The Use of Sodium Polyacrylate to Increase Crop Production in Dry-Land Farming

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Abstract
Sodium polyacrylate (C₃H₃NaO₂), originally developed by the Dow Chemical Company, is a polymer that is a mix of sodium acrylate and acrylic acid. Commonly found in baby diapers, it can absorb 500 times its mass in water. This polymer has potential as a soil additive. The hypothesis was if sodium polyacrylate was applied to farmable soil then the yield in the experimental section would be higher than the control section. This should be reflected by an increase in wheat crop growth and water retention. Three plots were planted for the full scale test, the Control Plot, the Experimental Plot 1 with a 2.5% sodium polyacrylate mixture and the Experimental Plot 2 with a 5.0% sodium polyacrylate mixture. Multiple data collections took place throughout the test including plant height, plant count, water present and yield. The Control Plot resulted in 26.8 bushels per acre, the Experimental Plot 1 with 32.8 bushels per acre and the Experimental Plot 2 with 34.1 bushels per acre. The hypothesis was accepted because both Experimental Plots had a statistically higher average plant height and yield then the Control Plot.

Introduction
Agriculture has been the foundation of civilization since it allowed the first people to permanently settle in Mesopotamia over six thousand years ago; today it is no different. Ninety-nine percent of all of food consumed by humans comes from cropland (Lang, 2006). But many factors contribute to the success or failure of agricultural production including drought, erosion, and average annual rainfall.

Today, the United States is experiencing severe cases of drought across the country. Eighteen out of 50 states including North and South Carolina, Wisconsin and Washington, have fallen victim to either hydrological droughts (drought due to deficiency in precipitation affecting local surface or subsurface water supply) or agricultural droughts (drought involving factors vital to agriculture production such as soil water deficiency) (NDMC, 2006) (Figure 1). Although a natural phenomenon, droughts are
extremely costly, causing $6-$8 billion dollars loss annually for the United States (Hayes, 2004). And, unlike other natural disasters such as hurricanes and tornados, droughts have more longstanding affects on a greater number of people. Several elements that contribute to drought’s devastation, is the lack of predictability, the length (droughts can last anywhere from several months to sixty years), and the wide scale of people it affects. For example, the Dust Bowl during the 1930’s lasted eight years, affected 260 million acres of cropland, and displaced nearly 2.5 million people (Monatana, 2009). A drought can directly harm farmers and ranchers, with the loss of animals and crops. The ripple consequences extending to the average person paying more for food. During the drought in Australia in 2008 when thousands of acres of wheat was lost, prices rose from $258 to $367 per ton in Australia and the global price of was inflated (Smith, 2008). It has been theorized that the likelihood of disasters like this occurring could be reduced or entirely eliminated with soil additives designed to absorb the moisture that is available. A chemical that has such potential is sodium polyacrylate.

Sodium polyacrylate (C₃H₇NaO₂)n, originally developed by the Dow Chemical Company, is a polymer that is a mix of sodium polyacrylate and acrylic acid (Figure 2).
Commonly found in baby diapers and household cleaners, it can absorb 500 times its mass in water and thus is classified as a hydrogel (France, 2008). A hydrogel is a colloidal gel in which water is the dispersion medium. Sodium polyacrylate exists in randomly coiled chains, and there is an absence of Na\(^+\) ions (salt is removed). The negative charges on the coils repel each other causing them to unwind. Water is then attracted to the negative ions and attached with hydrogen bonds. This phenomenon allows 500 times the polymers weight in pure water to be absorbed, slightly less with impure water (France, 2008). The polymer will continue to attach to water until all negative ions are linked to water (Figure 3). These bonds are physical, not chemical, allowing for the process to be reversed and then repeated indefinitely. Because of this property sodium polyacrylate could be valuable soil additive.

A factor that has to be taken into consideration for every new soil additive, like sodium polyacrylate, is cost effectiveness. Any treatment, no matter how beneficial, must not compromise the profit of the crop. Ideally the benefit (additional profit) of the

![Figure 2. Molecular structure of sodium polyacrylate (Kelien, 2010).](image)

![Figure 3. A model of dry coiled sodium polyacrylate (left), and an uncoiled strand bonded with water (Richer, 2007).](image)
additive, whether it is a fertilizer or a pesticide, will outweigh the cost. For example, if an additive cost $100 to seed an entire field then the additional yield resulting from its application to the soil would need to equal or surpass the $100 in order to be considered cost effective. In order for the sodium polyacrylate to be a viable soil additive it has to be cost effective. Since the sodium polyacrylate would cost approximately $0.83-$1.65 to seed one acre, the additional profit from the yield from that respective acre would have to exceed that (ZGEPTC, 2011). The additional yield would result from the availability of water that the chemical absorbed and the increased water potential.

Water potential is the possible amount of water a field can hold. This is also called field capacity. This capacity changes with soil type. There are three main types: sandy, loam and clay and they are named for the particle that is most present in its composition. Sand particles are the largest followed by loam then clay. The size of the resulting spaces between the particles, called capillaries, determines the suction force exerted on water in the soil (Figure 4). Because the retention of water through suction is less in sandy soils, sandy soils can not retain as much water resulting in a lower field capacity. The opposite is true in clay soils. Clay is the finest of the three particles so when soils are made up of mainly these particles, the resulting capillaries between the particles are smaller. The smaller the capillaries, the more suction in them, thus clay soils

![Figure 4. An illustration of the effect of capillary size on suction (Boama, 2009).](image-url)
can retain more water and have a higher field capacity. The downside to this is that water is hard to extract from the clay soils. With sandy soils the water cannot be retained adequately. The third type of soil is loamy or silty soil. Silt is the particle size between clay and sand. It allows for big enough capillaries to easily release water but small enough capillaries to provide adequate retention for growth. The relationship between these soil types and their resulting field capacity can be seen in the water retention curve. The soil type present at the Control and Experimental Plots was Shano Silt Loam. This variety of soil has a high, 29.0 cm (11.4 in), available water capacity (NRCS, 2009). It closely follows the loam line on the water retention curve (Figure 5).

The focus of this experiment was to test the effectiveness of sodium polyacrylate as a soil additive in farmable soil to increase crop production. The hypothesis was if sodium polyacrylate was applied to farmable soil then the yield in the experimental section will be higher than the control section. This should be reflected by an increase in wheat crop growth and water retention. Water retention in soil is directly linked to crop growth and can be observed through the water retention curve. The blue line, loam, is the closest to the Shono Loam Silt present in Plots (NIVAP, 2010).
production, so theoretically, if water availability in farmable soil is increased for crops, crop production should also be increased.

**Materials and Methods**

Pre-trials were done in the lab to determine the application method for the full scale tests. Soil from the field that would later be used for the full scale test was collected for laboratory tests. A small clear plastic tube was cut and wire mesh was hot glued to the bottom of one end to prevent anything aside from water passing through. It was held vertical, mesh down with a clamp and ring stand over a funneled graduated cylinder (Figure 6). With this apparatus, tests were conducted to find how to position the sodium polyacrylate in the soil (furrow or a broadcast method). The first test consisted of 100 g of soil and 50 g of water in order to get a control without sodium polyacrylate. The test lasted twenty four hours. The same procedure was repeated with 10 g sodium polyacrylate to 90 g soil, (10\% sodium polyacrylate), 5 g sodium polyacrylate to 95 g soil, (5\% sodium polyacrylate) and 1 g sodium polyacrylate to 99 g soil, (1\% sodium polyacrylate). Each set was also tested using the two methods: 1) the polymer was mixed into the soil, and 2) the polymer was set in as a layer at the bottom of apparatus. These

![Figure 6. The Pre-trial testing apparatus during a test (Powell, 2010).](image)
would represent furrow or broadcast application method options (Figure 7). This test was designed purely to determine which application method would be used. The various percentages of sodium polyacrylate were used in order to insure that whatever percentage was used in the full scale test the method would be applicable.

Furrow application was the first method considered and consisted of the chemical being inserted into the soil right along with the seed, theoretically keeping a supply of moisture readily available for the seed as it matures. This method is more labor intensive due to the fact that each field has to be separately planted with different ratios of seed to chemical. The other option available would be to use a broadcast method. Broadcasting differs from the furrow application as the chemical is applied to the soil before the seed. As the ground is tilled up in preparation for seeding, the chemical is applied and then the ground is seeded; it is mixed into the soil prior to the crop. Although less labor intensive then the furrow method, broadcasting is very imprecise. It would be hard to regulate the amount of chemical allocated to a certain section of soil, for example a test plot, thereby making it hard to run tests with varying ratios of chemical to seed. Due to this and the results from the small scale tests, the furrow method was selected for the full scale tests. The preciseness of the application and the ability to apply several different ratios of

![Figure 7. The furrow and broadcast methods as they are used in large scale agricultural. The picture on the left is of an example of machinery used for furrow application and the picture on the right is of a farmer churning up the soil after a broadcast application (Piako Tractors, 2009).](image)
chemical outweighed any disadvantages.

Sodium polyacrylate has never before been used in large scale agriculture and because of this fact, application rates were unknown. Similar products were researched and the application rates were based off their recommendations for their own products. The most closely related product, ZEBA® made by Absorbent Technologies Inc., is a starch based superabsorbent polymer that, like sodium polyacrylate absorbs approximately 500 times its weight in water (Absorbent Technologies, 2009). The company suggests using a 0.68 kg - 0.91 kg (1.5-2.0 lbs) application for wheat. This figure was the starting point for the application ratios in the sodium polyacrylate experimental test plots. A 0.68 kg (1.5 lbs) per acre application rate was used but instead of a 0.91 kg (2.0 lbs) rate, the amount of sodium polyacrylate was doubled for a 1.36 kg (3.0 lbs) per acre rate. It was determined that the 0.91 kg (2.0 lbs) was too close to the 0.68kg (1.5 lbs) per acre application for testing purposes.

For the full scale tests, a field located at 47.27° N and -118.85° W was selected (Figure 8). The field to be used was a corner section of a larger, in use wheat field. The

![Figure 8. The test plot locations at 47.27° N and -118.85° W outside of Odessa, Washington. EX2 represents Experimental Plot 2, EX1 for Experimental Plot 1, and C denotes the Control Plot (Google, 2010).]
ground was divided into three plots, a control and two test plots. Each was 3.66 m (12.0 ft) by 22.9 m (66.0 ft) long with 0.61 m (2.0 ft) spacing between each plot. Soil samples were taken for nitrogen, potassium, sulfate, and phosphorus. The same test was preformed after the completion of the project in order to determine if the sodium polyacrylate had any effect on the soil nutrients and also to confirm the soil was adequate for growing purposes. These samples were sent to Best-Test Analytical Services in Moses Lake, WA. Then the area was disced using a tillage attachment on the back of a tractor. This process allowed for the soil to be broken up and mixed, making it easier to insert the seeds. At this time fertilizer was applied to the test plots. The three individual fields were defined using marker flags to show the boundaries.

The Control Plot was seeded with soft white spring wheat, *Triticum aestivum*, of the Louise variety (Figure 9). This variety was developed and released by Washington State University in 2005. Its attributes include superior end-use quality and high grain yield potential. It also has a high-temperature adult-plant resistance to local races of stripe rust, a highly destructive leaf fungus extremely prevalent in Washington, and partial resistance to the Hessian fly, an insect that lays its eggs on wheat plants, destroying it in the process (Kidwell, 2005). The field was seeded with a wheat seeder attached to the

![Figure 9. The application method used for all three seedings. In this particular picture the Control Plot is being seeded (Powell, 2010).](image)
back of a tractor. The standard amount of wheat required to seed an entire acre is 27.2 kg (60.0 lbs). However, based on the test plot sizes, the wheat was measured for a half acre application, or 13.6 kg (30.0 lbs). The hopper was then cleaned out using a scoop and vacuum. For the Experimental Plot 1, wheat was mixed for a half an acre application, 13.6 kg (30.0 lbs) of wheat with 0.34 kg (0.75 lb) of sodium polyacrylate, a 1:40 chemical to wheat ratio or a 2.5 % sodium polyacrylate mixture. The chemical was weighed out using a hand held scale and then mixed in a large flat plastic tub by hand. Because the chemical was not evenly spread within the wheat a small amount of water was applied via spray bottle to adhere all the chemical to the wheat (Figure 10). This sample was inserted into the hopper and the Experimental Plot 1, was then seeded.

This process was then repeated for the Experimental Plot 2. The hopper was cleaned again, and the sample of sodium polyacrylate wheat was mixed. Once again it was a half acre batch. It comprised of 13.6 kg (30.0 lbs) of wheat and 0.68 kg (1.5 lbs) of sodium polyacrylate, a 1:20 chemical to wheat ratio or a 5.0 % sodium polyacrylate mixture. A light spray bottle mist of water had to be used to adhere the chemical to the wheat. This batch was then planted (Experimental Plot 2) and the planting stage of the project was complete.

Figure 10. Adhering the chemical using a spray bottle then mixing by hand to equally distribute the chemical (Powell, 2010).
In each of the three plots, three different weekly data collections took place throughout the growing season. The first was a water content test. The soil was tested using a garden Rapitest moisture meter. This meter had a scale of 0-4 with 0 being no moisture and 4 being completely saturated (Figure 11). The second test was a plant count. Using a 0.25 m² measuring square, the apparatus was dropped at random 10 times throughout all Plots. Each time the numbers of sprouts inside the area were counted and recorded (Figure 11). After the plants were counted the third set of data was collected in the same square. Five plants were chosen at random and measured for plant height (Figure 11). This resulted in 10 plant counts and 50 plant heights for each plot per week. Also ten wheat plants were collected from each of the plots. They were taken back to the lab and the root system was separated, dried using an oven and then massed. This would indicate whether the plant was making additional mass because of the possibility of additional water.

An alternate method for water content testing was also in the last week of the test. Three samples of soil were taken from each plot using a soil probe. These were put in separate plastic bags, sealed, and taken immediately to the lab and massed. This was considered wet mass. The wet mass was recorded and then the plastic bags were left open and the soil allowed to dry out (Figure 12). After 2 weeks, the samples were massed

![Figure 11. The measuring device used to define the plant count area is the wood square (left). The Rapitest moisture meter is visible in both pictures and the plants are measured for height (right) (Powell, 2010).](image)
again and recorded as dry mass. The wet mass was divided by the dry mass to find the percent mass loss in water.

After 136 days, the wheat was harvested for each Plot. A tarp was installed in the hopper of the combine to catch the wheat from its respective Plot. Each tarped sample was carefully extracted by lifting and tipping it into grain sacks (Figure 13). This process was carried out with care, insuring no grain was lost in transition from the combine to each sack. After each Plot was harvested, the wheat was collected and identified in sacks; the wheat sacks were weighed to find yield for each Plot.

To calculate the yield, the acreage of the test plots had to be determined. The area of each of the Plots was 74 m$^2$ (792 ft$^2$). Since an acre is 4,047 m$^2$ (43,560 ft$^2$), the
plots calculated to 0.018 of an acre. To complete the yield calculation, the weights of the wheat had to be converted into bushels. A bushel is 27.3 kg (60.0 lbs) of wheat. The masses of the individual plots were divided by the 27.3 kg to get the number of bushels. The number of bushels in the plots over the acreage of the plots was converted using the known bushels per acre, 27.3 kg (60 lbs), to find the bushels that would have been recorded had the plots been full size. Besides yield, kernel counts were taken for the yield. Random 5.0 g samples of the harvested kernels were retrieved and the individual kernels counted out. This number was recorded and the process was repeated 10 times for each Plot’s yield. From that data, the average kernel mass was found by dividing the 5.0 g by the number of kernels.

The local precipitation information was retrieved from weather station at the Odessa Grange Supply in town. They use an electronic gauge to measure the rainfall and upload their information to Weather Underground. The annual and the monthly averages for rainfall were collected and compared to previous years in order to determine if this could have had an effect on the experiment because of more or less available water throughout the growing season compared to other years.

All the data was analyzed and t-tests were run to find statistical differences. After the yield was concluded for each plot the cost effectiveness was calculated to ascertain whether this product was economically feasible in wide scale farm production.

**Results**

A soil test was run before the experiment to analyze the chemicals in the soil. The results showed nitrogen levels at 17 ppm, sulfate at 5 ppm, the phosphorous levels at 30 ppm, and the potassium levels at 708 ppm in the top 0.3 m of soil (Appendix A). Soil
tests were run at the conclusion of the test as well. For the Control Plot the nitrogen level was 3 ppm, the phosphorous at 32 ppm and the potassium at 939 ppm in the top 0.3 m soil. Sodium was present at 0.12 meq/100g (Appendix B). For the Experimental Plot 1, the nitrogen level was 4 ppm, the phosphorous level at 36 ppm and the potassium level at 795 ppm. Sodium was present at 0.12 meq/100g (Appendix C). For the Experimental Plot 2, the nitrogen level was 3 ppm, the phosphorous at 31 ppm and the potassium at 844 ppm. Sodium was present at 0.08 meq/100g (Appendix D).

The average wheat height within the Control Plot was 76.0 cm (±4.4) with a high of 85.0 cm and a low of 65.3 cm. The average wheat height within the Experimental Plot 1 was 81.6 cm (±3.2) with a high of 83.3 cm and a low of 16.8 cm. The average wheat height within the Experimental Plot 2 was 80.3 cm (±3.7) with the highest individual sample 90.0 cm and lowest sample 72.0 cm (Table 1). A two tailed t-test was used to statistically compare the plots. The difference between the average wheat height in Experimental Plot 1 and the Control Plot was significantly different at the 99.9% confidence level (t = ±7.258; df = 98; p < .001). The difference between the average wheat height in Experimental Plot 2 and Control Plot was significantly different at the 99.9% confidence level (t = ±5.243; df = 98; p < .001). There was no significant difference between the average wheat height in Experimental Plot 1 compared to

<table>
<thead>
<tr>
<th>Plot</th>
<th>N</th>
<th>Ave. Height (cm)</th>
<th>SD (cm)</th>
<th>Var. (cm)</th>
</tr>
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<tbody>
<tr>
<td>Control Plot</td>
<td>50</td>
<td>76.0</td>
<td>±4.42</td>
<td>19.5</td>
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<tr>
<td>Experimental Plot 1</td>
<td>50</td>
<td>81.6</td>
<td>±3.22</td>
<td>10.4</td>
</tr>
<tr>
<td>Experimental Plot 2</td>
<td>50</td>
<td>80.3</td>
<td>±3.77</td>
<td>14.2</td>
</tr>
</tbody>
</table>
Experimental Plot 2.

Within the Control Plot the average plant count was 35.0 (±6.6) with the high of 44 and a low of 24. Within the Experimental Plot 1 the average plant count was 41.7 (±2.6) with a high of 46 and a low of 38. Within the Experimental Plot 2, the average plant count was 38.7 (±9.4) with the high of 57 and a low of 27 (Table 2). A two-tailed t-test was used to statistically compare the plots. The difference between the average plant count at harvest in the Control Plot and Experimental Plot 1 was significantly different at the 95% confidence level (t = ±2.99; df = 18; p<.05). There was no significant difference between the average plant count in Control Plot and Experimental Plot 2 or between the average plant count in Experimental Plot 1 and Experimental Plot 2.

Root systems were taken from 10 samples from each plot. The average mass for the Control Plot was 0.30 g (±.14) with the high of 0.53 g and the low of 0.08 g. The average mass for the Experimental Plot 1 was 0.56 g (±0.20) with the high of 0.95 g and the low of 0.28 g. The average root mass for the Experimental Plot 2 was 0.40 g (±.08) with the high of 0.52 g and the low of 0.29 g (Table 3). A two-tailed t-test was used to statistically compare the plots. The difference between the average root mass in the Control Plot and Experimental Plot 1 was significantly different at the 99 % confidence level (t = ±3.24; df = 18; p < .01).There was no significant difference between the

<table>
<thead>
<tr>
<th>Plot</th>
<th>N</th>
<th>Ave. Count</th>
<th>SD</th>
<th>Var.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control Plot</td>
<td>10</td>
<td>35.0</td>
<td>±6.60</td>
<td>43.56</td>
</tr>
<tr>
<td>Experimental Plot 1</td>
<td>10</td>
<td>41.7</td>
<td>±2.58</td>
<td>6.66</td>
</tr>
<tr>
<td>Experimental Plot 2</td>
<td>10</td>
<td>38.7</td>
<td>±9.41</td>
<td>88.55</td>
</tr>
</tbody>
</table>
average root mass in the Control Plot and Experimental Plot 2. The difference between the average root mass in the Experimental Plot 1 and the Experimental Plot 2 was significantly different at the 95% confidence level ($t = \pm 2.33$; $df = 18$; $p < .05$).

Three soil samples were collected from each of the Plots at a depth of 0.35m (1ft). They were sealed and taken back to the lab. They were dry and wet massed and the percent water mass loss was recorded. The average water mass percent lost for the Control Plot was 1.018% ($\pm 0.0004$) with the high of 1.066% and the low of 0.987%. The average percent water mass lost for the Experimental Plot 1 was 1.041% ($\pm 0.0041$) with the high of 1.508% and the low of 0.749%. The average percent water mass lost for the Experimental Plot 2 was 0.726% ($\pm 0.0044$) with the high of 1.216% and the low of 0.341% (Table 4). A two-tailed t-test was used to statistically compare the plots. There was no significant difference between the average percent water mass lost in any of the Plots.

Table 3. Average Root Mass in the Control Plot, Experimental Plot 1 and Experimental Plot 2.

<table>
<thead>
<tr>
<th>Plot</th>
<th>N</th>
<th>Ave. Mass (g)</th>
<th>SD (g)</th>
<th>Var. (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control Plot</td>
<td>10</td>
<td>0.30</td>
<td>±0.14</td>
<td>0.0196</td>
</tr>
<tr>
<td>Experimental Plot 1</td>
<td>10</td>
<td>0.56</td>
<td>±0.20</td>
<td>0.0400</td>
</tr>
<tr>
<td>Experimental Plot 2</td>
<td>10</td>
<td>0.40</td>
<td>±0.08</td>
<td>0.0059</td>
</tr>
</tbody>
</table>

Table 4. Average Percent Water Mass Lost Between the Control Plot, Experimental Plot 1 and Experimental Plot 2.

<table>
<thead>
<tr>
<th>Plot</th>
<th>N</th>
<th>Ave. % Water Mass Lost</th>
<th>SD (%)</th>
<th>Var. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control Plot</td>
<td>3</td>
<td>1.018</td>
<td>±0.0004</td>
<td>1.6×10^{-7}</td>
</tr>
<tr>
<td>Experimental Plot 1</td>
<td>3</td>
<td>1.041</td>
<td>±0.0041</td>
<td>1.7×10^{-5}</td>
</tr>
<tr>
<td>Experimental Plot 2</td>
<td>3</td>
<td>0.726</td>
<td>±0.0044</td>
<td>1.9×10^{-5}</td>
</tr>
</tbody>
</table>


Kernel counts were taken for 5 g samples of the test plots. The Control average was 166.8 (±8.7) kernels with the high of 180.0 and the low of 153.0. The Experimental Plot 1 kernel count average was 158.2 (±8.0) kernels with the high being 174.0 and the low of 148.0. The Experimental Plot 2 kernel count average was 143.0 (±6.2) kernels with the high of 152.0 and the low of 133.0 (Table 5). A two-tailed t-test was used to statistically compare the plots. The difference between the average kernel count in the Control Plot and Experimental Plot 1 was significantly different at the 95 % confidence level (t = ±2.301; df = 18; p < .05). The difference between the average kernel count in the Control Plot and Experimental Plot 2 was significantly different at the 99.9 % confidence level (t = ±7.064; df = 18; p < .001). The difference between the average kernel count in Experimental Plot 1 and Experimental Plot 2 was significantly different at the 99.9 % confidence level (t = ±4.76; df = 18; p < .001).

From the kernel counts the kernel masses were calculated. The Control Plot average kernel mass was 0.0301 g with a high of 0.0327 g and a low of 0.0278 g. The Experimental Plot 1 average kernel mass was 0.0317 g with a high of 0.0338 g and a low of 0.0287 g. The Experimental Plot 2 average kernel mass was 0.0350 g with a high of 0.0376 g and a low of 0.0329 g (Table 6). The difference between the average kernel mass in the Control Plot and Experimental Plot 1 was significantly different at the 95 %

<table>
<thead>
<tr>
<th>Plot</th>
<th>N</th>
<th>Ave. Kernel Count</th>
<th>SD</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control Plot</td>
<td>10</td>
<td>166.8</td>
<td>±8.69</td>
<td>75.52</td>
</tr>
<tr>
<td>Experimental Plot 1</td>
<td>10</td>
<td>158.2</td>
<td>±8.01</td>
<td>64.16</td>
</tr>
<tr>
<td>Experimental Plot 2</td>
<td>10</td>
<td>143.0</td>
<td>±6.16</td>
<td>37.95</td>
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confidence level ($t = \pm 2.33; \text{df} = 18; p < .05$). The difference between the average kernel mass in the Control Plot and Experimental Plot 2 was significantly different at the 99.9% confidence level ($t = \pm 7.22; \text{df} = 18; p < 0.001$). The difference between the average kernel mass in Experimental Plot 1 and Experimental Plot 2 was significantly different at the 99.9% confidence level ($t = \pm 4.84; \text{df} = 18; p < 0.001$).

The wheat that was collected from each test plot was massed and the bushels/acre was calculated using the formula that was mentioned in the Materials and Methods. The Control Plot raw wheat weighed 13.27 kg (29.2 lbs), which when converted results in 26.8 bushels/acre. The Experimental Plot 1 raw wheat weighed 16.27 kg (35.8 lbs) which converted into 32.8 bushels/acre. The Experimental Plot 2 raw wheat weighed 16.91 kg (37.2 lbs), which when converted became 34.1 bushels/acre.

Rainfall was collected for the plots throughout the growing period. Rainfall observed for the month of April was 4.2 cm. May rainfall totaled 6.1 cm. The rainfall in June was 4.9 cm. The July rainfall totaled 0.6 cm and the August rainfall totaled 0.9 cm. The yearly total of rainfall for 2010 was 31.8 cm.

<table>
<thead>
<tr>
<th>Plot</th>
<th>N</th>
<th>Ave. Kernel Mass (g)</th>
<th>SD</th>
<th>Variance</th>
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<tr>
<td>Control Plot</td>
<td>10</td>
<td>0.0301 ±0.00156</td>
<td></td>
<td>2.43E-6</td>
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<tr>
<td>Experimental Plot 1</td>
<td>10</td>
<td>0.0317 ±0.00157</td>
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<tr>
<td>Experimental Plot 2</td>
<td>10</td>
<td>0.0350 ±0.00152</td>
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Discussion

The hypothesis was accepted because the plant height, kernel, and yield results supported the theory that the sodium polyacrylate’s addition to the soil resulted in increased crop growth and production.

The soil chemical test in the preliminary part of the planting stage showed that the levels of nutrients in the soil were adequate for crop growth. Because the parts per million fell between 2 ppm and 60 ppm, the level of phosphorus was classified as high and because the potassium level was between 50 ppm and 700 ppm, it was classified as very high. High levels of these minerals is not a negative, it is beneficial. These tests revealed the soil was full of nutrients needed for crop production.

The post-test soil data showed the sodium polyacrylate had no apparent negative effect on the soil. The nitrogen levels dropped from 5 ppm to 3 ppm, 4 ppm and 3 ppm for the Control, Experimental Plot 1 and Experimental Plot 2 respectively but this can be expected from a normal growth sequence.

The plant height data supported the hypothesis because the Control Plot was significantly different then both the Experimental Plot 1 and the Experimental Plot 2. This revealed that the sodium polyacrylate caused the wheat to grow higher. The growing trend of the wheat was compared to the time (in days) for each of the three Plots. As seen by the R² values, the plants in the Control Plot (R²=.991) (Figure 14), Experimental Plot 1 (R²=.970) (Figure 15), and Experimental Plot 2 (R²=.995) (Figure 16) all grew normally, yet the Experimental Plot 1 and Experimental Plot 2 grew with significantly higher averages than the Control Plot. This supports the hypothesis that the addition of the sodium polyacrylate increased crop growth.
The kernel counts also supported the hypothesis. The Control Plot count of 166.8 was significantly different at the 95% confidence level from the Experimental Plot 1 and the reduced number of kernels in the 5.0 g sample for the Experimental Plot 1 and Experimental Plot 2 allude to the fact that the individual kernels weigh more themselves (Figure 17).

The Control Plot kernels weighed an average of 0.0301 g, the Experimental Plot 1 kernels weighed an average of 0.0316 g and the Experimental Plot 2 kernels weighed an average of .0350 g (Figure 18). The Experimental Plot 1 kernels weighed 1.1% more than the Control Plot kernels and the Experimental Plot 2 kernels weighed 1.2% more than the Control Plot kernels. Higher kernel mass contributes to higher yields and higher test weights, which are desirable, (Squires, 2011). According to the

Figure 14. The Average Control Plot Wheat Height (cm) Through Time (days).
Washington Grain Commission, the higher average kernel mass of the Experimental Plots means processed, more flour would be produced as compared to the Control. Overall, the kernels contain more usable substance. Even though the kernels do not contain any more nutrients or protein, the bigger size is desirable because it increases yield. Kernels also indicate how stressful the growing season was on the plants. When kernels are large and heavy, it means they had plenty of the requirements needed for healthy growth, light, nutrients and most of all water. Water availability and kernel size are directly linked (Engle, 2011). The results of this test show that water was available for the plant throughout the growing season which was the focus of this research.

The calculated yields for the three plots were truly the indicator of whether the sodium polyacrylate was successful in retaining water. The Control Plot yielded 26.8
bushels/acre. The Experimental Plot 1 yielded 32.8 bushels/acre which was a 22% increase from the Control Plot. The Experimental Plot 2 yielded 34.1 bushels/acre which was a 27% increase from the Control Plot. These percents are significant because farmers are looking for ways to increase their crop and if sodium polyacrylate provides at least a 20% increase in raw yield, then it can be applicable in large scale farming.

Although the yield increase is interesting it is the cost effectiveness that is truly astounding. The current price of grain is $7.41 per bushel (Odessa Union, 2011). A 640 acre field (one square mile also called a section) without sodium polyacrylate would harvest approximately 52 bushel/acre (the state average for spring wheat in 2010) resulting in a total of 33,280 bushels (Knopf, 2010). If this was multiplied by the price of one bushel, there would be a gross of $246,605. If the same field was treated with a 0.68 kg (1.5 lbs) per acre application rate of sodium polyacrylate, there should be an expected
22% increase in bushels/acre (as shown in Experimental Plot 1 and Plot 2). This would increase harvest to a rate of 63 bushels/acre, which translates into 40,320 total bushels or $298,771. That is an increase of $52,166 in revenue. If you take out the cost of the sodium polyacrylate to seed that same area ($531) then the revenue increase would be $51,635 and the gross total would be $298,240. The use of the 1.36 kg (3.0 lbs) application rate was also cost effective. It resulted in 66 bushel/acre harvest (27% increase), 42,240 total bushels, $312,998 gross, and a $65,337 revenue increase (cost of sodium polyacrylate would be $1056) (Figure 19).

It is noted that the bushels per acre for all three of the plots were lower than the average yield for dry-land farming in the area. This could be due to the contraction of a stripe rust infection on June 25. Stripe rust is a fungus that infects the leaf part of the wheat plant producing yellow, orange uredospores. If left untreated, the fungus will
completely overrun the plant and the wheat will die. However, the variety used for this
test had been genetically modified to contain a gene that is activated by heat to stop the
rust infection. At the initial onset of the infection, the weather was not quite hot enough
to stop the spread but over the next week the temperature heated up to activate the
resistance gene thus halting the infection. Because of the delay in the stoppage of the
infection, the rust could have affected the overall yield by harming the wheat. Also, it
was observed that the severity of the infection was the same throughout the three plots
and therefore should have affected the respective plot yields equally. Without the
infection the yields of the three Plots would likely have been higher.

In conclusion, the hypothesis was accepted. The application of sodium
polyacrylate increased crop growth in dry-land farming, as shown through the improved
average height, kernel count/mass, and yield results. It increased the bushels/acre by at
least 20%. For farmers this is a highly attractive figure. The application rates used in the
Experimental Plot 1 and the Experimental Plot 2 were both cost effective. Further avenues of research include experimental full-size fields, the application to various crops, and long-term study in the same plot to determine if the chemical is as effective over time. Another attribute that would make this additive applicable to large scale farming is the fact that it is reusable. Sodium polyacrylate theoretically can absorb and then release water indefinitely and therefore would only have to be applied to a field once as opposed to repeat applications of other additives. This fact cuts the cost for farmers while providing the same benefit.

Figure 19. Comparison of Application Rate, Total Bushels and Revenue.
Acknowledgements

I would like to thank Mr. Jeff Schibel for the use of his land, equipment, and seed as well as farming advice for an amateur as the study progressed. Also, I would like to acknowledge my parents, Steven and Linda Powell for helping with transportation and encouragement. I would like to thank Soiltest Farm Consultants, Inc. for graciously providing free soil analysis for my research. Lastly, I would like to thank my science teacher, Mr. Wehr for all his assistance in all stages of the project, from the initial idea on paper to the completion of this paper, his help was invaluable.
Appendix A. Pre-experimentation soil analysis for the Control, Experimental Plot 1, and Experimental Plot 2 fields.

<table>
<thead>
<tr>
<th>NUTRIENTS</th>
<th>Soil Bulk Density</th>
<th>NO$_3$N</th>
<th>NO$_2$N</th>
<th>NH$_4$N</th>
<th>NH$_4$N</th>
<th>SO$_4$S</th>
<th>SO$_4$S</th>
<th>Available H$_2$O</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>inches (inches)</td>
<td>ppm (mg/kg)</td>
<td>ppm (mg/kg)</td>
<td>ppm (mg/kg)</td>
<td>ppm (mg/kg)</td>
<td>inches/depth</td>
<td>inches/depth</td>
<td></td>
</tr>
<tr>
<td>0/12</td>
<td>3.85</td>
<td>17</td>
<td>62</td>
<td>5</td>
<td>18</td>
<td>168</td>
<td>18</td>
<td>168</td>
</tr>
<tr>
<td>12/24</td>
<td>3.70</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total (sum of depths) lbs/acre</td>
<td>168</td>
<td>0</td>
<td>18</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Estimated N Release from Organic Matter (ENROM) = 0

Sum of Available N (NO$_3$N + NH$_4$N + ENROM) = 168

<table>
<thead>
<tr>
<th>1st depth result</th>
<th>Extraction Method</th>
<th>ppm (mg/kg)</th>
<th>lbs/acre-depth</th>
<th>Interpretation (1st depth)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phosphorus, Olsen</td>
<td>(0.5N NH$_4$CO$_3$)</td>
<td>(PO$_4$)</td>
<td>30</td>
<td>251</td>
</tr>
<tr>
<td>Phosphorus, Bray P1</td>
<td>(NH$_4$F, HCI)</td>
<td>(PO$_4$)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phosphorus, Bray P2</td>
<td>(NH$_4$F, HCl x 4 )</td>
<td>(PO$_4$)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Potassium, Olsen</td>
<td>(0.5N NH$_4$CO$_3$)</td>
<td>(K)</td>
<td>708</td>
<td>3114</td>
</tr>
<tr>
<td>Boron</td>
<td>(Ca(H$_2$PO$_4$)$_2$)</td>
<td>(B)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zinc</td>
<td>(DTPA)</td>
<td>(Zn)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manganese</td>
<td>(DTPA)</td>
<td>(Mn)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Copper</td>
<td>(DTPA)</td>
<td>(Cu)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iron</td>
<td>(DTPA)</td>
<td>(Fe)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chloride</td>
<td>(Cl)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

SOIL CHARACTERISTICS

<table>
<thead>
<tr>
<th>pH (1 H$_2$O:1 Soil)</th>
<th>Electrical Cond. (EC 1:1) (dS/m)</th>
<th>Soluble Salts (Sat Paste) (ds/m)</th>
<th>Organic Matter % (Walkley-Black)</th>
<th>Effervescence (Scale = 1 to 7)</th>
<th>% Lime (Calcium Carbonate CaCO$_3$)</th>
<th>Buffer pH for lime mg</th>
</tr>
</thead>
</table>

EXCHANGEABLE BASES

Typical ranges in %

<table>
<thead>
<tr>
<th>Calcium (Ca)</th>
<th>Magnesium (Mg)</th>
<th>Sodium (Na)</th>
<th>Potassium (K)</th>
<th>Total Bases (Ca + Mg + Na + K)</th>
<th>Cation Exchange Capacity (CEC)</th>
<th>Percent Base Saturation (TB/CEC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(55 - 75)</td>
<td>(15 - 40)</td>
<td>(0.1 - 5)</td>
<td>(2 - 8)</td>
<td>1.81</td>
<td>708</td>
<td>2583</td>
</tr>
</tbody>
</table>

RECOMMENDATION GUIDE

Yield Goal: Units

- Nitrogen (N), lbs/ac
- Phosphorus as (P$_2$O$_5$), lbs/ac
- Potassium as Potash (K$_2$O), lbs/ac
- Sulfur (S), lbs/ac
- Boron (B), lbs/ac
- Zinc (Zn), lbs/ac
- Manganese (Mn), lbs/ac
- Copper (Cu), lbs/ac
- Iron (Fe), lbs/ac
- Chloride (Cl), lbs/ac
- Magnesium (Mg), lbs/ac
- Lime Requirement, 100% Lime Equivalents, lbs/ac
- Gypsum Requirement, lbs/ac
- Elemental Sulfur (S) Req, lbs/ac

--- Recommendation Crop(s) ---

Previous Crop: Units

Fax #
Appendix B. Post-experimentation soil analysis for the Control field.
Appendix C. Post-experimentation soil analysis for the Experimental Plot 1 field (2.5% SPA).
Appendix D. Post-experimentation soil analysis for the Experimental Plot 2 field (5.0% SPA).

![Soil Test Results Image]

**Soil Test Results**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phosphorus Olsens mg/kg</td>
<td>31</td>
</tr>
<tr>
<td>Potassium Olsens mg/kg</td>
<td>844</td>
</tr>
<tr>
<td>Boron mg/kg</td>
<td></td>
</tr>
<tr>
<td>Zinc mg/kg</td>
<td></td>
</tr>
<tr>
<td>Manganese mg/kg</td>
<td></td>
</tr>
<tr>
<td>Copper mg/kg</td>
<td></td>
</tr>
<tr>
<td>Iron mg/kg</td>
<td></td>
</tr>
<tr>
<td>Calcium NH4OAC meq/100g</td>
<td>3.0</td>
</tr>
<tr>
<td>Magnesium NH4OAC meq/100g</td>
<td>1.5</td>
</tr>
<tr>
<td>Sodium NH4OAC meq/100g</td>
<td>0.09</td>
</tr>
<tr>
<td>Buffer pH</td>
<td></td>
</tr>
<tr>
<td>Lime Req Tons/Acre</td>
<td></td>
</tr>
<tr>
<td>CEC meq/100g</td>
<td></td>
</tr>
<tr>
<td>Total Bases meq/100g</td>
<td>6.7</td>
</tr>
<tr>
<td>Base Saturation %</td>
<td></td>
</tr>
<tr>
<td>Chloride mg/kg</td>
<td></td>
</tr>
<tr>
<td>Gypsum Req. Tons/Acre</td>
<td></td>
</tr>
</tbody>
</table>

**Soil Test Results Details**

- **PH**: 5.5
- **EC**: 0.09 mhos/cm
- **ESI Sat Pasc E.C.**: 0.23 mhos/cm
- **Effloscence**: None
- **Lbs/Acre**
  - Ammonium-N: 1.4 @ 12" = 6
  - Organic Matter W.B.: 1.4 = 28
- **Depth**: 0 - 12 inches
- **Nitrate N**: 3.1 lbs/acre
- **Sulfate-S**: 12
- **Moisture**: 12

**Interpretation Guide**

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen (lbs/acre)</td>
<td>45</td>
<td>60</td>
<td>75</td>
</tr>
<tr>
<td>Phosphorus (ppm)</td>
<td>31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Potassium (ppm)</td>
<td>844</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sulfur (ppm)</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boron (ppm)</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zinc (ppm)</td>
<td>0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Fertilizer Recommendations**

- **30 Bushels of SPRING WHEAT DRY after UNKNOWN**
  - Nitrogen: 45 lbs/acre
  - Phosphorus: 31 lbs/acre
  - Potassium: 844 lbs/acre
  - Sulfur: 0 lbs/acre
  - Boron: 0 lbs/acre
  - Zinc: 0 lbs/acre
  - 30 lbs of Actual Nitrogen
  - 0 lbs of Actual P2O5
  - 0 lbs of Actual K2O
  - 0 lbs of Actual Sulfur
  - 0 lbs of Actual Boron
  - 0 lbs of Actual Zinc

*We make every effort to provide an accurate analysis of your sample. For reasonable cause we will repeat tests, but because of factors beyond our control in sampling procedures and the inherent variability of soil, our liability is limited to the price of the tests. Recommendations are to be used as general guides and should be modified for specific field conditions and situations.*

**This is your invoice.**

*Invoice Details*

- Act#: 1001
- P.O. #: 5
- Reviewed by: Brent Thyssen
- CPSSc
- List Price: $0.00
References & Literature Cited


