was conducted by Cactus Hill Ag Consulting during weekly field visits to the trials. Pest monitoring consists of sweep net and leaf pull counts, visual monitoring and plant digging to determine the presence of insect pests and diseases.

Water Management Methods and Monitoring Results:

Planting of the trials took place May 9th through 11th into very dry ground due to delays in drip installation and setup. From the very start, it was impossible to wet the soil profile in the buried drip (subsurface drip) and it was quickly decided that there is no capillary movement in the soils that prevail in the Hooper Area (see figure 5). The 3 fields consist of 75% Mc Ginty Series and 25 % Gunbarrel Series, typical Aridisols in the Hooper area. Mc Ginty Series' textural description is a Sandy Loam to 60 inches; Gunbarrel is a loamy sand to 48 inches then from 48 inches to 60 inches a coarse loamy sand.

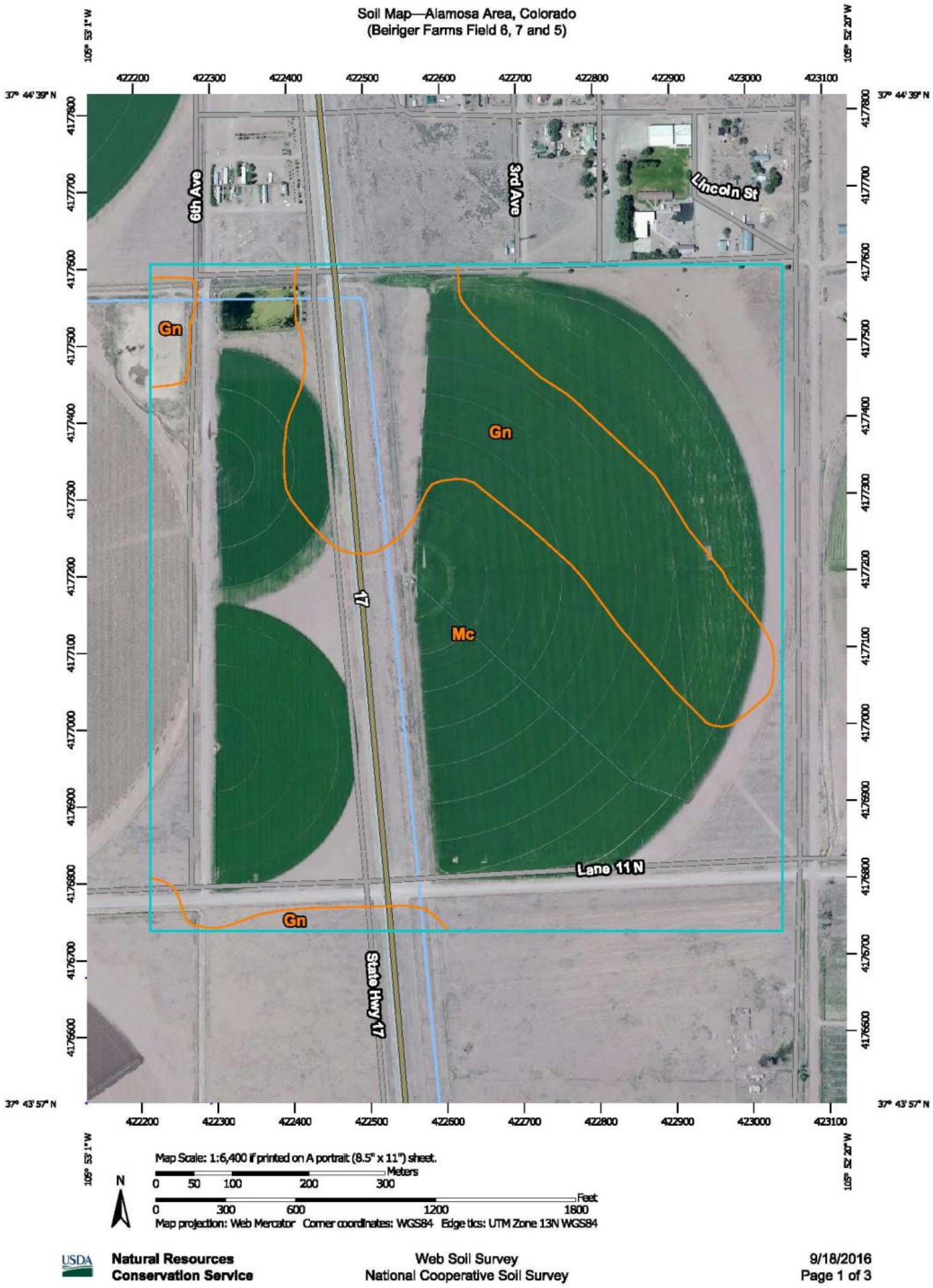


Figure 5: Soil Map of Beiriger field 6, 7 and 5 (Table Percent: 75% Mc Ginty Sandy Loam and 25% Gunbarrel Loamy Sand)

The inability to wet the root zone on Field 7 (Subsurface) resulted in various management schemes which finally met with slight success using “Program 6”, where sub-surface drip was irrigated in 1:15 hr surges on 6 zones for 7.5 hrs, and the surface drip was irrigated in 2.25 hour surges, 4 zones, for a total of 9 hours, 2 cycles, lasting 33 hours total. The 2 day crop water use replacement method that was first attempted was too much water at once, with greater losses to deep percolation. All programs attempted to replace crop water use only, without consideration of efficiencies, and so the current crop water use was accessed on a daily basis to program. Crop water use for the 2013 irrigation season is presented in Table 1.

Table 1: Crop Water Use for Late Planted Norkotah Russet, 2013 (Far right column)

Crop Water Use and Weather Data for 2013

Julian Date	Date Calendar	Tmax	Tmin	Solar Rs	Wind Run wind	Tavg	ETo	ETr	Norkotah ET
166	15-Jun	80.2	41.1	615.2	124.3	60.6	0.22	0.27	0.04
167	16-Jun	76.4	45.8	526.6	171.2	61.1	0.19	0.23	0.04
168	17-Jun	77.9	40.4	604.7	119.9	59.1	0.2	0.24	0.04
169	18-Jun	77.3	43.4	737.3	133.1	60.3	0.27	0.32	0.05
170	19-Jun	82.4	38.4	717.5	139.0	60.4	0.26	0.31	0.06
171	20-Jun	82.2	39.8	722.3	115.8	61.0	0.25	0.3	0.07
172	21-Jun	81.4	38.6	595.6	150.4	60.0	0.21	0.26	0.06
173	22-Jun	80.0	46.3	530.4	158.0	63.2	0.2	0.24	0.07
174	23-Jun	82.8	39.9	666.1	145.2	61.3	0.25	0.29	0.09
175	24-Jun	78.3	43.4	612.4	180.0	60.8	0.22	0.27	0.09
176	25-Jun	80.6	45.3	738.3	120.5	63.0	0.28	0.33	0.12
177	26-Jun	86.3	52.7	715.8	112.2	69.5	0.28	0.34	0.13
178	27-Jun	89.8	56.4	677.8	118.9	73.1	0.28	0.34	0.14
179	28-Jun	83.9	53.8	510.6	131.9	68.8	0.21	0.25	0.11
180	29-Jun	80.1	47.5	431.3	106.2	63.8	0.16	0.19	0.09
181	30-Jun	77.9	46.0	509.6	111.8	61.9	0.18	0.21	0.1
182	1-Jul	76.8	45.0	730.4	100.3	60.9	0.25	0.3	0.16
183	2-Jul	78.3	47.3	715.3	90.3	62.8	0.25	0.31	0.17
184	3-Jul	76.5	43.7	634.6	94.7	60.1	0.22	0.26	0.15
185	4-Jul	81.9	48.1	720.8	91.1	65.0	0.27	0.32	0.19
186	5-Jul	75.1	49.8	321.8	80.0	62.4	0.11	0.14	0.09
187	6-Jul	80.8	48.2	544.0	81.0	64.5	0.2	0.24	0.15
188	7-Jul	84.7	51.8	633.6	87.6	68.2	0.25	0.29	0.2
189	8-Jul	79.2	52.1	568.2	119.4	65.6	0.21	0.25	0.18
190	9-Jul	86.0	54.1	573.9	115.3	70.0	0.23	0.27	0.2
191	10-Jul	81.8	52.2	532.1	113.9	67.0	0.2	0.24	0.18
192	11-Jul	80.7	47.4	541.6	94.2	64.0	0.2	0.24	0.18
193	12-Jul	79.5	55.4	541.4	140.1	67.4	0.22	0.26	0.21
194	13-Jul	80.8	51.3	583.9	107.3	66.1	0.22	0.26	0.22
195	14-Jul	82.8	52.9	578.9	107.8	67.8	0.22	0.27	0.23
196	15-Jul	68.9	52.5	395.2	83.8	60.7	0.14	0.16	0.15
197	16-Jul	75.2	48.4	713.4	84.0	61.8	0.25	0.3	0.28
198	17-Jul	77.6	45.9	738.7	65.9	61.7	0.24	0.29	0.27
199	18-Jul	81.8	46.8	642.5	120.5	64.3	0.25	0.3	0.27
200	19-Jul	79.9	50.5	682.4	95.0	65.2	0.25	0.3	0.28
201	20-Jul	84.6	50.5	637.7	67.9	67.6	0.23	0.28	0.25
202	21-Jul	83.7	50.2	656.1	75.2	67.0	0.23	0.28	0.26
203	22-Jul	86.9	51.7	577.2	74.2	69.3	0.21	0.26	0.23
204	23-Jul	87.9	50.5	701.9	108.8	69.2	0.28	0.33	0.3
205	24-Jul	79.6	53.6	463.5	108.2	66.6	0.18	0.21	0.19
206	25-Jul	80.8	48.3	672.3	77.6	64.5	0.23	0.28	0.25
207	26-Jul	78.8	46.9	621.2	92.8	62.8	0.22	0.27	0.24
208	27-Jul	73.4	45.7	441.3	104.1	59.6	0.15	0.18	0.16
209	28-Jul	66.8	49.6	362.9	74.9	58.2	0.11	0.14	0.12
210	29-Jul	72.2	47.7	489.5	76.9	60.0	0.16	0.19	0.17
211	30-Jul	80.3	43.1	679.7	74.4	61.7	0.22	0.27	0.25
212	31-Jul	82.0	49.4	696.9	104.2	65.7	0.26	0.31	0.29
213	1-Aug	74.9	47.1	396.6	106.8	61.0	0.14	0.16	0.15
214	2-Aug	79.6	49.8	558.6	124.9	64.7	0.22	0.26	0.24
215	3-Aug	81.5	52.6	563.1	107.7	67.1	0.21	0.26	0.24
216	4-Aug	83.3	48.2	592.3	109.1	65.8	0.22	0.27	0.24
217	5-Aug	75.9	50.3	508.9	96.8	63.1	0.18	0.22	0.2
218	6-Aug	74.9	51.0	458.5	116.1	63.0	0.16	0.2	0.18
219	7-Aug	64.4	47.9	247.5	96.0	56.1	0.08	0.09	0.09
220	8-Aug	71.6	47.1	417.4	121.4	59.3	0.15	0.18	0.16
221	9-Aug	71.0	40.6	593.5	100.9	55.8	0.19	0.23	0.21
222	10-Aug	76.0	43.4	518.0	130.3	59.7	0.19	0.22	0.2
223	11-Aug	75.1	41.1	667.3	81.8	58.1	0.22	0.26	0.23
224	12-Aug	73.2	46.2	409.3	134.9	59.7	0.15	0.18	0.15
225	13-Aug	70.5	45.9	502.7	128.5	58.2	0.18	0.21	0.17
226	14-Aug	77.2	45.5	615.7	115.7	61.3	0.21	0.26	0.2
227	15-Aug	81.3	42.3	599.2	88.8	61.8	0.21	0.25	0.19
228	16-Aug	84.0	45.3	654.6	102.5	64.7	0.24	0.29	0.21
229	17-Aug	84.8	49.7	579.1	75.5	67.2	0.21	0.25	0.17
230	18-Aug	82.0	46.9	527.1	101.0	64.5	0.19	0.23	0.15
231	19-Aug	83.8	48.3	613.1	127.5	66.0	0.24	0.29	0.19
232	20-Aug	84.8	48.6	604.2	100.6	66.7	0.23	0.27	0.17
233	21-Aug	85.1	49.7	567.0	119.4	67.4	0.22	0.26	0.15
234	22-Aug	81.4	50.1	528.0	107.6	65.7	0.2	0.24	0.13

Moisture sensors were installed on June 11 and moved to more appropriate locations on 2 occasions on the subsurface stations. Data is presented in Appendix A, showing the changes that occurred once programming was changed, when stations were moved and after rainfall events. In general, the subsurface shallow sensors (A) had to be moved deeper in the profile because they weren't showing any changes in moisture. The deeper sensors (D) were usually showing wetter soils.

Sensors indicate that on the subsurface drip, capillary movement was not adequate to meet crop water use needs. A field visit from Diversity D and Danny, a Texas grower using subsurface drip successfully, was an eye opener for both parties, since in better developed soils, capillary movement works very well for these more "permanent" drip installations. A visit in 2014 from Israeli growers was very educational for local drip applications, since they do surface installations and roll up the drip tape annually for recycled use for 3 or more seasons. This practice holds potential for use in the San Luis Valley.

Program 6 was used, with variations, until the end of the season. The variations included fertilizer applications on the second surge/cycle during July (see notes in Appendix B).

Appendix C includes soil test results and the tissue testing results from the 2 sampling events in 2013. What these graphs show is that in the subsurface drip trial, the fertilizer band was inaccessible to the deeper root system since it was never wetted. In order to fertilize shallow rooted potatoes under drip irrigation, it may be preferable to change the placement of the fertilizer band. For sub-surface installations, a deeper band may be preferable. For surface drip, especially in alternating rows, a single band placed on the wet side of the two row "bed" would also be better, as would a bed system, rather than the standard row system that prevails in the San Luis Valley.

Pest and Disease monitoring indicate that under drip irrigation, the incidence of Early Blight (*Alternaria solani*) is much reduced. Only one fungicide application was used in 2013. There was no difference in insect counts on the Drip versus Center Pivot irrigated potatoes. The Sub-Surface Drip trial showed an unusual outbreak of *Alterneria alternata* (a leaf spot fungus) not usually seen in potatoes in the San Luis Valley except in plats infected with Potato Virus Y. This may be the result of drought stress.

Weeds were not an issue in the subsurface drip trial until very much later in the season, when it rained, due to the dry surface of the soil to 10 inches (see Figure 6). The surface Drip trial had a serious weed infestation that required manual weeding by a crew. For future surface drip installations, a banded application of herbicide along the drip tape is recommended, which still reduces chemical costs by at least 50%.

In 2014, both fields were planted to Coors C69 malting barley, and an attempt was made to grow field 7 using the buried drip. Field 6 was watered using only center pivot overhead sprinkler irrigation. Barley was established using center pivot irrigation on both fields and then on field 7, switched to subsurface drip. Immediately a new problem was discovered with subsurface installations and that was the perforation and damage due to pocket gophers. Various repellents were tried to no avail. Again, the lack of upward capillary movement of water resulted in severe banding of drought stressed barley (See Figure 7) and after 3 weeks, the field was switched to sprinkler irrigation.

Figure 6: Dry soil surface prevailed on Subsurface Drip trial until rainfall event in Late July. Low residue crop the prior year aggravated water holding capacity and capillary movement of water.

Figure 7: Drought stripes in Barley on Field 7

Summary and Conclusions:

Overall issues with both Drip Installations:

- Potatoes were planted into very dry soil because:
    - Planted into residue-poor soil: potatoes on potatoes
    - Installation very close to planting

In general, Drip Irrigation is high cost and there is no local infrastructure for installation.

Sub-Surface (Buried) Drip:

- The necessary packing action after installation of the buried drip resulted in a compaction layer where soil was powder dry above vs. where there was some deeper moisture.
- The compaction layer resulted in:
    - Too shallow a planting depth for the depth of the tape (12");
    - Prevention of capillary movement of water upward past this compaction layer, already an issue due to sandy soil type (Aridisols);
    - Slow early root development since surface soil was so dry;
    - Little to no access to a "moistened" fertilizer band (low phosphate in petioles);
    - Limited space for tubers to set in (especially Tebina)
- 2 Day ET replacement schedule was too much water at one time, surges too far apart, resulting in losses due to gravity.

Hindsight:

- ✓ *Avoid packing soil when there is variable moisture status.*
- ✓ *Pre-plant band below and to the side of the seedpiece?*
- ✓ *Deeper planting, plant into moisture.*
- ✓ *Actually proved that potatoes are tough: "hardened" potatoes were more resilient, and developed a deeper root system.*
- ✓ *Pre-emerge use of Glyphosate herbicide in conventional systems since Dual, Matrix, Chateau, others don't work in dry soils and need moisture for activation.*

Surface (Shallow) Drip:

- Standard 34 inch centers likely need adjustment to more of a "bed". The standard row setup resulted in plants on the side of the hill and some rows further from drip line than others.
- The split fertilizer band resulted in only the wet row band being available. If a two ro bed setup is used, fertilizer can be placed on the side that gets watered.
- Weed Control was a big problem, with the water line germinating a thick matt of weeds. These were impossible to cultivate using standard equipment.

Hindsight:

- ✓ *Use a 2 row bed planter with 2 rows planted closer together (no furrow between) and 2 wider apart so the "shared" drip line is providing equal water.*
- ✓ *Pre-plant band below and to the side of the seedpiece on the water side of the row, since the un-watered side band was never moist.*

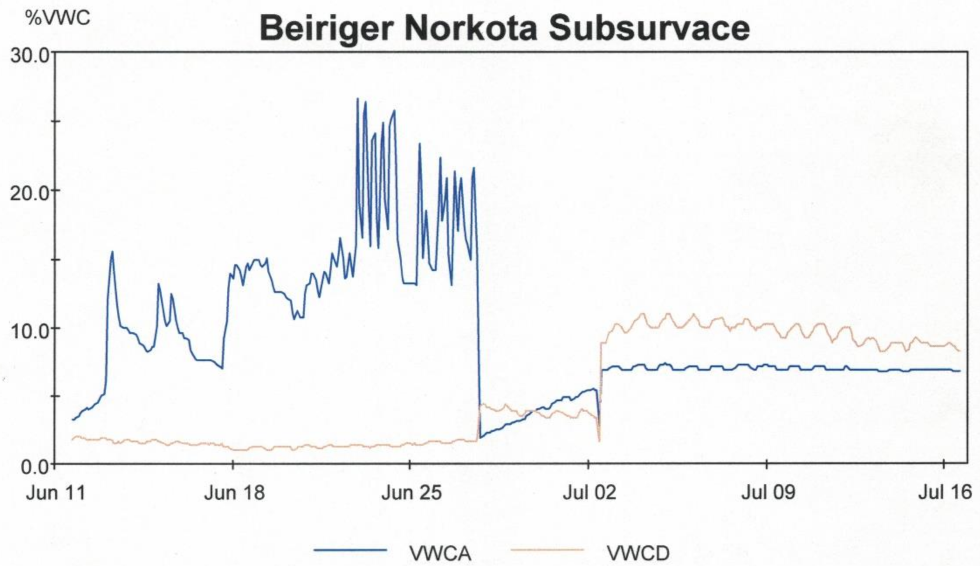
- ✓ *A weed control method is needed, with one idea of spray nozzles mounted on cultivator that supply a banded application of metribuzin along wetting line.*
- ✓ *Pre-emerge use of Glyphosate may be valuable since Matrix, Chateau, others don't work in dry soils and need moisture for activation.*
- ✓ *Need to develop cultivation equipment that lifts drip line and replaces it behind, like a rod weeder.*

Unfortunately, our soils types (poorly developed aridisols) that do not allow capillary water movement upward or laterally and the incipient presence of pocket gophers do not lend themselves to sub-surface buried "permanent" drip installations.

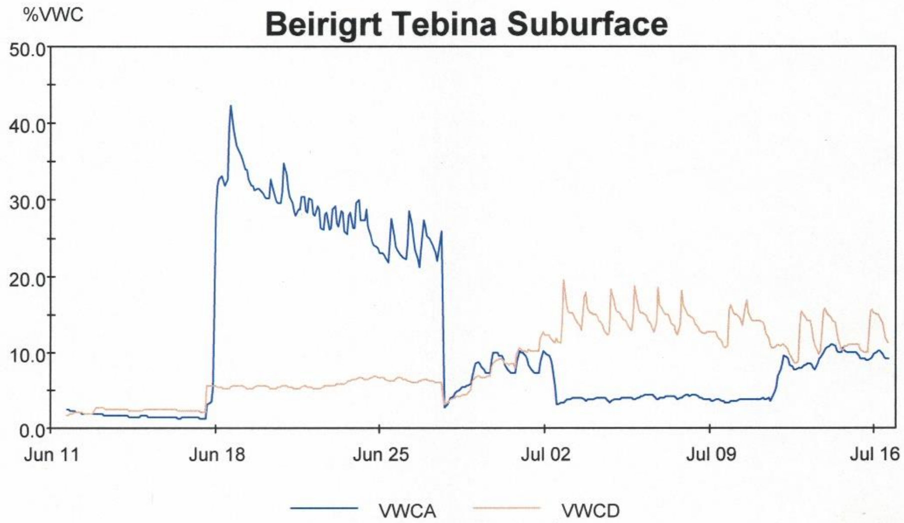
Surface drip installations are currently too expensive and the infrastructure for their installation and winter storage are not locally available but hold potential for future use.

Appendix A:

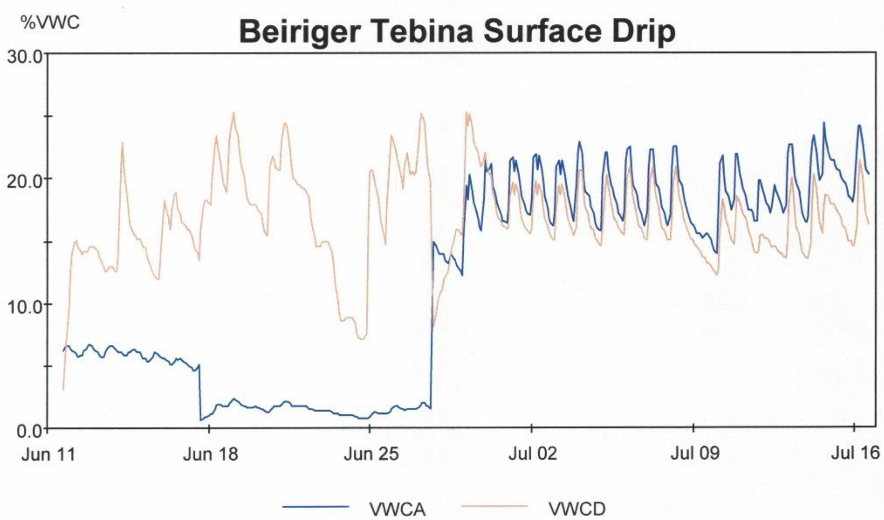
Moisture Sensor Data from various time periods



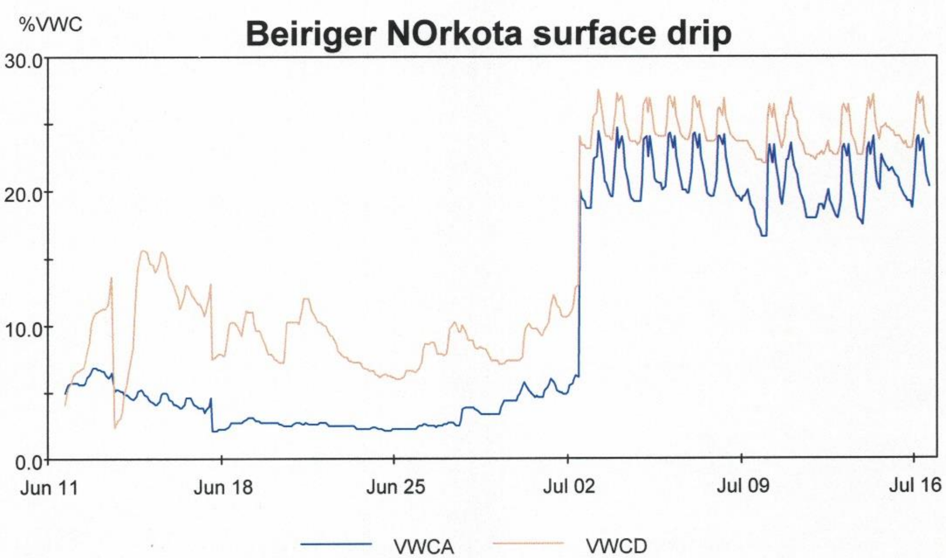
%VWC
Beiriger Norkota Subsurvace
30.0
20.0
10.0
0.0
Jun 11
Jun 18
Jun 25
Jul 02
Jul 09
Jul 16
VWCA
VWCD



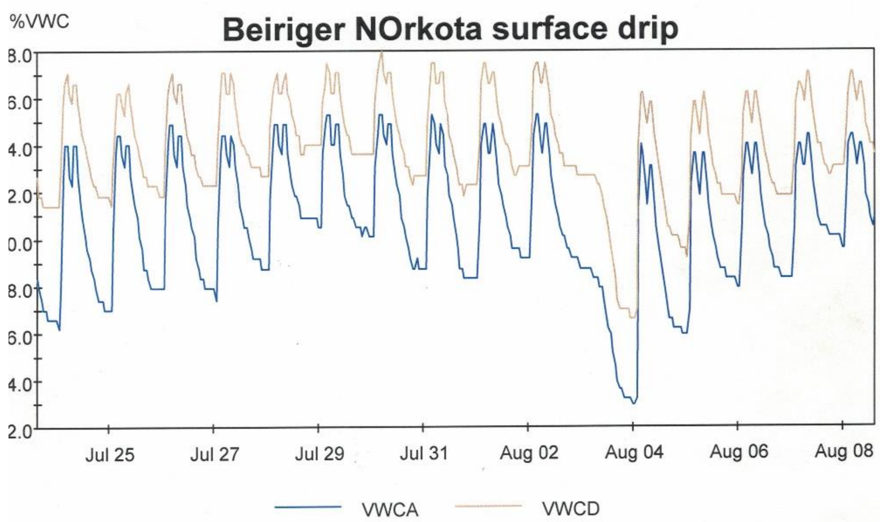
%VWC
Beirigrt Tebina Suburface
50.0
40.0
30.0
20.0
10.0
0.0
Jun 11
Jun 18
Jun 25
Jul 02
Jul 09
Jul 16
VWCA
VWCD



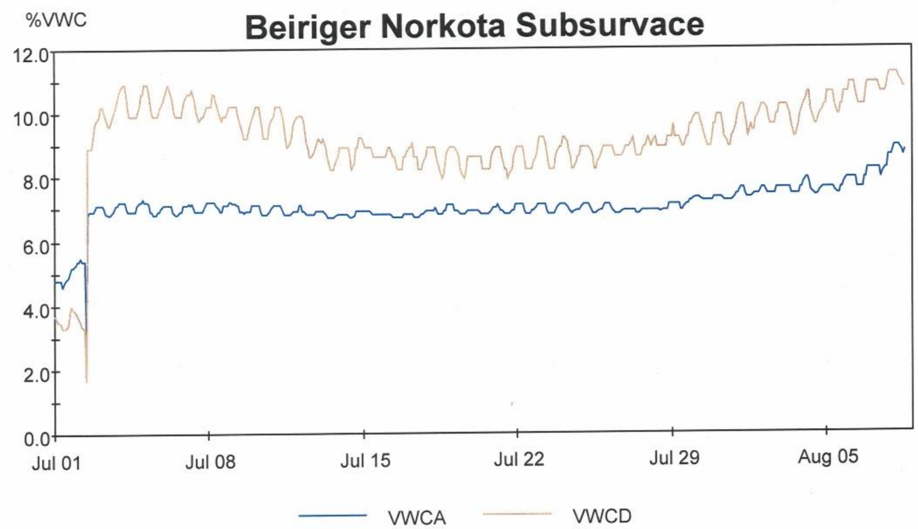
%VWC
Beiriger Tebina Surface Drip
30.0
20.0
10.0
0.0
Jun 11
Jun 18
Jun 25
Jul 02
Jul 09
Jul 16
VWCA
VWCD



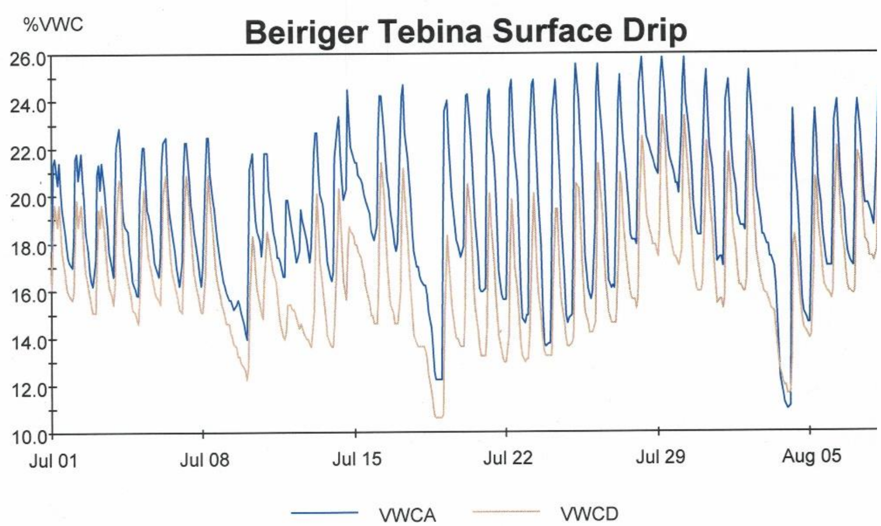
%VWC
Beiriger NOrkota surface drip
30.0
20.0
10.0
0.0
Jun 11
Jun 18
Jun 25
Jul 02
Jul 09
Jul 16
VWCA
VWCD



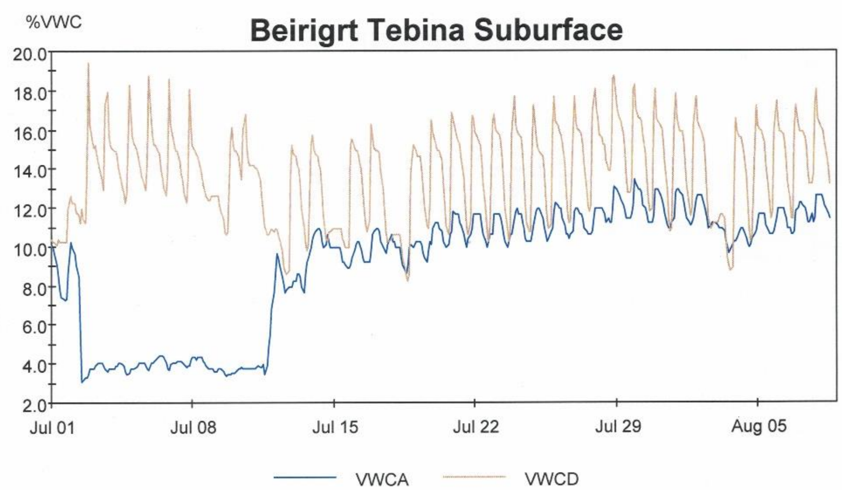
%VWC
Beiriger NOrkota surface drip
Jul 25
Jul 27
Jul 29
Jul 31
Aug 02
Aug 04
Aug 06
Aug 08
VWCA
VWCD



%VWC
Beiriger Norkota Subsurvace
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Jul 01
Jul 08
Jul 15
Jul 22
Jul 29
Aug 05
VWCA
VWCD



%VWC
Beiriger Tebina Surface Drip
26.0
24.0
22.0
20.0
18.0
16.0
14.0
12.0
10.0
Jul 01
Jul 08
Jul 15
Jul 22
Jul 29
Aug 05
VWCA
VWCD



%VWC
Beirigrt Tebina Suburface
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
Jul 01
Jul 08
Jul 15
Jul 22
Jul 29
Aug 05
VWCA
VWCD

Appendix B:

Field Schedules and Notes

Beiriger Farms

Field:7

MAY, 2013

Date		Predicted Irrigation	Actual Irrigation	Rainfall	Crop ET	Predicted Fertilizer	Actual Fertilizer	Herbicides, Pesticides, Other Notes
29	Sun							
30	Mon							
31	Tues							
1	Weds							
2	Thurs							
3	Fri							
4	Sat							
5	Sun							
6	Mon							
7	Tues							
8	Weds							
9	Thurs							
10	Fri	PLANT						
11	Sat							
12	Sun							Start buried drip.
13	Mon							
14	Tues							
15	Weds							
16	Thurs	Keep on Trucking - Sub						Subsurface: 15% at seedpiece
17	Fri							moisture, remainder still
18	Sat							below - not much difference
19	Sun							top or bottom
20	Mon							Surface Drip: 102° on top;
21	Tues							when? 57 at seedpiece
22	Weds							
23	Thurs							
24	Fri							
25	Sat							
26	Sun							
27	Mon							
28	Tues							
29	Weds							
30	Thurs							
31	Fri							
1	Sat							
2	Sun							

Beiriger Farms Field:7

JUNE, 2013

Date		Predicted Irrigation	Actual Irrigation	Rainfall	Crop ET	Predicted Fertilizer	Actual Fertilizer	Herbicides, Pesticides, Other Notes
29	Weds							
30	Thurs							
31	Fri							
1	Sat							
2	Sun							
3	Mon							
4	Tues							
5	Weds							
6	Thurs							
7	Fri	START Subsurface						after 5 is done
8	Sat							
9	Sun							
10	Mon	Start Surface						24 hrs - OK
11	Tues					HOT + WINDY		Installed Moisture Monitors
12	Weds							
13	Thurs						-	Wind -
14	Fri	2x4pm						Subsurface
15	Sat	2x6 surf						
16	Sun							17 AF So far
17	Mon	10hr cycle		Meeting with Ross				Subsurface 16hrs from 1 minute
18	Tues	8hr on Surface			+ Danny			New Program: 1.2x6: switch see duf
19	Weds							
20	Thurs							
21	Fri							
22	Sat	subsurf						went all north w/Prog 5
23	Sun							
24	Mon	Surface						235 Gpm Back to #1 ALL
25	Tues	Am: 18hr 8 hrs Sub 10 hrs surface						
26	Weds	pm						
27	Thurs	OFF	Shut down as per Ross For 1 Day					
28	Fri	17:00 Prog6						when turn Back on Prog 6 For 1 time
29	Sat	Pm						
30	Sun	17:00 Prog6						
1	Mon	Pm						
2	Tues	17:00 Prog6						
3	Weds							
4	Thurs							

Beiriger Farms Field:7

JULY, 2013

Date		Predicted Irrigation	Actual Irrigation	Rainfall	Crop ET	Predicted Fertilizer	Actual Fertilizer	Herbicides, Pesticides, Other Notes
28	Fri							
29	Sat							
30	Sun							
1	Mon							
2	Tues	5pm Prog 6						Prog 6 = 2 surges {8hr surf / 7hr sub}
3	Weds							
4	Thurs	5pm Prog						
5	Fri							
6	Sat	5pm Prog 6						The dose setting 3gal need more
7	Sun							
8	Mon							put about 25 gals on the field
9	Tues					3gals = 10 [illegible]		
10	Weds							
11	Thurs							
12	Fri							
13	Sat							
14	Sun							
15	Mon							
16	Tues							
17	Weds							
18	Thurs	4pm						
19	Fri	start *						Stop 48hr → 24hr ET sub
20	Sat							
21	Sun							
22	Mon							
23	Tues							Dosing SUB 50min
24	Weds							Suf 1:30 m
25	Thurs							
26	Fri							Stop N Tebihos - 60N inject
27	Sat							
28	Sun							
29	Mon							
30	Tues							
31	Weds							
1	Thurs							
2	Fri							Running Prog 8

Fert NORK 1+2+7

Beiriger Farms

Field:7

AUGUST, 2013

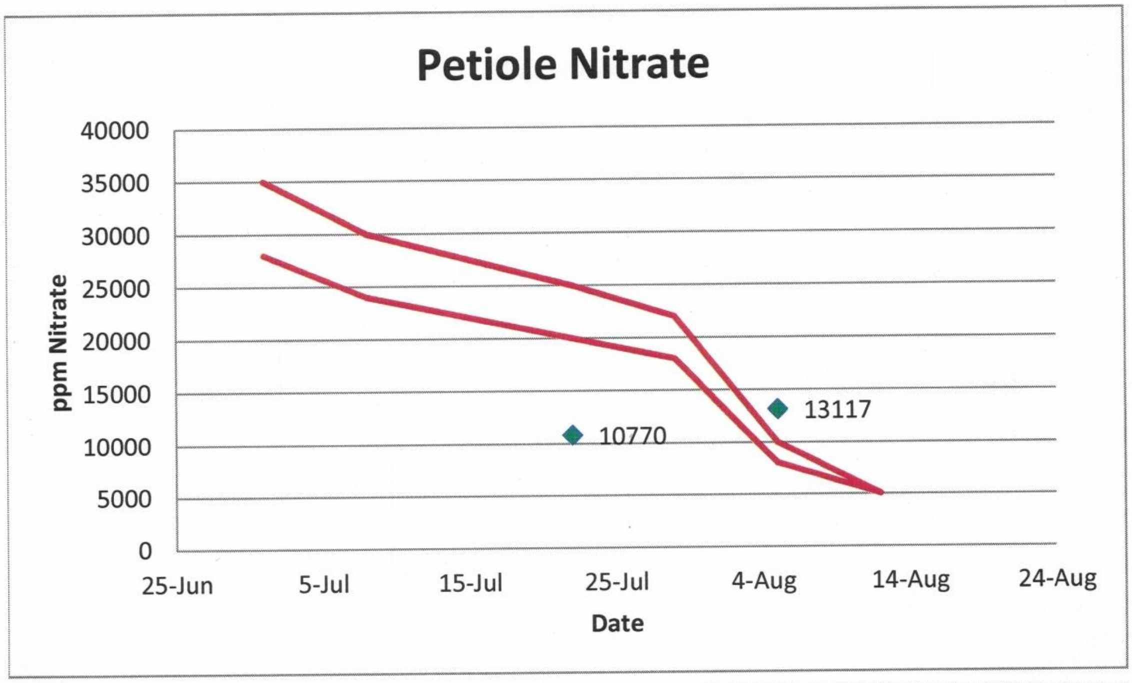
Date		Predicted Irrigation	Actual Irrigation	Rainfall	Crop ET	Predicted Fertilizer	Actual Fertilizer	Herbicides, Pesticides, Other Notes
28	Sun							
29	Mon							
30	Tues							
31	Weds							
1	Thurs							
2	Fri							
3	Sat							
4	Sun							
5	Mon							
6	Tues							
7	Weds							
8	Thurs							
9	Fri							
10	Sat			Keep Filter Flushing				cleaned Filter disc 3 All
11	Sun							
12	Mon							
13	Tues							
14	Weds							
15	Thurs							
16	Fri							
17	Sat							
18	Sun							
19	Mon							
20	Tues							
21	Weds							
22	Thurs							
23	Fri							
24	Sat							
25	Sun							
26	Mon							
27	Tues							
28	Weds							
29	Thurs							
30	Fri							
31	Sat							
1	Sun							
2	Mon							

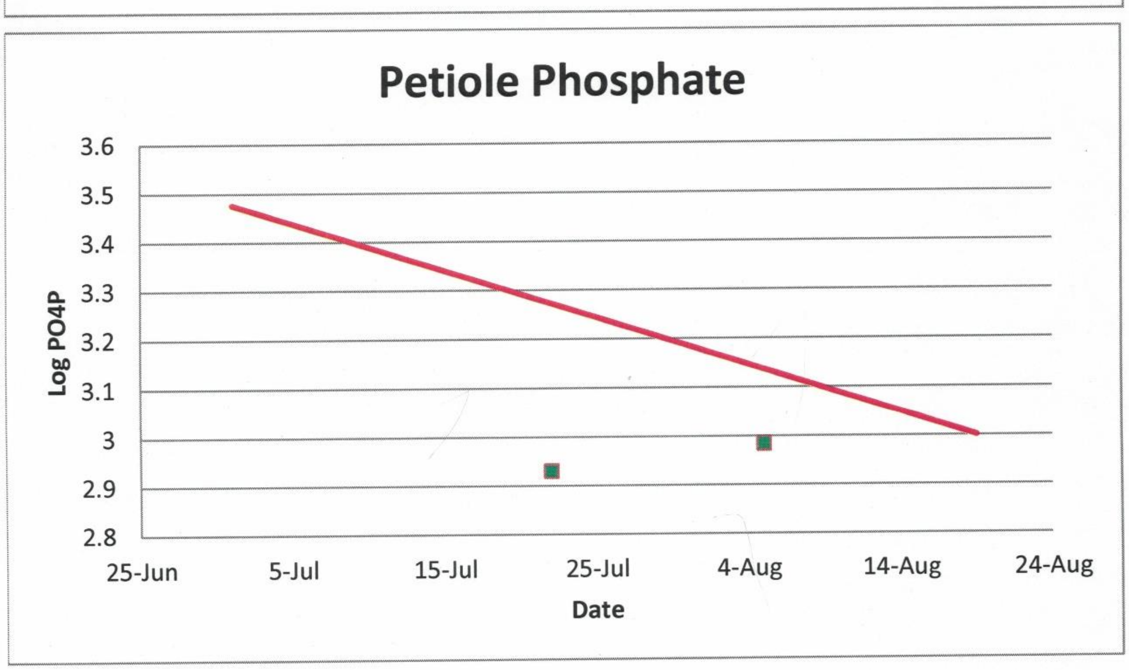
Appendix C:
Soil Test Results and
Potato Petiole Results

BEIRIGER FARMS SOILS RESULTS, 2013

Lab No	48316	48317
Field ID	**67N**	**67S**
Cultivar	Misc	Misc
	4/15/2013	4/15/2013
1:1 Soil pH	7.5	7.7
1:1 S Salts mmho/cm	0.47	0.5
Excess Lime	NONE	NONE
Organic Matter LOI %	1.3	1.4
Nitrate-N ppm N	16	16.6
N lbs N/A	**48**	**50**
Mehlich P-III ppm P	**84**	**91**
Potassium ppm K	**414**	**457**
Sulfate-S ppm S	25	26
Zinc ppm Zn	2.02	1.99
Iron ppm Fe	10.1	9
Manganese ppm Mn	7.4	6.9
Copper ppm Cu	0.63	0.61
Calcium ppm Ca	**1782**	**2492**
Magnesium ppm Mg	270	257
Sodium ppm Na	119	103
Boron ppm B	1.66	2.1
CEC/Sum of Cations	12.7	16.2
%H Sat	0	0
%K Sat	8	7
%Ca Sat	70	77
%Mg Sat	18	13
%Na Sat	4	3

AMP
Field Subsurface Drip
Norkota 3





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Account No. : 1970

Plant Analysis Report

TER KUILE-MILLER, MAYA
CACTUS HILL AG CONSULTING
20758 CR 10
LA JARA CO 81140

Invoice No. : 1136155
Date Received : 07/24/2013
Date Reported : 07/25/2013

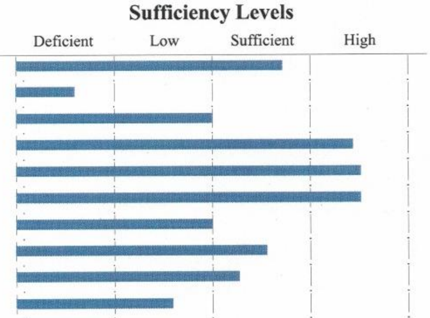
Lab Number : 5360

Results For : AMP
Location : POTATO PETIOLES
Sample ID : DRIP SUBSURFACE NORKOTA

Plant Type : Potato Petiole
Stage : Petiole

	Result Dry Basis
Nitrogen ,% N	2.59
Phosphorus, % P	0.12
Potassium, % K	8.48
Calcium, % Ca	1.725
Magnesium, % Mg	0.751
Sulfur, % S	0.20
Zinc, ppm Zn	16
Iron, ppm Fe	211
Manganese, ppm Mn	49
Copper, ppm Cu	3.2
Nitrate-N, ppm N	10770
Phosphate-P, ppm P	851

Sufficiency Levels



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Kearney, Nebraska 68848-0788

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Account No. : 1970

Plant Analysis Report

TER KUILE-MILLER, MAYA
CACTUS HILL AG CONSULTING
20758 CR 10
LA JARA CO 81140

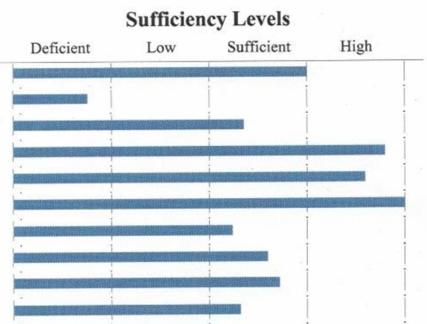
Invoice No. : 1137052
Date Received : 08/07/2013
Date Reported : 08/08/2013

Lab Number : 6221

Results For : AMP
Location : POTATO PETIOLES
Sample ID : SUB 6N NORKOTA SUB

Plant Type : Potato Petiole
Stage : Petiole

	Result Dry Basis
Nitrogen ,% N	3.00
Phosphorus, % P	0.15
Potassium, % K	9.36
Calcium, % Ca	1.903
Magnesium, % Mg	0.797
Sulfur, % S	0.25
Zinc, ppm Zn	23
Iron, ppm Fe	217
Manganese, ppm Mn	80
Copper, ppm Cu	4.6
Nitrate-N, ppm N	13117
Phosphate-P, ppm P	964



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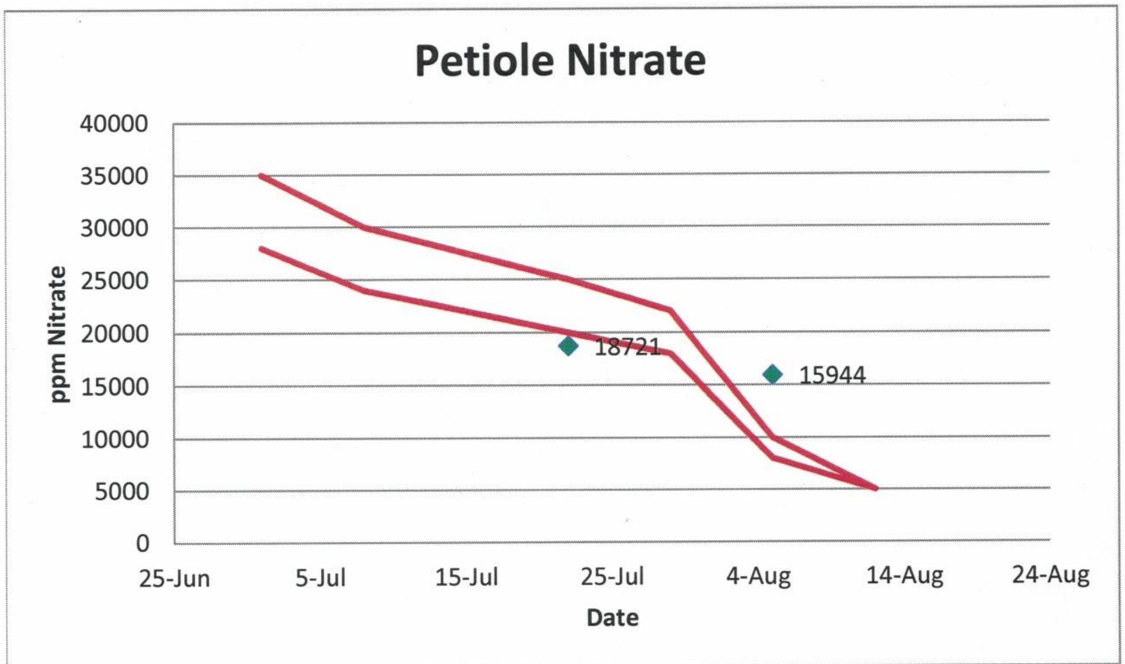
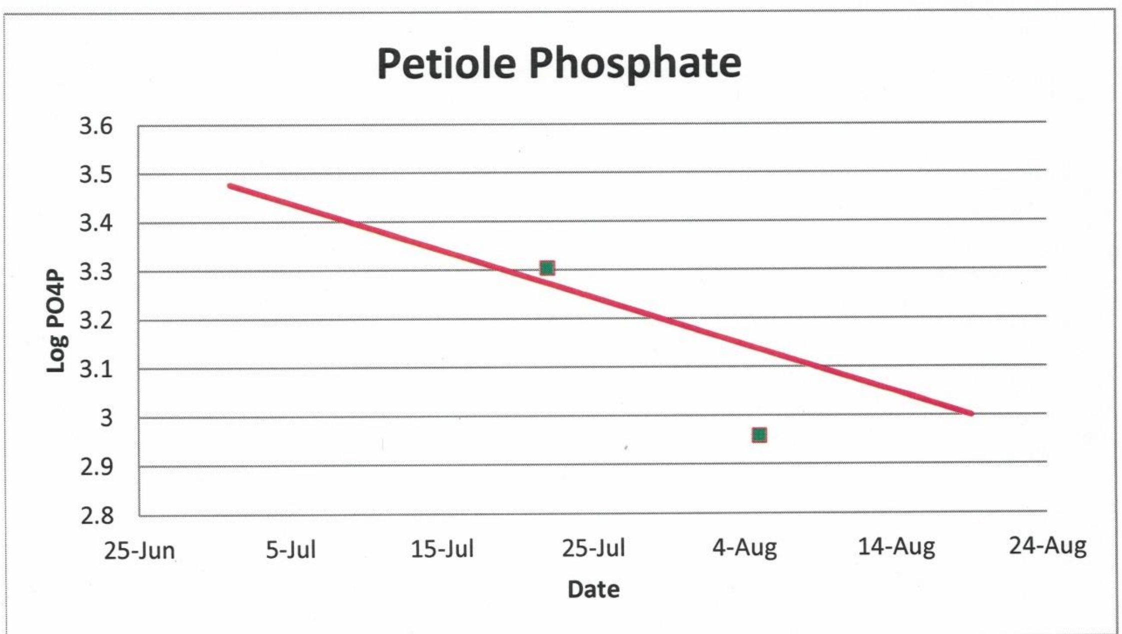
AMP
Field Surface Drip
Norkota 3





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20758 CR 10
LA JARA CO 81140

Invoice No. : 1136155
Date Received : 07/24/2013
Date Reported : 07/25/2013

Lab Number : 5358

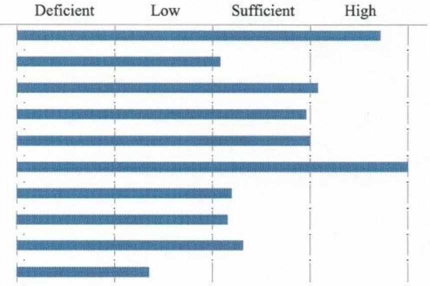
Results For : AMP
Location : POTATO PETIOLES
Sample ID : DRIP SURFACE NORKOTA

Plant Type : Potato Petiole
Stage : Petiole

	Result Dry Basis
Nitrogen ,% N	4.08
Phosphorus, % P	0.26
Potassium, % K	11.25
Calcium, % Ca	1.471
Magnesium, % Mg	0.498
Sulfur, % S	0.30
Zinc, ppm Zn	21
Iron, ppm Fe	123
Manganese, ppm Mn	52
Copper, ppm Cu	2.7
Nitrate-N, ppm N	18721
Phosphate-P, ppm P	2010

Sufficiency Levels

Deficient Low Sufficient High



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20758 CR 10
LA JARA CO 81140

Invoice No. : 1137052
Date Received : 08/07/2013
Date Reported : 08/08/2013

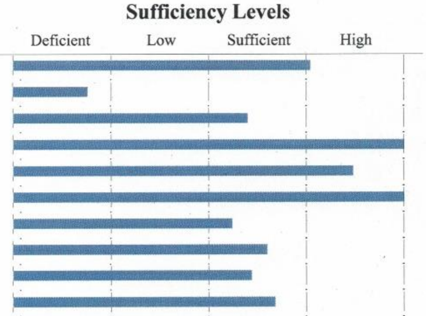
Lab Number : 6220

Results For : AMP
Location : POTATO PETIOLES
Sample ID : SURF 7N NORKOTA SURF

Plant Type : Potato Petiole
Stage : Petiole

	Result Dry Basis
Nitrogen ,% N	3.03
Phosphorus, % P	0.15
Potassium, % K	9.46
Calcium, % Ca	2.056
Magnesium, % Mg	0.738
Sulfur, % S	0.26
Zinc, ppm Zn	24
Iron, ppm Fe	216
Manganese, ppm Mn	61
Copper, ppm Cu	5.4
Nitrate-N, ppm N	15944
Phosphate-P, ppm P	907

Sufficiency Levels



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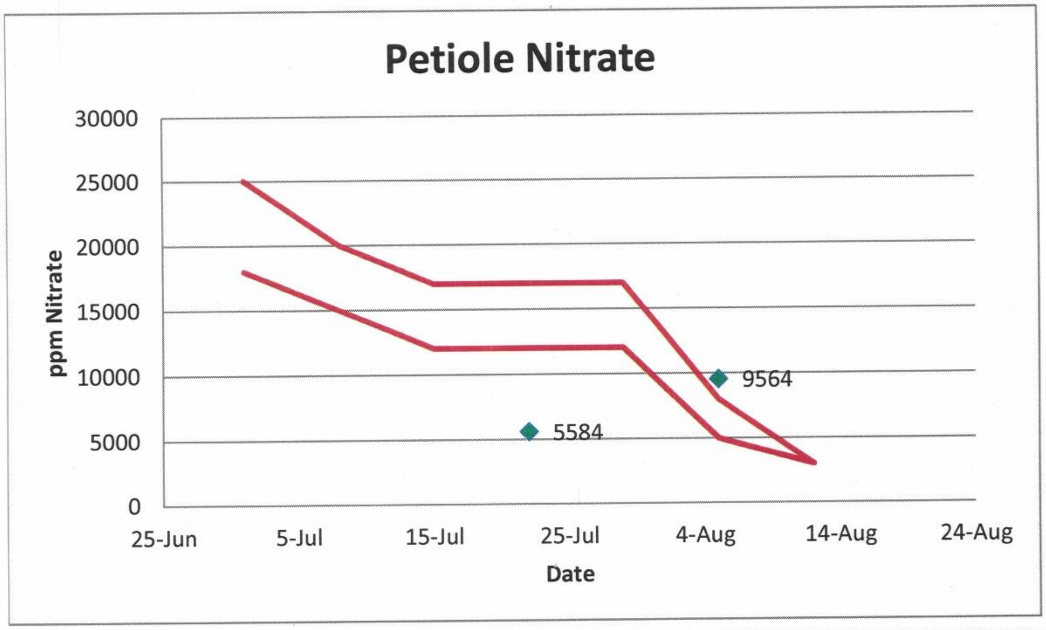
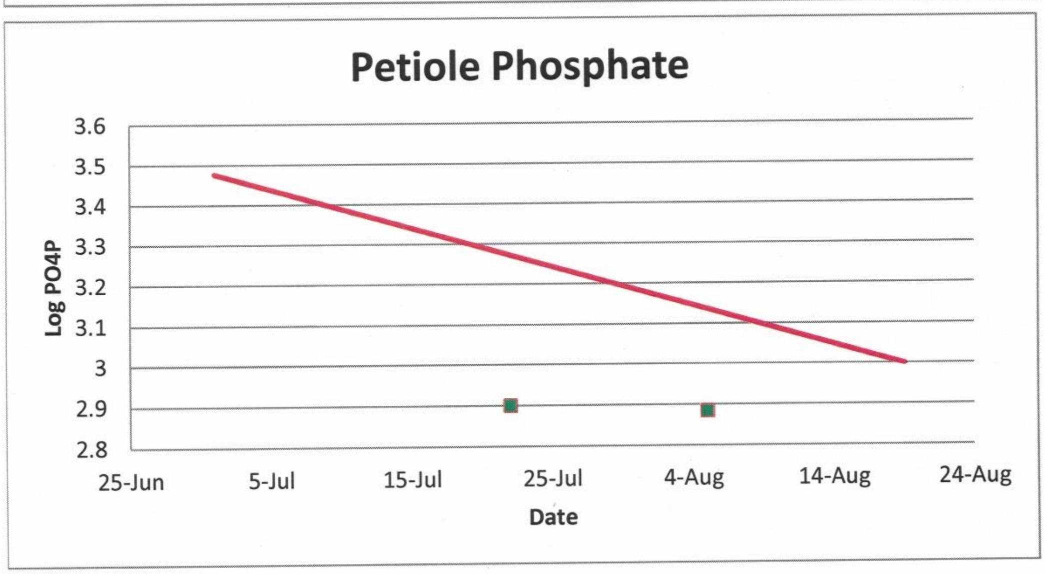
AMP
Field Subsurface Drip
Tebina





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Account No. : 1970

Plant Analysis Report

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CACTUS HILL AG CONSULTING
20758 CR 10
LA JARA CO 81140

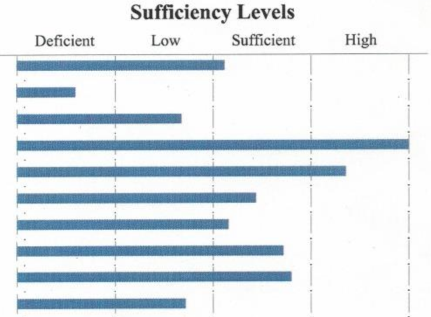
Invoice No. :	1136155
Date Received :	07/24/2013
Date Reported :	07/25/2013
Lab Number :	5359

Results For : AMP
Location : POTATO PETIOLES
Sample ID : DRIP SUBSURFACE TEBINA

Plant Type : Potato Petiole
Stage : Petiole

	Result Dry Basis
Nitrogen ,% N	1.69
Phosphorus, % P	0.12
Potassium, % K	7.74
Calcium, % Ca	2.156
Magnesium, % Mg	0.682
Sulfur, % S	0.12
Zinc, ppm Zn	20
Iron, ppm Fe	243
Manganese, ppm Mn	86
Copper, ppm Cu	3.5
Nitrate-N, ppm N	5584
Phosphate-P, ppm P	794

Sufficiency Levels



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20758 CR 10
LA JARA CO 81140

Invoice No. : 1137052
Date Received : 08/07/2013
Date Reported : 08/08/2013

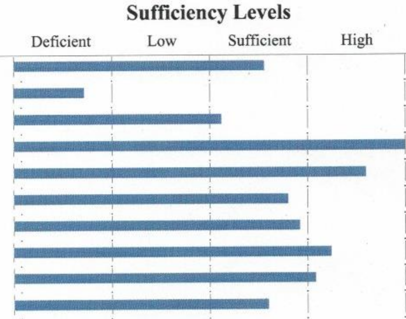
Lab Number : 6219

Results For : AMP
Location : POTATO PETIOLES
Sample ID : SUB 6T TEBINA SUB

Plant Type : Potato Petiole
Stage : Petiole

	Result Dry Basis
Nitrogen ,% N	2.31
Phosphorus, % P	0.14
Potassium, % K	8.82
Calcium, % Ca	2.191
Magnesium, % Mg	0.801
Sulfur, % S	0.14
Zinc, ppm Zn	48
Iron, ppm Fe	348
Manganese, ppm Mn	108
Copper, ppm Cu	5.2
Nitrate-N, ppm N	9564
Phosphate-P, ppm P	766

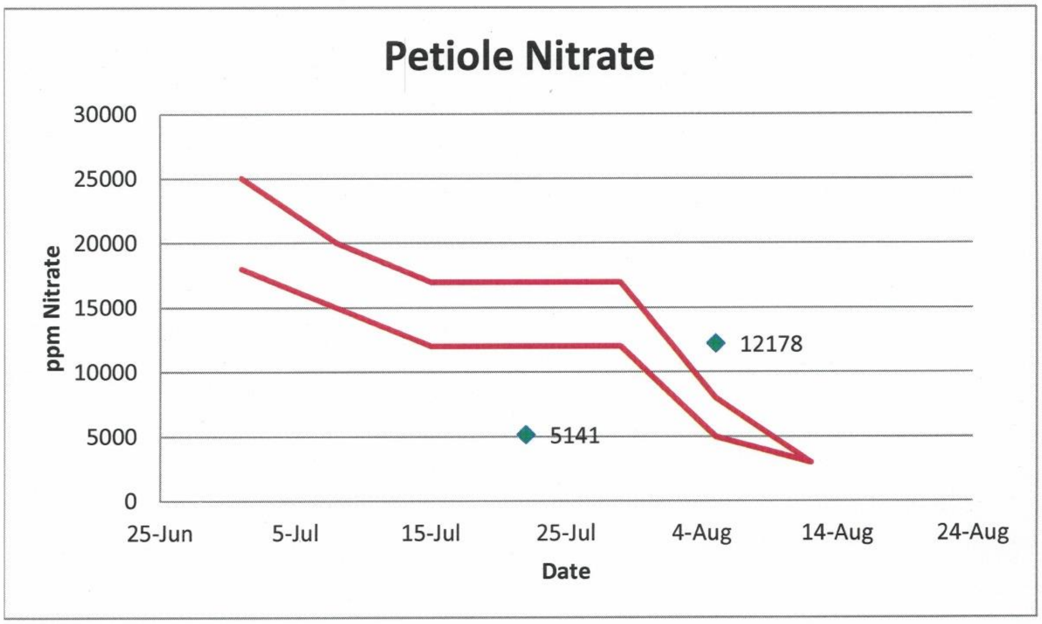
Sufficiency Levels

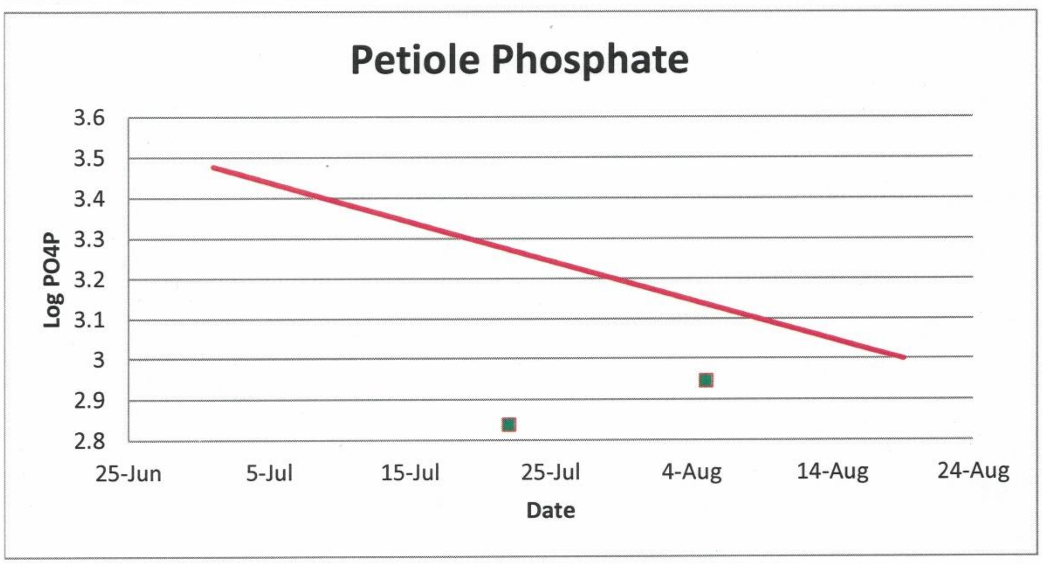


Reviewed By : Raymond Ward 8/9/2013 Copy :1

Bus: 308-234-2418
Fax: 308-234-1940
web site
www.wardlab.com
4007 Cherry Ave., P.O. Box 788
Kearney, Nebraska 68848-0788

AMP
Field Surface Drip
Tebina





WARD Laboratories, Inc.

Ag Testing - Consulting

Account No. : 1970

Plant Analysis Report

TER KUILE-MILLER, MAYA
CACTUS HILL AG CONSULTING
20758 CR 10
LA JARA CO 81140

Invoice No. : 1136155
Date Received : 07/24/2013
Date Reported : 07/25/2013

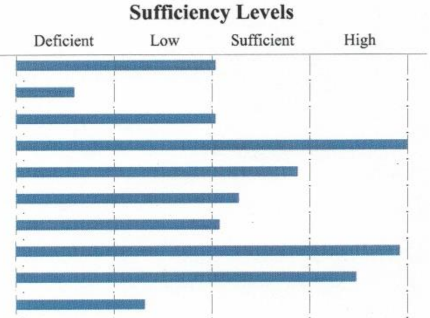
Lab Number : 5357

Results For : AMP
Location : POTATO PETIOLES
Sample ID : DRIP SURFACE TEBINA

Plant Type : Potato Petiole
Stage : Petiole

	Result Dry Basis
Nitrogen ,% N	1.57
Phosphorus, % P	0.12
Potassium, % K	8.58
Calcium, % Ca	2.594
Magnesium, % Mg	0.471
Sulfur, % S	0.11
Zinc, ppm Zn	17
Iron, ppm Fe	483
Manganese, ppm Mn	149
Copper, ppm Cu	2.7
Nitrate-N, ppm N	5141
Phosphate-P, ppm P	688

Sufficiency Levels



Reviewed By : Raymond Ward 7/26/2013 Copy :1 Page 1 of 1

Ag Testing - Consulting

Account No. : 1970

Plant Analysis Report

TER KUILE-MILLER, MAYA
CACTUS HILL AG CONSULTING
20758 CR 10
LA JARA CO 81140

Invoice No. : 1137052
Date Received : 08/07/2013
Date Reported : 08/08/2013

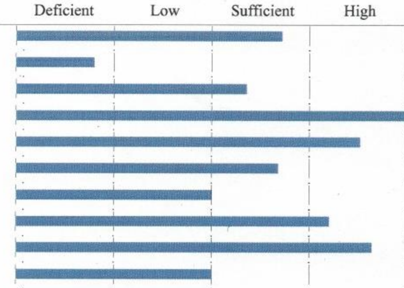
Lab Number : 6218

Results For : AMP
Location : POTATO PETIOLES
Sample ID : SURF 7T TEBINA SURF

Plant Type : Potato Petiole
Stage : Petiole

	Result Dry Basis
Nitrogen ,% N	2.57
Phosphorus, % P	0.16
Potassium, % K	9.41
Calcium, % Ca	2.321
Magnesium, % Mg	0.756
Sulfur, % S	0.13
Zinc, ppm Zn	15
Iron, ppm Fe	338
Manganese, ppm Mn	163
Copper, ppm Cu	4.0
Nitrate-N, ppm N	12178
Phosphate-P, ppm P	882

Sufficiency Levels



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