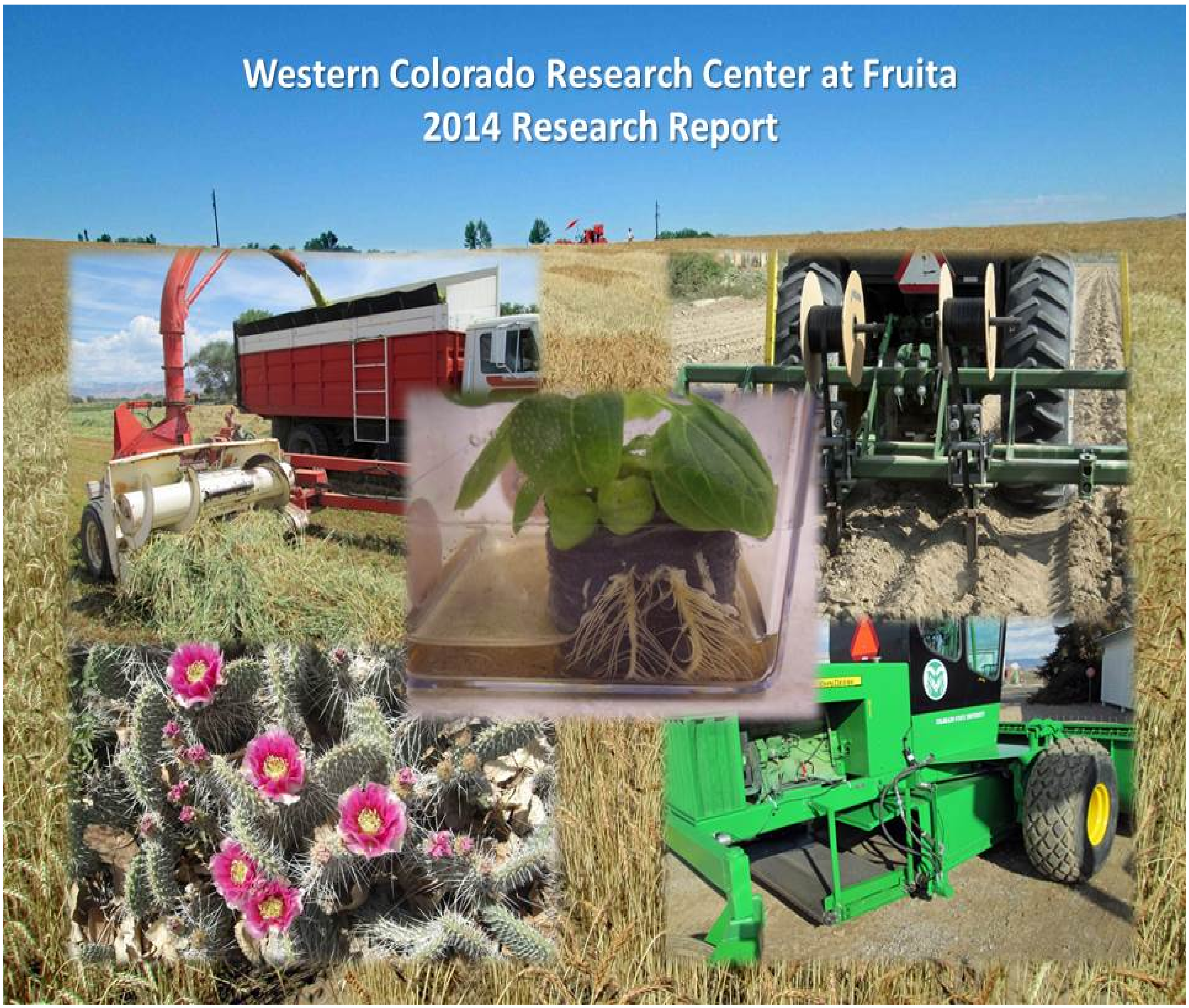
**Technical Report** **TR15-03**

# Agricultural Experiment Station

Colorado State University

College of Agricultural Sciences     Agricultural Experiment Station     Western Colorado Research Center



Green chopping oats/pea. See article starting on page 31. Photo by Calvin H. Pearson.

Prickly pear cactus being grown under modern agricultural production. See article starting on page 35. Photo by Calvin H. Pearson.


Installing subsurface drips lines. See related article starting on page 17. Photo by Calvin H. Pearson.

Automated forage plot harvester. See related article starting on page 43. Photo by Calvin H. Pearson.

Background photo of mature winter wheat field at Craig, Colorado. See article starting on page 49. Center photo of a transgenic sunflower that was regenerated in a tissue culture chamber at the Western Colorado Research Center at Fruita. See article on genetically engineered crops starting on page 9. Photos by Calvin H. Pearson.

College of Agricultural Sciences
Agricultural Experiment Station
Western Colorado Research Center

# Western Colorado Research Center at Fruita
# 2014 Research Report

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## Site Description

Fruita Site

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The Fruita site is located 15 miles northwest of Grand Junction. With an average growing season of 180 days at an elevation of 4600 feet, a diversity of agronomic research is conducted at the Western Colorado Research Center at Fruita, including variety performance trials in alfalfa, corn silage, corn grain, canola, grasses, small grains; new and alternative crops; irrigation; cropping systems; soil fertility; and new crop trait evaluation. The Colorado State University Foundation Dry Bean Project is located at Fruita.

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# Genetically Engineered Crops – An Agronomist's Viewpoint

Calvin H. Pearson,[1,2]

**Summary**

Agriculture is the foundation of modern civilization and we are decidedly dependent on agriculture to provide us with food, feed, fiber, fuel, and other products. Agriculture should be of interest to all of us given we are dependent on it to feed us every day of every year. Genetic engineering (GE) is defined as the manipulation of an organism's genes (DNA) by introducing, eliminating, rearranging, or varying the expression of specific genes (traits) using the modern methods of molecular biology. At the end of 2014 the global agricultural biotech market was valued at $27.8 billion. It is estimated that 70% of processed foods in the United States contain at least one ingredient from GE plants. Approximately half of the land (169 million acres) used for crop production in the U.S. in 2013 was planted to GE crops. To date, a total of 165 GE crop events in 19 plant species have been approved in the United States, but not all have been grown commercially. The average cost associated with the entire R&D process required to launch a product with a new GE trait using regulated biotechnology techniques is approximately $136 million and takes on average 13.1 years to complete. In 2013, 93% of soybean, 90% of cotton, 90% of corn, and 95% of sugarbeets in the United States were grown using GE varieties with one or more traits. The adoption of several improved agronomic production practices such as conservation tillage and reduced uses of pesticides would not be possible without GE crops and varieties. Numerous studies have shown that GE and conventional crops are functionally and compositionally equivalent. Mandatory labeling of GE foods based on legislative action is a topic of current interest and action. I discuss several issues in this article related to mandatory labeling of GE crops in the U.S. Continuing education and open dialogue with regard to GE crops are important to provide sound, science-based information to avoid misinformation, distrust, and anxiety. Policy decisions related to GE technology must be based on sound, science-based information.

## Introduction

**Agriculture** is the foundation of modern civilization. As a society we are decidedly dependent on agriculture to provide us with food, feed, fiber, fuel, and other products to support the large and growing human population of 7.2 billion. A symbiotic relationship exists between humans and crops- we are dependent on them and they are dependent on us. If either one were to disappear the other would soon follow. Thus, agriculture should be of interest to all of us given our dependence on it to feed us every day of every year.

Genetic engineering (GE) is defined as the manipulation of an organism's genes (DNA) by introducing, eliminating, rearranging, or varying the expression of genes for specific traits using the modern methods of molecular biology commonly referred to as "biotechnology" and more

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widely referred to by the scientific community as “recombinant DNA” or “rDNA” technology.

Some people refer to GE crops and products as genetically modified (GM) or genetically modified organisms (GMO). These two terms are not preferred because they are imprecise. Over the centuries all crop plants have been genetically modified from their original wild state. Crops for humanity have been subject to domestication, selection, natural mutation, and conventional plant breeding. All crops produced today have been genetically modified to one degree or another.

Manipulating genes by adding new ones obtained from another living organism such as bacteria or other plant and non-plant species or changing how genes are expressed can create crop plants that are more resistant to insects and diseases, allow improved weed control, more efficient harvest, higher crop yields, improved product quality, or better nutrition.

### Personal Experience with GE Crops

The first U.S. approved genetically engineered plant was a tomato developed in 1982. As a GE crop it did not enter the U.S. marketplace until 1994 and was marketed as the Flavr-Savr® tomato designed to be transported to market once it ripened on the vine because of a delayed softening characteristic. Transporting vine-ripened fruit would have changed the current practice of picking and shipping green tomatoes; however, this GE tomato was pulled from the market because of harvesting and marketing problems.

Seeds of commercially available agronomic GE crops first became available in 1996. I first conducted research on agronomic GE crops in 1998 at the Western Colorado Research Center at Fruita. My GE research at that time was a field experiment with herbicide-tolerant corn. Over the years I have worked with a variety of GE crops on a number of projects and at various research levels (keeping in mind I am an agronomist and not a molecular biologist). I continue to work each year with de-regulated GE corn, alfalfa, and canola. Over the years I have conducted or I am currently conducting nonregulated GE research on soybean, sunflower, and grass. The sunflower GE research was at a cutting edge level. Working with colleagues from several institutions around the US and Canada. I have dealt not only with basic scientific research, but also many aspects of regulatory compliance at the university, state, and federal levels. Furthermore, several years ago, I was also actively involved as an expert witness with international litigation involving GE LLRice 601. I had specific expertise on numerous aspects of GE crop and seed containment associated with research plot testing and farmer production to prevent escape and mingling of GE rice with conventional rice. My expert testimony was essential to successfully settling the lawsuit and preventing it from going to trial.

### Scope of GE Crops

The cumulative economic benefits from planting GE crops from 1996-2011 was $49.6 billion in developing countries and $48.6 billion in developed countries. At the end of 2014 the annual global agricultural biotech market was valued at $27.8 billion and is projected to increase an additional 11% over the next five years.

In 2014, there were 448 million acres of biotech crops produced globally with 40% of that acreage being grown in the United States. Approximately half of the land (180 million acres) used for crop production in the U.S. in 2014 was planted to GE crops. There are 20 developing and 8 industrialized countries that produced GE crops in 2014. These 28 countries represent more than 60% of the world's population.

The use of GE technology in agriculture is arguably one of the fastest to be adopted of any technology in history. Farmers realize benefits from growing GE crops through higher crop yields, improved crop quality, lower production costs, and management time-savings.

A total of 165 GE crop biotech events in 19 plant species have been approved in the United States, although not all of these are being produced commercially. These biotech GE events are in alfalfa (2), canola (20), chicory (3), corn (38), cotton (27), creeping bentgrass (1), flax (1), melon (2), papaya (3), plum (1), potato (28), rice (3), rose (2), soybean (19), squash (2), sugarbeet (3), tobacco (1), tomato (8) and wheat (1). Other events and crops are in various stages of GE development but have not yet reached the approval stage. Between 2005 and 2013 there has been a 5-fold increase in the release of GE varieties containing various agronomic traits. Specifically, there were 1,043 field releases in 2005 and in 2013 there were 5,190 field releases of GE varieties.

Numerous GE traits have been identified and tested including herbicide resistance, insect resistance, viral/fungal resistance, cold tolerance, drought tolerance, frost tolerance, salinity tolerance, increased nitrogen use efficiency, increased yield, modified lignin content, delayed ripening, increased flavor, improved texture, increased protein and carbohydrate content, changes in fatty acid content, changes in micronutrient content, modified starch content, color modification, fiber properties, gluten content, nutraceuticals (added vitamins, antioxidants), pharma-ceuticals, and others.

Discovery, development, and regulatory approval of products containing new traits that use regulated genetic engineering techniques is scientifically, regulatory, and legally complex, expensive, and time consuming. The mean cost associated with the entire R&D process required to launch a product with a new trait using regulated biotechnology techniques is approximately $136 million and takes on average 13.1 years to complete. Of that $136 million, $31 million is spent on trait discovery, $70 million is spent on product development and testing of the trait, and $35 million is spent on regulatory science, compliance, and registration.

Several major crops in the United States are widely grown using GE varieties. In 2013 93% of soybean, 90% of cotton, 90% of corn, and 95% of sugarbeets in the United States were grown using GE varieties containing one or more traits. Similar adoption rates have occurred in other countries such as Canada, South Africa, Brazil, and Argentina.

The adoption of several improved agronomic production practices would not be possible without GE crops and varieties. Various conservation tillage practices such as no-till, strip tillage, reduced tillage, reduced pesticide applications, and the use of less toxic pesticides are possible when used in combination with GE crops and varieties. For example, in 2006 approximately 86% of herbicide-tolerant soybeans were planted under conservation tillage systems in the U.S. compared to just 36% of conventionally-planted soybean acres. Other similar examples can be found in corn and cotton. The implementation of many modern agronomic practices creates benefits that are sustainable to the environment, the economy, and food security.

The development of new and improved crop varieties require access to genetic diversity in order to identify and incorporate useful genes into new varieties that can be grown to produce our food and feed. For more than 100 years, plant explorers and plant breeders have scoured the earth searching for useful genetic diversity as found in native populations or crop relatives. These scientists have also attempted to create useful genetic diversity in the laboratory by inducing mutations using chemicals or radiation. The advent of genetic engineering provides scientists with the powerful tools of biotechnology to obtain new sources of genetic diversity to meet the many needs of a growing and diverse human population.

It is estimated that 70% of processed foods in the United States contain at least one ingredient from GE plants, mainly coming from GE corn and soybean. Extensive scientific research performed by independent scientists around the world has concluded that there are no negative effects when GE crops are consumed. These findings are based on peer-reviewed publications in which feeding studies were conducted on a wide variety of animal species including chickens, quail, pigs, sheep, dairy cows, beef cattle, goats, rabbits, and fish. Various parameters were quantified including feed intake, nutrient digestions, performance, and health. The National Academy of Sciences has concluded, "To date, no adverse health effects attributed to genetic engineering have been documented in the human population."

Commercial livestock is the largest consumer of GE crops, consuming 70-90% of genetically engineered crops. Billions of animals have been fed GE products for nearly 20 years. Research studies have shown that the GE crops are compositionally equivalent to non-GE feed. Furthermore, scientific research has shown animals that consume GE feed do not differ in feed digestibility, performance, or health than livestock fed non-GE feed. Additionally, it is not possible to detect differences in nutritional profiles of animal products when animals consume GE feed.

## Regulation of GE Crops

In the United States, three agencies are responsible for shared regulatory oversight and the release of GE plants: The Animal and Plant Health Inspection Service (APHIS), the Food and Drug Administration (FDA) and the Environmental Protection Agency (EPA).

The Animal and Plant Health Inspection Service (APHIS) is an agency within USDA that regulates the planting, importation, transportation, and ultimately the environmental release and safety of GE plants/crops. APHIS has a central role in regulating the field-testing of agricultural biotech crops.

The Food and Drug Administration (FDA) regulates the safety of most human and animal food products in the U.S. including GE food and feed. They are also responsible for the proper labeling of GE plant-derived food and feed.

The Environmental Protection Agency (EPA) regulates pesticides and microorganisms which includes the safety of pesticidal traits that have been inserted into GE plants.

GE research requires that a highly detailed and comprehensive standard operating procedure (SOP) be developed and implemented for each specific project. SOP's are needed for proper execution of the project and to protect the environment. We had a GE project for many years on enhancing the natural rubber biosynthesis of sunflower. Given that sunflower is an open-pollinated, native plant and it was imperative that we prevent pollen from our transgenic sunflowers reaching and pollinating wild sunflowers. We developed a very detailed SOP with strict laboratory and greenhouse procedures to make sure that gene flow from our putative GE sunflowers did not occur.

## Labeling of GE Foods

Mandatory labeling of GE foods based on legislative action is a topic of current interest and action in several states in the United States. Initiatives for mandatory labeling have been based primarily on food safety concerns and right-to-know about GE products in the food we eat. Additionally, the argument for GE labeling is that the products containing GE ingredients are intrinsically different because they are not found in nature.

Complex legal issues between states and existing federal labeling laws have been raised. If new laws are enacted considerable litigation is likely in an effort to resolve numerous conflicts among various state agencies, federal authorities, and private companies and organizations. Current labeling authority resides at the federal level and established federal laws typically trump conflicting state GE labeling laws.

Interestingly, the labeling of GE foods involves First Amendment issues given that the First Amendment prohibits government compulsion of commercial speech unless the speech is factual, uncontroversial, and reasonable. GE labeling on a state-by-state basis would create additional legal issues related to interstate commerce that are regulated under federal law. Also, GE labeling at the national and state levels is likely to complicate and impact international trade.

Companies large and small would likely encounter difficulty complying with GE food labeling laws that differ among states. This would undoubtedly increase costs to consumers and may cause companies, particularly small companies, to reduce or eliminate markets and possibly go out of business. Furthermore, varying GE labeling laws from state-to-state may cause companies to change marketing strategies and eliminate markets in select states or regions; thus, shopper options, product diversity, and competition could be adversely affected.

Many cost factors would be affected by GE labeling including those related to implementation of GE labeling. Such labeling would take several years to fully implement, costs among states would likely vary, and costs related to product and ingredient exemptions would likely vary from state to state, to name only a few. An important consideration is that increased food costs brought about by mandatory GE labeling would cause selective hardship on the poor.

Some questions about GE labeling are worth pondering. Under what specific criteria should products be required to have a GE label? Should a product be labeled if a GE ingredient is added but loses its identity during processing? If an existing protein or minor ingredient is augmented or increased through GE should the resulting product be required to have a GE label? While the labeling of GE foods raises numerous questions and complex issues the safety of GE foods currently on the market is not in doubt. In a 2012 report by the American Medical Association they conclude that …"there is no scientific justification for special labeling of bioengineered foods, as a class."

## Risks Associated with GE Crops

There are associated risks with nearly every activity and every technology we deploy. Those associated risks should be identified and managed to hold them at a realistic and acceptable level. Some of the risks associated with GE plants and crops include the potential of introducing allergens or other anti-nutritional factors in our food and feed. Risks must also be managed to prevent a GE crop or crop variety from escaping agriculture to become weedy or to cross with wild relatives. Some GE plants produce toxins to control pests and these toxins should not adversely affect non-target organisms. Additionally, there may be risks for pests to become resistant to a toxin that is produced by a GE crop.

### The Future of GE Crops

Much of the R&D and commercialization of GE crops and varieties has focused on agronomic crops and this is likely to continue. However, considerable biotechnological effort is being directed on the development of GE horticultural and ornamental crops. Numerous GE traits have already been introduced in horticultural and ornamental crops including flower color, fragrance, flower shape, plant architecture, flowering time, post-harvest life, amelioration of biotic and abiotic stresses.

The R&D and commercialization (lab-to-bag) of GE crops continues to move forward at a rapid pace. Given the scientific and regulatory complexities associated with GE technology it is crucial that ongoing and open dialogue occur among scientists, regulators, politicians, and the public. Continuing education and open dialogue with regard to GE crops are also important to provide sound, science-based information to avoid misinformation, distrust, and anxiety.

Policy decisions related to GE technology must be grounded in sound, science-based information on a trait-by-trait basis. The current regulatory process is likely to become more challenging as gene-editing technologies and other advanced technologies for DNA modification become widely accepted and utilized. Some of these technologies do not result in adding foreign DNA into the resulting plant, although GE techniques are used in development. Biotech products created from advanced GE tools will be more difficult and possibly impossible to trace or track.

As with any activity, product, or process, we must assess the risks versus the benefits. Not only should the risks and benefits of GE crop plants, in and of themselves, be considered, we should also weigh the risks of adopting versus not adopting commercial production of GE crops and varieties. Furthermore, the current regulatory framework used in the U.S. may not be suitable to assess the risks and benefits of GE crops and varieties developed using advanced biotech technologies.

Most of the world's land area available for crop production is currently in production. This land area is finite and shrinking. In 1991, 0.81 acres of farmland was available to feed each person. By 2050 that area will be reduced to 0.37 acres. The U.S. population is currently at 320 million and is projected to be 458 million by 2050. The world population is expected to reach 9.6 billion by 2050. Thus, the productivity of each acre of cropland must be substantially increased. The tools of modern biotechnology will be valuable in meeting these challenging needs.

Lastly, keep in mind that as scientists we shop at the same markets, go to the same restaurants, and eat the same food products as the general public and we too desire a safe, healthy, diverse, and ample food supply.

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# Using Subsurface Drip Irrigation in Alfalfa in Western Colorado, 2014

Calvin H. Pearson[1] and Wayne Guccini[2]


## Summary

Increasing competition for water resources particularly those used by agriculture and demands for irrigation practices that are environmentally friendly are motivating factors to use agricultural irrigation water more efficiently. The objective of this study was to compare irrigation performance, forage yields, and forage quality of subsurface drip irrigation (SDI) with traditional furrow irrigation using gated pipe at the Colorado State University, Agricultural Experiment Station, Western Colorado Research Center at Fruita during the 2014 growing season. Based on data obtained from soil moisture tension sensors, soil moisture was concentrated in the soil profile where alfalfa roots can readily obtain soil moisture without water losses occurring to evaporation or deep percolation. There were no significant differences in alfalfa forage yields between irrigation treatments in the first, third, fourth, and total 2014 forage yields. The average total 2014 dry matter forage yield was 9.17 tons/acre. Forage yield in the furrow irrigation treatment in the second cutting was significantly higher than in the SDI treatments which indicate we were not applying enough irrigation water in the SDI treatments to obtain high alfalfa yields. In 2014, 16.42 acre inches of water were applied to each of the SDI treatments, and under furrow irrigation 65.5 acre inches of water were applied to the field with an estimate of 39.6 acre inches of tailwater (runoff) and 25.9 acre inches of infiltration water resulting in approximately 40% irrigation efficiency under furrow irrigation. Thus, with furrow irrigation nearly 4 times more water was needed than in the SDI to produce the same amount of alfalfa hay. Data obtained in 2014 indicate that not only is irrigation water used much more efficiently to produce high yields but important forage quality factors can also be improved when alfalfa is grown under SDI as compared to conventional furrow irrigation.


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## Introduction

**Increasing** competition for water resources particularly those used by agriculture and demands for irrigation practices that are environmentally friendly are motivating factors to use agricultural irrigation water more efficiently. Additionally, sustainable crop production systems require more efficient irrigation water applications. This dictates the use of improved management and the adoption of advanced irrigation technologies by irrigators to avoid overwatering to reduce runoff, deep percolation, and salt and selenium loading and other contaminants into water supplies that affect downstream users.

When irrigation water is cheap, plentiful, readily accessible, and is a major factor to


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achieve high crop yields, overwatering is likely (Sadler and Turner, 1994). Good management along with proven technology is essential to apply irrigation water in an optimum manner. The use of good management and proven technology would likely result in a reduction in the amount of water needed to meet crop water requirements (Clegg and Francis, 1994).

In Colorado, nearly 660,000 acres (6,578 farms) are furrow-irrigated (USDA, 2008). Furrow irrigation is a partial surface flooding method of irrigation where water is applied in furrows at the top of a sloping field and gravity moves the water to the end of the field. Numerous conditions influence the amount of water that infiltrates into the soil along the length of the field and the amount of water that drains off the end of the field as runoff or tailwater (Pearson et al., 1998).

Subsurface drip irrigation (SDI) is a low pressure, high efficiency irrigation system that uses buried drip lines (tube or tape) to meet crop water needs. SDI technology has been commercialized since the 1960s, but in recent times has gained in popularity primarily because of increasing scarcity of water resources and advancements in SDI technologies (Reich et al., 2009).

With SDI, water is applied below the soil surface at a depth to meet crop water needs while allowing for crop production using mechanization. Optimum management and performance of SDI systems can reduce soil crusting, use less water, eliminate surface water and evaporation, eliminate deep percolation, eliminate irrigation water runoff, and reduce weeds and diseases. Furthermore, high fertilizer application efficiencies are possible when fertilizers are applied through SDI systems. Many of the advantages of SDI have been summarized by Netafim USA (n.d.)

Purchase and installation costs of SDI systems are higher than those for furrow irrigation. The cost of the SDI equipment and associated installation costs vary from $1,000 to $2,000 per acre depending on various factors specific to the farm and field situation. The life of an SDI system is expected to range from 12 to 15 years (Reich et al., 2009).

Agronomic field research has been previously conducted with SDI in alfalfa in Kansas (Alam et al., 2002). They compared SDI with center pivot sprinkler irrigation. The objective of our study was to compare irrigation performance, forage yields, and forage quality of SDI with traditional furrow irrigation at the Colorado State University, Agricultural Experiment Station, Western Colorado Research Center at Fruita. SDI drip lines were installed at 8-inch and 16-inch depths to compare the performance of these two drip lines. Drip lines at a 16-inch depth are preferred in many cases over 8-inch deep drip lines to allow tillage operations without damaging the buried drip lines. This report describes results obtained during the 2014 growing season.

## Materials and Methods

A field study in a side-by-side comparison of furrow and subsurface drip irrigation (SDI) on alfalfa over three years starting in 2012. The study was initiated to compare irrigation performance, forage yields, and forage quality of subsurface drip irrigation (SDI) with traditional furrow irrigation at the Colorado State University, Agricultural Experiment Station, Western Colorado Research Center. Details of the study were previously presented by Pearson et al. (2014). Recommendations for the design, management, and maintenance of an SDI system in alfalfa have been presented by Netafim USA (n.d.). The SDI study was again conducted similarly during the 2014 growing season.

Alfalfa water use during 2014 was estimated using a CoAgMet weather station (http://www.coagmet.colostate.edu/) located at the Western Colorado Research Center near the study site. Irrigation water application was determined with a gated pipe flow meter (McCrometer Model MO300 flow meter, Hemet, CA installed in gated pipe section, MCCrometer Great Plains, Model MD306, Aurora, NE) and tailwater was determined using a broad-crested flume fitted with a water level sensor (Global Water, Model WL16U-03,25ft, College Station, TX).

Soil moisture tension was monitored using data loggers (M. K. Hanson, model no. AM400-02A, Wenatchee, WA). Soil moisture tension sensors (Watermark, model no. 200SS, Irrometer Co., Riverside, CA) were buried at 8, 16, and 32-inch depths. Sensors were installed approximately 30 feet from the top and bottom of the field, at approximately the middle of the 16-inch and 8-inch zones. In the furrow irrigation field, soil moisture tension sensors were installed in the middle of the field from side to side and at approximately ¼ of the way down from the top and at approximately ¼ of the distance up from the bottom of the field.

## Results and Discussion

Water use during 2014 was again estimated with a CoAgMet weather station onsite at the research center, with gated pipe flow meters, and with tailwater flumes. Based on data from our CoAgMet weather station, alfalfa reference ET from May 1 to Sept 30 was 42.5 inches (Fig. 1).

Rainfall during the period May 2014 through September 2014 was 4.85 inches (Fig. 2). Of this total amount a portion of it would be effective rainfall that would have contributed to alfalfa production. Effective rainfall was not estimated and was not included in our water calculations.

During 2014 we applied irrigation water in the SDI at a rate of 0.12 inch per hour. We began irrigating with the SDI on April 17, 2014 and we irrigated 4 hrs per zone once a week until the second cutting. After second cutting we applied irrigation water in the SDI at 4 hrs/zone twice a week. The SDI irrigation system was shut down at the end of the growing season during the second week of September given the rainfall we experienced during August and September (Fig. 2).

Based on readings from an inline flow meter in the SDI irrigation system 16.42 acre inches of water were applied to each of the SDI treatments. Given the application rate and application times for the SDI irrigation system, we applied 16.3 acre inches of irrigation water to alfalfa during the growing season (Fig. 3). Thus, the amount of water applied through SDI was determined by two different methods with these two calculations being in close agreement.

The data in Fig. 4 indicate that good irrigation efficiency can be achieved with SDI. The soil surface in the SDI was not wetted during the growing season and thus evaporation was minimized, if not eliminated, as noted by the responses of Sensors #1 and #4. Additionally, as shown by the responses of Sensor #3 and #6 positioned at a 32-inch depth the soil was dry and deep percolation did not occur. The responses of Sensors #2 and #5 show that irrigation water was concentrated at the 16-inch depth at a location where water was readily available to the alfalfa root system, thus, irrigation water was provided to the alfalfa plant without applying water that was subject to losses from evaporation or deep percolation. We had considerable rain events during the month of September and this response is indicated by the data from Sensors #1 and #4 during the last half of August and early September.

The data presented in Fig. 4 also indicate the irrigation efficiency that can be achieved with SDI when the drip lines are located at both the 8 and 16-inch depths. The data in Fig. 4 indicate there is a range of soil moisture tensions that are acceptable and result in the production of high alfalfa yields without causing soil moisture losses to evaporation or deep percolation.

The responses obtained from sensors located at the three soil depths at the top end of the furrow-irrigated alfalfa field readily show the large variations in soil moisture that occur under furrow irrigation (Fig. 5). These responses of soil moisture under furrow irrigation in 2014 as shown in Fig. 5 are similar to those observed in 2013. Furrow irrigation wets the soil profile increasing the potential for deep percolation and increasing evaporation at the soil surface. Thus, substantially more irrigation water is needed to accommodate losses to evaporation, deep percolation, and runoff in order to obtain high crop yields.

There were no significant differences in alfalfa forage yields between irrigation treatments in the first, third, fourth, and total 2014 forage yields (Table 1). The forage yield in the furrow irrigation treatment in the second cutting was significantly higher than in the SDI treatments. This finding indicates that we were not applying enough irrigation water in the SDI treatments to obtain high alfalfa yields. We observed this at the time of the second cutting and accordingly we increased irrigation water application in the SDI from once a week to twice a week.

Moisture contents of alfalfa were determined at harvest. There were no significant differences in harvested alfalfa moisture contents between irrigation treatments in the third and fourth cuttings (Table 2). The moisture content of harvested alfalfa in the first cutting in the furrow irrigation treatment was significantly higher than in the 8-inch depth and in the 16-inch depth treatments. In the second cutting the opposite situation occurred. The moisture content of harvested alfalfa in the second cutting in the furrow irrigation treatment was significantly lower than in the 8-inch depth and in the 16-inch depth treatments. A possible explanation for these results is that under the cooler temperatures during the first cutting soil moisture was higher under furrow irrigation which maintained higher hay moisture at harvest. During the second cutting the opposite occurred, with higher temperatures during the second cutting soil moisture was lower under furrow irrigation which caused lower hay moistures at harvest than in the SDI treatments.

Growing alfalfa using SDI was much more efficient in producing harvestable alfalfa hay than when alfalfa is produced using furrow irrigation (Table 3). In 2014, 16.42 acre inches of water were applied to each of the SDI treatments, and under furrow irrigation 65.5 acre inches of water were applied to the field with an estimate of 39.6 acre inches of tailwater (runoff) and 25.9 acre inches of infiltration water resulting in approximately 40% irrigation efficiency under furrow irrigation. Thus, with furrow irrigation nearly 4 times more water was needed than in the SDI to produce the same amount of alfalfa hay. In other words, compared to furrow irrigation, 49.1 acre inches less water were required under SDI to produce the same amount of alfalfa hay compared to alfalfa grown with furrow irrigation. Effective rainfall was not included in these calculations.

Soil samples were collected in March 2014 from 4 depths- the soil surface, 1, 2, and 3-foot depths in the three irrigation treatments. Soil salinity was determined using a Kelway tester and the data obtained were corrected to a saturated paste electrical conductivity test. Soil salinity tended to increase with soil depth, but there did not appear to be salinity differences among the irrigation treatments (Table 4). Furthermore, salinity values among the irrigation treatments at the soil surface were all less than 1 mmhos/cm and did not reach a level that would be damaging to alfalfa (Soltanpour and Follett, 1995. Crop tolerance to soil salinity. No. 0.505. Colorado State University Cooperative Extension. Fort Collins, CO). A concern has been expressed that SDI could increase soil salinity at or near the soil surface. Although these data are non-replicated it appears that SDI does not increase soil salinity at the soil surface or at deeper depths that would be detrimental to crop production beyond what occurs under furrow irrigation. Keeping in mind that SDI does not allow for periodic leaching irrigations to flush soils in which salinity levels may increase to a damaging level.

The quality of the water from the Colorado River used for irrigation in the Grand Valley is good (0.3 mmhos/cm; fall - 1.0 mmhos/cm), but some soils in the valley are known to contain considerable salts. Thus, periodically it may be wise to perform soil sampling and analysis to determine if salts are being concentrated within the soil profile that could be damaging to crops.

Forage quality of alfalfa is important to producers and buyers. Forage quality of the alfalfa grown under the three irrigation treatments was excellent for all four cuttings in 2014. Alfalfa grown under SDI and furrow irrigation in 2014 did not affect ADF, fat, phosphorus, or TDN in any of the four cuttings (Table 5).

Alfalfa grown under SDI and furrow irrigation in 2014 affected one or more forage quality factors in all four cuttings (Table 5). In the first cutting only one forage quality factor was affected by irrigation treatments. In the second cutting, six forage quality factors were affected. In the third cutting four forage quality factors was affected while three forage quality factors were affected by irrigation treatments in the fourth cutting.

In the first cutting in 2014 potassium concentrations in the 16-inch and the 8-inch SDI treatments were increased by 23% and 16%, respectively, compared the furrow irrigation treatment (Table 5).

The six forage quality factors affected by irrigation treatment in the second cutting in 2014 were ash, potassium, magnesium, neutral detergent fiber (NDF), crude protein, and relative feed value (RFV) (Table 5). Ash concentrations in the 16-inch and the 8-inch SDI treatments ash were increased by 12% and 10%, respectively, compared to the control treatment. Potassium concentrations in the 16-inch and the 8-inch SDI treatments were increased by 37% and 39%, respectively, compared to the control treatment. Magnesium concentrations in the 16-inch and the 8-inch SDI treatments were decreased by 7% and 10%, respectively, compared to the control treatment.

NDF in the 16-inch SDI treatment was decreased by 10% compared to the control treatment. There was no significant difference in NDF concentration between the 8-inch SDI treatment and the furrow irrigation treatment in the second cutting in 2014. Neutral detergent fiber is a forage quality factor for digestibility. NDF is an indicator of the structural components of the plant. NDF is a predictor of voluntary intake because it provides bulk fiber. In general, low NDF values are desired because NDF increases as forages mature.

Crude proteins in the second cutting in 2014 were increased in the 16-inch and the 8-inch SDI treatments by 11% and 7%, respectively, compared to the control treatment. RFV in the 16-inch SDI treatment was increased by 16% compared to the control treatment. There was no significant difference in RFV concentration between the 8-inch SDI treatment and the furrow irrigation treatment in the second cutting in

2014.

The four forage quality factors affected by irrigation treatment in the third cutting in 2014 were potassium, NDF, crude protein, and RFV (Table 5). Potassium concentrations in the 16-inch and the 8-inch SDI treatments were increased by 26% and 14%, respectively, compared to the control treatment. NDF in the 16-inch SDI treatment was decreased by 11% compared to the control treatment. There was no significant difference in NDF concentration between the 8-inch SDI treatment and the furrow irrigation treatment in the second cutting in 2014.

Crude protein in the third cutting in 2014 in the 16-inch and the 8-inch SDI treatments was increased by 11% compared to the control treatment. There was no significant difference in crude protein concentration between the 8-inch SDI treatment and the furrow irrigation treatment in the second cutting in 2014. RFV in the 16-inch SDI treatment was increased by 18% compared to the control treatment. There was no significant difference in RFV concentration between the 8-inch SDI treatment and the furrow irrigation treatment in the second cutting in 2014.

The three forage quality factors affected by irrigation treatment in the fourth cutting in 2014 were calcium, potassium, and magnesium (Table 5). Calcium concentrations in the 16-inch and the 8-inch SDI treatments were decreased by 12% and 9%, respectively, compared to the control treatment. Potassium concentrations in the 16-inch and the 8-inch SDI treatments were increased by 26% and 31%, respectively, compared to the control treatment. Magnesium concentrations in the 16-inch and the 8-inch SDI treatments were each decreased by 13% compared to the control treatment.

Data obtained in 2014 indicate that not only is irrigation water used much more efficiently to produce high yields but important forage quality factors can also be improved when alfalfa is grown under SDI as compared to conventional furrow irrigation.

## Acknowledgments

Appreciation is extended to Fred Judson and Kevin Gobbo (Western Colorado Research Center staff), Anna Mudd (summer hourly employee), and Evan Cunningham (summer intern) who assisted with this research. Funding support of this project was provided by the Colorado Water Conservation Board and the Colorado River District.

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Table 1. Alfalfa forage yields in the subsurface drip irrigation study at Colorado State University, Western Colorado Research Center, Fruita, CO during 2014.

| Treatment | First cutting May 28 | Second cutting July 7 | Third cutting Aug. 11 | Fourth cutting Sept. 24 | Total 2014 forage yield |
|---|---|---|---|---|---|
| | | Dry matter (tons/acre) | | | |
| 16-inch drip line depth | 3.07 | 2.54 | 2.03 | 1.44 | 9.08 |
| 8-inch drip line depth | 2.89 | 2.48 | 2.13 | 1.37 | 8.87 |
| Furrow irrigation comparison | 3.01 | 2.94 | 2.15 | 1.45 | 9.55 |
| Ave | 2.99 | 2.65 | 2.10 | 1.42 | 9.17 |
| CV (%) | 6.7 | 6.5 | 8.7 | 6.5 | 6.1 |
| LSD (0.05) | NS | 0.30 | NS | NS | NS |

Table 2. Moisture content of harvested alfalfa hay in the subsurface drip irrigation study at Colorado State University, Western Colorado Research Center, Fruita, CO during 2014.

| Treatment | First cutting | Second cutting | Third cutting | Fourth cutting |
|---|---|---|---|---|
| | | Moisture content (%) | | |
| 16-inch drip line depth | 21.3 | 24.1 | 22.4 | 20.2 |
| 8-inch drip line depth | 21.4 | 23.2 | 22.0 | 20.0 |
| Furrow irrigation comparison | 23.4 | 21.9 | 22.5 | 20.7 |
| Ave | 22.0 | 23.1 | 22.3 | 20.3 |
| CV (%) | 3.8 | 2.4 | 3.0 | 4.8 |
| LSD (0.05) | 1.5 | 1.0 | NS | NS |

Table 3. Subsurface drip irrigation demonstration: water applied per dry ton of alfalfa at the Western Colorado Research Center, Fruita, CO.

| Treatment | Inches of water per dry ton of alfalfa |
|---|---|
| 16-inch drip line depth | 1.81 |
| 8-inch drip line depth | 1.85 |
| Furrow irrigation | 6.86[1] |

[1]Total amount of irrigation water applied under furrow irrigation was used in the calculation.

Table 4. Soil salinity determined in the subsurface drip irrigation study at Colorado State University, Western Colorado Research Center, Fruita, CO during spring 2014.

| Irrigation treatment | Soil sampling depth (ft) | Soil salinity (mmhos/cm) |
|---|---|---|
| Furrow | 0 | 0.4 |
| | 1 | 0.4 |
| | 2 | 0.6 |
| | 3 | 1.2 |
| 16-inch | 0 | 0.4 |
| | 1 | 1.0 |
| | 2 | 1.6 |
| | 3 | 1.6 |
| 8-inch | 0 | 0.7 |
| | 1 | 1.1 |
| | 2 | 1.4 |
| | 3 | 0.7 |

Table 5. Forage quality analysis for acid detergent fiber (ADF), ash, calcium (Ca), fat, potassium (K), magnesium (Mg), neutral detergent fiber (NDF), and phosphorus (P) in subsurface drip and furrow-irrigation alfalfa at the Colorado State University, Western Colorado Research Center at Fruita during the 2014 growing season.

| Treatment | ADF | Ash | Ca | Fat | K | Mg | NDF[†] | P |
|---|---|---|---|---|---|---|---|---|
| | % | % | % | % | % | % | % | % |
| First cutting | | | | | | | | |
| 16-inch depth | 28.8 | 9.37 | 1.46 | 2.14 | 2.56a | 0.31 | 33.68 | 0.36 |
| 8-inch depth | 30.0 | 9.23 | 1.42 | 2.04 | 2.42a | 0.29 | 34.88 | 0.35 |
| Furrow | 28.6 | 8.88 | 1.57 | 2.19 | 2.08b | 0.34 | 33.45 | 0.34 |
| Second cutting | | | | | | | | |
| 16-inch depth | 31.5 | 9.82a | 1.38 | 1.70 | 2.66a | 0.28b | 37.05b | 0.32 |
| 8-inch depth | 33.7 | 9.57a | 1.34 | 1.65 | 2.70a | 0.27b | 39.58ab | 0.33 |
| Furrow | 34.4 | 8.73b | 1.50 | 1.74 | 1.94b | 0.30a | 41.20a | 0.32 |
| Third cutting | | | | | | | | |
| 16-inch depth | 30.4 | 10.5 | 1.50 | 1.92 | 2.68a | 0.32 | 34.98b | 0.35 |
| 8-inch depth | 31.9 | 10.0 | 1.50 | 1.87 | 2.42ab | 0.29 | 36.85ab | 0.33 |
| Furrow | 33.5 | 9.4 | 1.59 | 1.89 | 2.12b | 0.33 | 39.52a | 0.34 |
| Fourth cutting | | | | | | | | |
| 16-inch depth | 29.0 | 11.3 | 1.77b | 1.75 | 2.58a | 0.34b | 33.45 | 0.35 |
| 8-inch depth | 28.3 | 11.8 | 1.83b | 1.86 | 2.68a | 0.34b | 31.68 | 0.35 |
| Furrow | 28.2 | 11.1 | 2.02a | 2.00 | 2.05b | 0.39a | 32.10 | 0.35 |

[†]Denotes digestible NDF at 48 hours of incubation.

Table 5 (continued). Forage quality analysis for crude protein, relative feed value (RFV), and total digestible nutrients (TDN) in subsurface drip and furrow-irrigation alfalfa at the Colorado State University, Western Colorado Research Center at Fruita during the 2014 growing season.

| Treatment | Crude protein | RFV | TDN |
|---|---|---|---|
| | % | % | % |
| First cutting | | | |
| 16-inch depth | 19.1 | 184 | 70.3 |
| 8-inch depth | 18.6 | 175 | 69.0 |
| Furrow | 19.0 | 186 | 70.5 |
| Second cutting | | | |
| 16-inch depth | 20.2a | 162a | 67.3 |
| 8-inch depth | 19.5a | 148ab | 64.8 |
| Furrow | 18.2b | 140b | 64.1 |
| Third cutting | | | |
| 16-inch depth | 21.0a | 174a | 68.5 |
| 8-inch depth | 20.5ab | 162ab | 66.9 |
| Furrow | 19.0b | 147b | 65.0 |
| Fourth cutting | | | |
| 16-inch depth | 21.7 | 185 | 70.0 |
| 8-inch depth | 22.2 | 196 | 70.8 |
| Furrow | 22.4 | 194 | 70.9 |

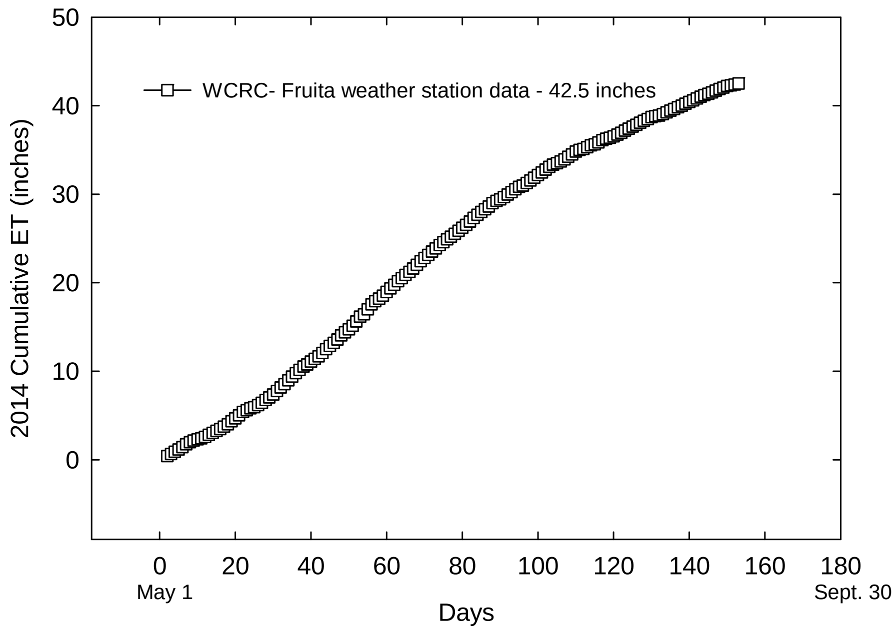


Fig. 1. Seasonal alfalfa reference ET from the CoAgMet weather station at WCRC-Fruita.

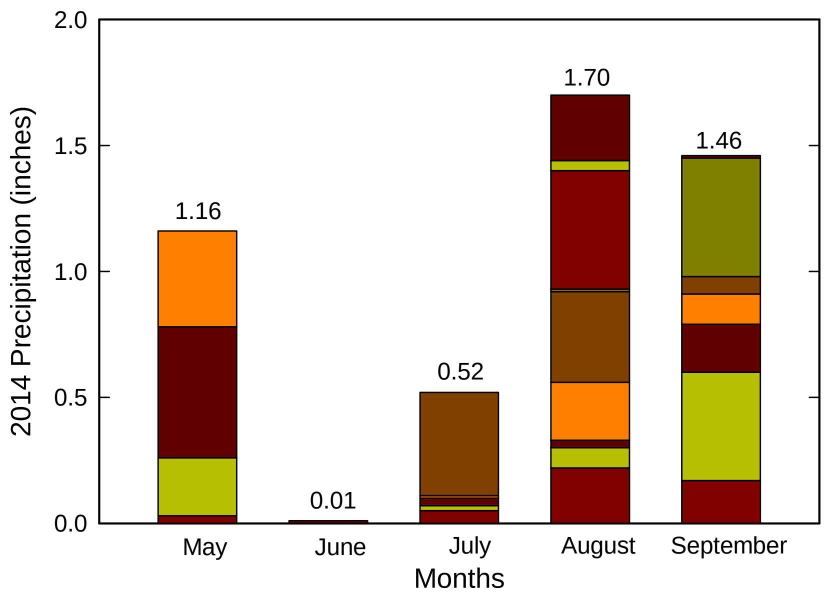


Fig. 2. Monthly cumulative rainfall during the 2014 alfalfa growing season at the Western Colorado Research Center at Fruita. Rainfall totals for each month are presented above the stacked bars. The various colors in each stacked bar represent separate rainfall events.

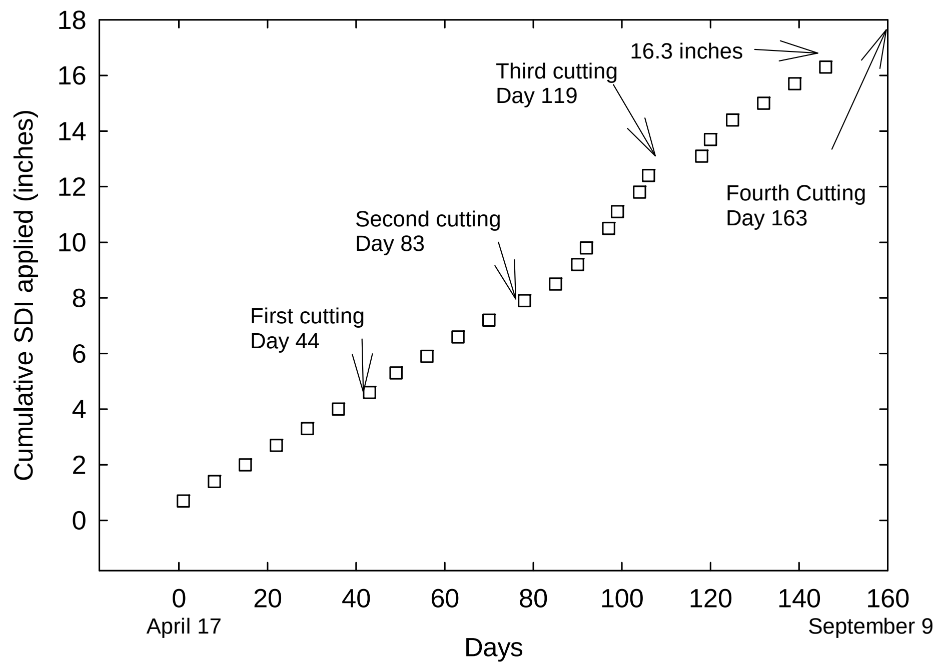


Fig. 3. Calculated cumulative irrigation water applied to alfalfa using a subsurface drip system at the Colorado State University, Western Colorado Research Center at Fruita during 2014.

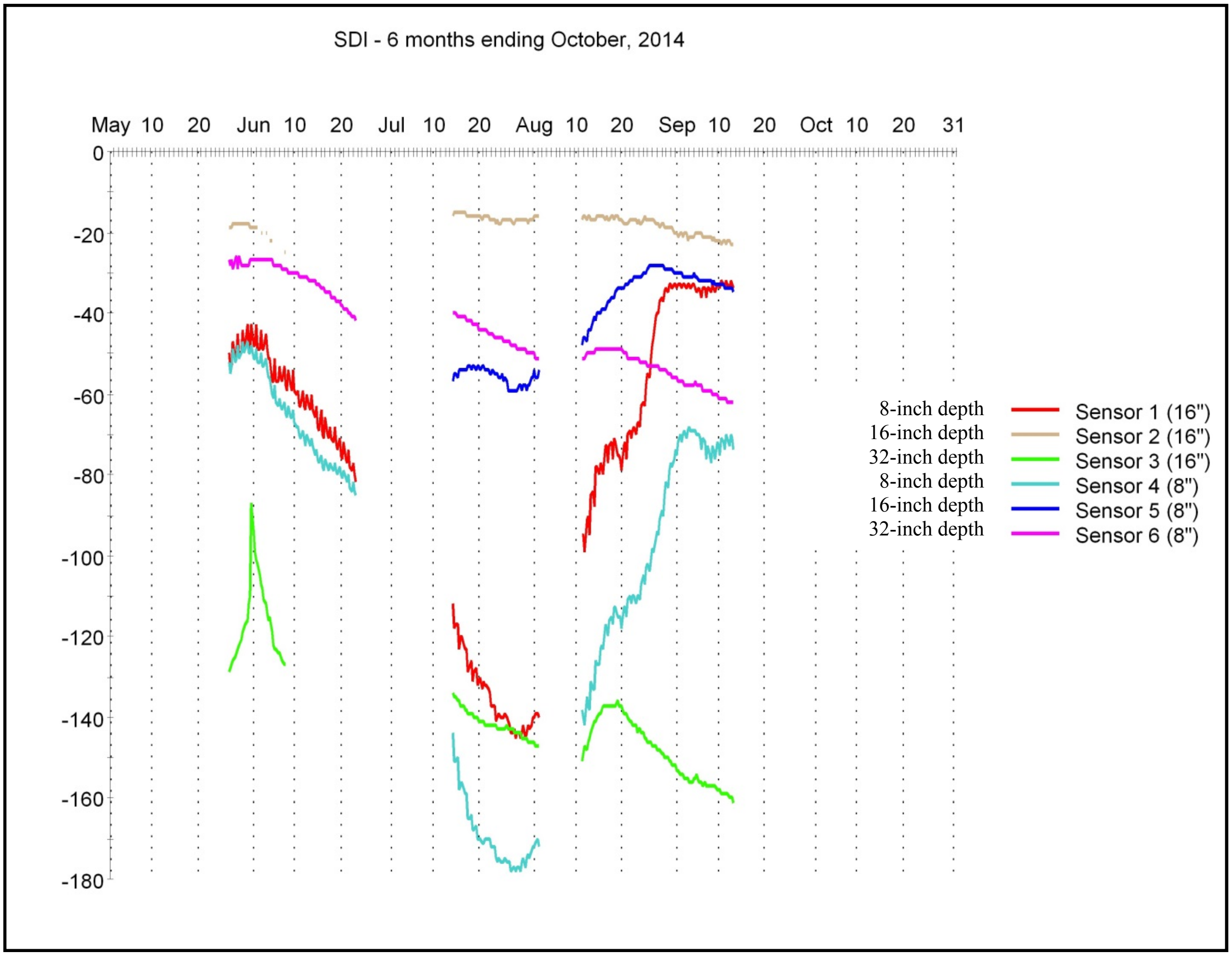


Fig. 4. Soil moisture tensions under alfalfa grown with subsurface drip irrigation (SDI) with drip lines installed at 8-inch and 16-inch depths during the 2014 growing season at the CSU Western Colorado Research Center at Fruita. Calendar date is the x-axis and the units on the y-axis are centibars.

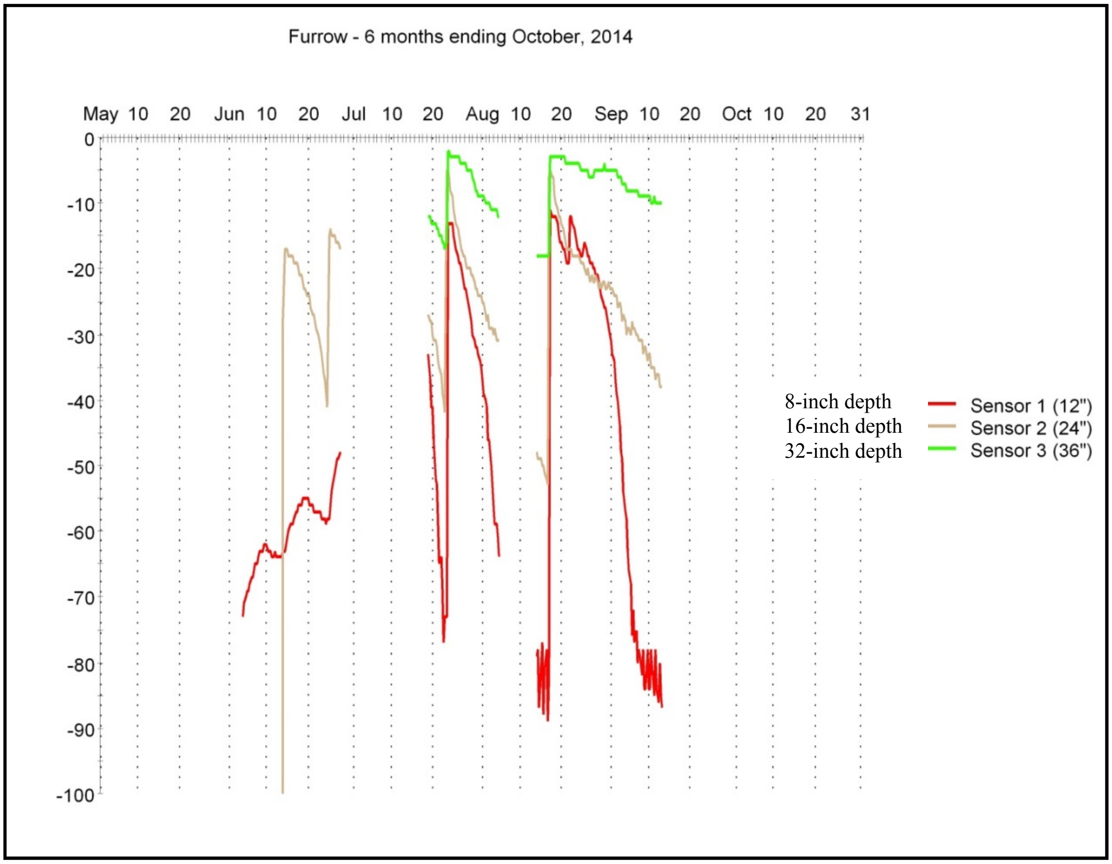


Fig. 5. Soil moisture tensions at the top end of the field in alfalfa grown with furrow irrigation during the 2014 growing season at the CSU Western Colorado Research Center at Fruita. Calendar date is the x-axis and the units on the y-axis are centibars.

# Evaluating a Pea/Oat Seed Mixture as a Forage for Western Colorado

Calvin H. Pearson,[1,2]

**Summary**

Forages are an important crop in Colorado and are grown throughout the state including western Colorado. While alfalfa hay and other hay are the most widely grown forages in the state other types of forages may be worthwhile to support the livestock industry in Colorado and provide alternative crops to meet the production needs of growers. The objective of this study was to evaluate a pea/oat seed mixture as an alternative irrigated forage crop for western Colorado. A pea/oat seed mixture performance test was conducted at the Colorado State University WCRC at Fruita during the 2014 growing season. The three treatments were: 1) peas only- planted at 100 lbs seed per acre, 2) oats only- planted at 100 lbs seed per acre, and 3) pea/oat seed mixture- each planted at 50 lbs seed per acre. Forage yield in the oats only treatment and the pea/oat mix was similar. Forage yield in the peas only treatment averaged 38% less than in the other two treatments. Crude protein in the peas only treatment was twice as high as the other two treatments. However, crude protein between the oats only treatment and the pea/oat mix was not significantly different. Additional research is needed to determine the correct planting rate and ratio of peas to oats in order to maintain high forage yields and improve forage quality of the harvested forage for western Colorado production conditions.

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## Introduction

**Forages** are an important crop in Colorado and are grown throughout the state including western Colorado. In 2013, hay (of all types) was valued at nearly $863 million (Colorado Department of Agriculture, 2013). Forages are essential to support the valuable livestock industry in the state. Livestock and their products in Colorado in 2012 were valued at more than $4.7 billion (Colorado Department of Agriculture, 2013).

Fig. 1. Forage plots of oats and peas grown at the CSU Western Colorado Research Center during 2014. Photo by Calvin H. Pearson.

While alfalfa hay and other hay are the most widely grown forages in the state, other types of forages may be worthwhile to support the livestock industry in Colorado and provide alternative crops to meet the production needs of growers.

The objective of this study was to evaluate a pea/oat seed mixture as an alternative irrigated forage crop for western Colorado.

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Fig. 2. Peas growing with oats at the CSU Western Colorado Research Center at Fruita during the 2014 growing season. Photo by Calvin H. Pearson.

**Materials and Methods**

A pea/oat seed mixture performance test was conducted at the Colorado State University Western Colorado Research Center (WCRC) at Fruita during the 2014 growing season (Fig. 1). The elevation at Fruita, Colorado is 4510 feet. Average annual precipitation is 8.4 inches. Average frost-free days are 181.

Crops at WCRC-Fruita are furrow-irrigated with water from the Colorado River. Irrigation water is delivered to farms through a canal system.

The pea/oat performance test was a randomized complete block experiment design with four replications. Plot size was 5 feet wide and 25 feet long.

The soil was a Youngston clay loam. Fertilizer was applied prior to planting at a rate of 104 lbs $P_2O_5$/acre and 22 lbs N/acre broadcast as 11-52-0 on April 4, 2014. The three treatments were: 1) peas only- planted at 100 lbs seed per acre , 2) oats only- planted at 100 lbs seed per acre, and 3) pea/oat seed mixture with each being planted at 50 lbs seed per acre (Fig. 2). Planting occurred on April 7, 2014 using 'Monida' oats and 'Arvika' spring peas. The oats were drilled and the peas were broadcast. Following planting the field area was furrowed to create 30 inch furrows. Plots were furrow-irrigated with gated pipe throughout the growing season to prevent water stress. Six irrigations were applied averaging 10.4 hours per irrigation.

Just prior to harvest, plant height was determined in three random locations within each plot. Plant height was measured from the soil surface to the top of the plants.

Plots were harvested on July 15, 2014 using an automated forage plot harvester (Pearson, 2007). A subsample was collected at harvest, weighed, oven-dried at 50°C to a constant weight, and reweighed to determine moisture content at harvest.

Oven-dried samples were ground in a Wiley Mill (Arthur H. Thomas, Model 4, Philadelphia, PA) fitted with a 2-mm mesh screen. Ground samples were analyzed by Weld Laboratories in Greeley, Colorado to determine forage quality parameters of crude protein, acid detergent fiber, and neutral detergent fiber (www.weldlabs.com, phone #970-353-8118). Weld Laboratories is certified by the National Forage Testing Association in both NIRS and wet chemistry.

Forage yields are reported at 65% moisture concentration as is commonly used for silage/haylage products.

Fig. 3. Field of a pea/oat seed mixture at the CSU Western Colorado Research Center at Fruita. Photo by Calvin H. Pearson.

Statistical analyses were performed by analysis of variance using Statistix 10 (Analytical Software, 2013). Differences among treatments were considered significant at $P \leq 0.05$ using an F-protected LSD.

## Results and Discussion

The last spring frost in 2014 occurred on May 1, 2014 and the first fall frost occurred on October 29, 2014, thus, the frost-free days for 2014 were 181 (28°F base).

Weed control was excellent in the oats only, and the pea/oat mix (Table 1; Fig. 3). The peas only treatment was not as competitive against weeds as the other two treatments. More weed growth occurred in the peas only treatment with the major weed species being kochia. Plant height in the oats only treatment and the pea/oat mix was similar while plant height in the peas only was approximately 5 inches shorter than in the other two treatments (Table 1).

Moisture content at harvest was similar among the three forage treatments and averaged 68.4% (Table 1).

Forage yield in the oats only treatment and the pea/oat mix was similar (Table 1). Forage yield in the peas only treatment averaged 38% less than in the other two treatments.

As expected crude protein in the peas only treatment was significantly higher with nearly twice as much protein as the other two treatments (Table 2). Crude protein between the oats only treatment and the pea/oat mix was not significantly different.

Acid detergent fiber (ADF) is a forage quality determination for intake. ADF is the least digestible plant components, including cellulose and lignin. ADF values are inversely related to digestibility, thus, forages with low ADF concentrations are usually higher in energy. ADF between the oats only treatment and the pea/oat mix was not significantly different (Table 2). Also, ADF between the oats only and the peas only treatments was not significantly different. ADF of the peas only treatment was 17% lower than the pea/oat mix. This is not surprising given the peas only treatment would be expected to have less fiber and higher digestibility than oats.

Neutral detergent fiber (NDF) is a forage quality factor for digestibility. NDF is an indicator of the structural components of the plant. NDF is a predictor of voluntary intake because it provides bulk fiber. In general, low NDF values are desired because NDF increases as forages mature. As expected NDF in the peas only treatment was significantly lower than in the other two forage treatments (Table 2). NDF in the peas only treatment averaged 21% less than in the other two treatments.

Fig. 4. Chopping a bulk field of a pea/oat seed mixture at the CSU Western Colorado Research Center at Fruita. Photo by Calvin H. Pearson.

## Conclusion

Planting a pea/oat mixture has the potential to improve forage quality over an oat only planting without sacrificing forage yield (Fig.4). However, planting peas and oats at 50 lbs each per acre was not sufficient to increase forage quality of the harvested forage. Changing the planting ratio to a higher amount of peas or reducing the planting rate of the oats may increase forage quality of the mixture. Alternate row planting may be another option to help reduce competition between the peas and oats. Additional research is needed to determine the correct planting rate and ratio of peas to oats in order to maintain high forage yields and improve quality of the harvested forage for western Colorado production conditions.

## Acknowledgments

We thank CSU Western Colorado Research Center staff (Fred Judson and Kevin Gobbo) and also Ben Steele (CSU summer hourly employee) who assisted with this research.

Table 1. Weed rating, plant height, moisture content at harvest, and forage yield of oats, peas, and a pea/oat mix grown for forage at the Colorado State University, Western Colorado Research Center at Fruita during the 2014 growing season.

| Treatment | Weed rating[1] | Plant height | Moisture content | Forage yield[2] |
|---|---|---|---|---|
| | 1-5 | inches | % | Tons/acre |
| Oats only | 1.0 | 43.5 | 66.6 | 14.6 |
| Peas only | 1.9 | 39.0 | 69.7 | 9.0 |
| Pea/oat mix | 1.0 | 43.9 | 69.0 | 14.2 |
| Ave. | 1.3 | 42.1 | 68.4 | 12.6 |
| C.V. (%) | 11.1 | 4.0 | 3.3 | 15.3 |
| LSD (0.05) | 0.2 | 2.9 | NS | 3.3 |

[1]Weed rating, 1= no weeds, 5= very weedy.

2 Forage yields were standardized and are reported at a 65% moisture content.

Table 2. Crude protein, acid detergent fiber, and neutral detergent fiber of oats, peas, and a pea/oat mix grown for forage at the Colorado State University, Western Colorado Research Center at Fruita during the 2014 growing season.

| Treatment | Crude protein | Acid detergent fiber | Neutral detergent fiber |
|---|---|---|---|
| | % | % | % |
| Oats only | 7.0 | 33.4 | 53.0 |
| Peas only | 13.7 | 31.8 | 41.9 |
| Pea/oat mix | 6.2 | 38.1 | 53.4 |
| Ave. | 9.0 | 34.4 | 49.4 |
| C.V. (%) | 19.6 | 8.8 | 5.0 |
| LSD (0.05) | 3.0 | 5.3 | 4.3 |

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# Agricultural Production of Prickly Pear Cactus for Biomass in the Intermountain West

Calvin H. Pearson[1,2], Morgan Williams[2], and Crosby D. Rock[2]

**Summary**

Prickly pear cactus (*Opuntia polyacantha* spp.) is a native plant widely distributed throughout the Intermountain West of the USA and is well adapted to areas of limited rainfall where high heat and drought stresses are common. The objective of our study was to determine the potential of *Opuntia* cactus as a biomass to biofuel resource in the Intermountain West of the USA when grown in agriculture. A study was conducted at the Colorado State University, Agricultural Experiment Station, Western Colorado Research Center, Fruita, Colorado for four years from 2010-2013 to determine the potential of prickly pear cactus as a source of biomass when grown under agricultural conditions. Native *Opuntia* plants were collected in western Colorado under permit from the U.S. Department of Interior, Bureau of Land Management. *Opuntia* varieties were also obtained from a dryland site located at the WCRC-Fruita. Cacti were deficit-irrigated with only one or two irrigations per year. Average plant population and cladodes of *O. polyacantha* varieties were 12,076 plants/acre and 5.3 cladodes per plant, respectively. Average moisture content of *O. polyacantha* varieties at harvest was 75.9%. Prickly pear cactus yields ranged from 12.5 to 21.6 tons/acre of aerial phytomass dry matter. Weed control during the testing period was challenging and considerable hand weeding was required to maintain weed-free plots. Cochineal, mealybug, (*Dactylopius coccus*), insect infestation occurred in the cactus planting beginning in the second year of the planting. The varieties *O. tortispina* and *O. polyacantha* var. *rhodantha* experienced the most damage while *O. polyacantha* var. *juniperina* had the least amount of damage.

## Introduction

**Prickly pear cactus** (*Opuntia polyacantha* Haw spp.) is a native plant species widely distributed throughout the Intermountain West of the USA (Fig. 1). *Opuntia* is well adapted to areas of limited rainfall where high heat and drought stresses are common. Prickly pear cactus utilizes the unique and highly water-use efficient photosynthetic pathway of crassulacean acid metabolism (CAM) (Mizrahi and Nerd, 1999). This unique metabolic pathway allows CAM plant species to grow and develop in high light intensities and high water stress environments by allowing them to open their stomata to take up $CO_2$ at night when evaporation is low (Mizrahi, et al., 1997). Of the approximately 300,000 species of vascular plants, CAM occurs in only about 7% (Mizrahi et al., 1997).

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Fig. 1. *Opuntia polyacantha* (prickly pear cactus) during flowering. This species is cold tolerant and native to the Intermountain west. The plant contains numerous spines. Photo by Calvin H. Pearson.

Historical uses of *Opuntia* have been primarily for food and feed dating back to pre-Columbian times (Mondragon and Perez, 1996). Ripe fruits, cladodes, and nopalitos have been consumed by humans in various parts of the world including southwestern United States, Mexico, and Spain (Russell and Felker, 1987). It is mainly during periods of drought when *Opuntia* species is used as cattle feed in the U.S. For *Opuntia* species that contain spines to be safe and palatable for grazing the spines are removed by burning (Russell, 1986; Mueller et al., 1994; Felker, 1996).

*Opuntia* has also been used for medicinal and health purposes (Hegwood, 1990), in ornamental plantings (Barbera et al., 1992), and industrial applications (Mizrahi et al., 1997). Hamdi (1997) proposed that *Opuntia* is a suitable raw material source for fermentation processes, pigments, food cultures and processes, and substrates.

Most of the scientific literature has focused on spineless, fast-growing cactus species primarily, *Opuntia ficus-indica* (L.) Mill., which are adapted to US Department of Agriculture cold hardiness zones of greater than 8 and latitudes south of 29° N (Guevara et al., 2009).

*Opuntia* has been evaluated under agricultural production conditions in subtropical semiarid environments, primarily in northern Mexico, Spain, Sicily, and southern Texas (Barbera et al., 1992; Mondragon-Jacobo, C., 1999; Russell and Felker, 1987). Intensive utilization of wild populations of *Opuntia* has occurred routinely in various regions around the world including North and South America, Latin American, Africa, and Mediterranean countries (Russell and Felker, 1987).

Retamal et al. (1987) evaluated the potential of using *Opuntia ficus-indica* for ethanol fuel production. They concluded that 32 gallons/acre of ethanol could be produced under dryland and up to 320 gallons/acre could be produced under irrigated conditions. They also noted that biomass production with *Opuntia* could make use of land area that had previously been unusable. Borland et al. (2009) provided a thorough discussion on the potential of CAM plants as a source of biomass and bioenergy on marginal land.

The potential of *Opuntia polyacantha* that is native to the Intermountain West as a biomass to biofuel resource has not been investigated. The objective of our study was to determine the potential of prickly pear cactus (*Opuntia polyacantha*) as a biomass to biofuel resource in the Intermountain West of the USA when grown under modern agricultural production systems.

Fig. 2. Prickly pear cactus just after planting on June 9, 2010. Photo by Calvin H. Pearson.

**Materials and Methods**

A study was conducted at the Colorado State University, Agricultural Experiment Station, Western Colorado Research Center, Fruita, Colorado for four years from 2010-2013 to

Fig. 3. *Opuntia polyacantha* being grown under an agricultural production system in western Colorado. Photo by Calvin H. Pearson.

determine the potential of *Opuntia polyacantha* varieties (4 entries, Table 1) as a source of biomass when grown under modern agricultural production conditions. Native *O. polyacantha* plants were collected in western Colorado on May 11, 2010 under permit from the U.S. Department of Interior, Bureau of Land Management. *O. polyacantha* varieties were also obtained on May 17, 2010 from a dryland site located at the WCRC-Fruita. These *O. polyacantha* materials were obtained from a previous planting performed years earlier. The *O. polyacantha* varieties harvested at the research center were planted in the plot area at the same time as the native collections. *O. polyacantha* was hand-planted on June 9, 2010 in rows spaced 30-inches apart (Fig. 2).

Cacti were deficit-irrigated with only one or two irrigations per year. The field was flood-irrigated using gated pipe equipped with gates 30-inches apart and with irrigation socks. Hand-weeding, and cultivation with a walk behind small rototiller were performed during each growing season as needed to maintain adequate weed control (Figs. 3, 5).

*O. polyacantha* cactus was hand-harvested on July 31, 2013. Harvested row lengths varied from 1.4 feet to 2.3 feet. Plants were harvested at the soil surface using tongs and heavy leather gloves to avoid injury from spines. Plant material was harvested into large paper bags, weighed, and oven-dried for several days at 60°C until constant weights were obtained. Biomass yields are reported on a dry matter basis.

Cochineal, mealybug, (*Dactylopius coccus*) insect infestation occurred in the cactus planting beginning in the second year of the planting (Figs. 4, 5). During the third year of production we rated the *O. polyacantha* varieties for damage caused by cochineal. We used a 1-5 rating scale with 1 = no damage and 5 = severely damaged.

Statistical analyses were performed by analysis of variance using Statistix 10 (Analytical Software, 2013). Differences among *O. polyacantha* varieties were considered significant at P≤0.05 using an F-protected LSD.

**Results and Discussion**

Plant populations and cladodes per plant were determined soon after planting. There was no statistical difference among *O. polyacantha* varieties for plant population or the number cladodes per plant (Table 1). Average plant population and cladodes of *O. polyacantha* varieties were 12,076 plants/acre and 5.3 cladodes per plant, respectively.

Average moisture content of *O. polyacantha* varieties at harvest was 75.9%. Moisture content at harvest of *O. polyacantha* var. *hystricina* and *O. polyacantha* var. *juniperina* was 39.4 and 38.1% higher than var. *O. tortispina*, respectively, while the moisture contents of *O. tortispina* and *O. polyacantha* var. *rhodantha* were not significantly different (Table 1).

Average dry matter biomass yield of *O.*

Fig. 4. *Opuntia polyacantha* being grown under an agricultural production system in western Colorado. Note the difference in growth and performance of cactus varieties. Photo by Calvin H. Pearson.

*polyacantha* varieties was 16.8 tons/acre. While there was no statistical difference among the varieties a wide range in yield occurred among the varieties. *O. polyacantha* var. *hystricina* had the highest yield at 21.6 tons/acre and *O. tortispina* had the lowest yield at 12.5 tons/acre. There was considerable variation in the data that may have prevented us from identifying statistical differences in variety performance for dry matter biomass yield. A larger sample size may have reduced data variability and allowed us to identify statistically significant differences in biomass yield among *O. polyacantha* varieties.

Yields of an 8-year old stand of *Opuntia fiscus-indica* in Sicily ranged from 5.4 to 13.4 tons/acre (Barbera et al., 1992. Dry matter yields of *Opuntia fiscus-indica* in Brazil and Argentina ranged from a low of 2.5 tons/acre/year to as high as 13.9 tons/acre/year (Guevara et al., 2009).

Several factors related to biomass quality were determined for the *O. polyacantha* varieties grown in our trial (Table 2). There were no differences among *O. polyacantha* varieties for protein, fiber, and lignin. Acid detergent fiber (ADF) concentration in *O. tortispina* and *O. polyacantha* var. *hystricina* was significantly higher than in *O. polyacantha* var. *rhodantha* and *O. polyacantha* var. *juniperina*. Ash concentration was significantly lower in *O. polyacantha* var. *juniperina* than in the other varieties. Carbohydrate concentration in *O. tortispina* was significantly higher than in other varieties.

Fat concentration in *O. polyacantha* var. *hysticina* and *O. polyacantha* var. *rhodantha* was higher than in *O. tortispina* and *O. polyacantha* var. *juniperina* (Table 2). Starch concentration in *O. polyacantha* var. *juniperina* was significantly higher than in other varieties. Sugar concentration was higher in *O. polyacantha* var. *hystricina* and *O. polyacantha* var. *juniperina* than in *O. tortispina* and *O. polyacantha* var. *rhodantha*. These data indicate that genetic variation exists that could be exploited for crop improvement of *O. polyacantha* and the development of released cultivars.

Published data on the chemical composition of *O. polyacantha* as a biomass source is scant. The focus of our research was on the agronomy of *O. polyacantha* as a potential biomass resource. Several researchers have studied the chemical composition of a diversity of biomass sources (Sorek et al., 2014; Tumuluru et al., 2011; Johnson et al., 2007; Vassilev et al., 2010). The chemical composition of *Opunti*a species as a biomass resource was not included in any of these reports. Detailed chemical analyses are needed to determine the potential of *O. polyacantha* as a biomass source from the standpoint of its conversion to various biofuels or energy sources.

The varieties *O. tortispina* and *O. polyacantha* var. *rhodantha* experienced the most damage from cochineal while *O. polyacantha* var. *juniperina* had the least amount of damage. These data indicate that genetic variation may exist within *O. polyacantha* that could be exploited to develop improved resistance to cochineal.

Fig. 5. Damage to *Opuntia polyacantha* cactus caused by cochineal. Photo by Calvin H. Pearson.

We harvested *O. polyacantha* plants using tongs and heavy leather gloves to avoid injury from spines. Developing practical and economic equipment and methodology that would allow for mechanical harvesting of *O. polyacantha* is desirable.

Meuller et al. (1994) also recognized the need for developing equipment for mechanical harvesting of prickly pear cactus. Their objective was to develop a harvester that would uproot and windrow *O. polyacantha* as a means to control prickly pear while providing a feed source for cattle. At the same time their harvest procedure removed the cactus from the land it also improved the production of grass species. Mechanical harvesting of *O. polyacantha* for biomass should leave roots and enough aerial biomass to allow for regrowth.

## Conclusion

Prickly pear cactus yields over a 4-year testing period at WCRC-Fruita grown under agricultural conditions with limited irrigation ranged from 12.5 to 21.6 tons/acre of dry matter biomass. Weed control during the testing period was challenging and considerable hand weeding was required to maintain weed-free plots. Without using adequate control measures weeds quickly became a problem in our *O. polyacantha* trial (Fig. 6). *O. polyacantha* was not very competitive against many of the weed species that are common in our western Colorado agriculture production systems. The use of possible herbicides for weed control in *Opuntia* has been discussed by Felker et al. (2006), although how various herbicides will perform on specific *Opuntia* species and varieties and in specific production systems and environments will require thorough investigation.

Cochineal insects are specific to cacti and this insect has been used for biological control of *Opuntia* in the rangelands of North America (Russell and Felker, 1987). However, when *Opuntia* is grown as an agronomic crop damage caused by cochineal can reduce crop productivity. Several varieties of *O. polyacantha* were susceptible to cochineal and experienced severe damage. *O. polyacantha* var. *juniperina* experienced much less damage to cochineal than other varieties and may contain some resistance to this insect.

Fig. 6. Weed infestation in *Opuntia polyacantha* cactus when grown under an agricultural production system in western Colorado. Weeds are mostly kochia, pigweed, and lambsquarter. Photo by Calvin H. Pearson.

To be produced with mechanized agriculture several problems would have to be solved including equipment that would be suitable for mechanical planting and harvesting. Russell and Felker (1987) and Borland et al (2009) discuss the potential for genetic improvement and development of management practices for CAM plants and *Opuntia* spp. for agricultural production in the low rainfall environments and on marginal lands.

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Table 1. Agronomic characteristics of *Opuntia polyacantha* varieties when grown under agricultural conditions at the Colorado State University, Western Colorado Research Center. Fruita, Colorado.

| *O. polyacantha* variety | Plant population | Cladodes per plant | Moisture | Dry matter biomass yield | Insect damage rating |
|---|---|---|---|---|---|
| | Plants/acre | no. | % | tons/acre | 1-5 score |
| *O. tortispina* | 9,166 | 4.8 | 60.6b[1] | 12.5 | 3.8a |
| *O. polyacantha* var. *hystricina* | 12,279 | 5.3 | 84.5a | 21.6 | 2.0bc |
| *O. polyacantha* var. *rhodantha* | 11,489 | 4.1 | 74.8ab | 16.9 | 3.1ab |
| *O. polyacantha* var. *juniperina* | 15,369 | 7.3 | 83.7a | 16.1 | 1.5c |
| Ave. | 12,076 | 5.3 | 75.9 | 16.8 | 2.6 |

[1]Numbers within a column with different letters are significantly different at the 0.05 level of probability.

Table 2. Acid detergent fiber (ADF), ash, protein, and carbohydrate content of *Opuntia polyacantha* varieties when grown under agricultural conditions at the Colorado State University, Western Colorado Research Center. Fruita, Colorado.

| *O. polyacantha* variety | ADF | Ash | Protein | Carbohydrates |
|---|---|---|---|---|
| | % | % | % | % |
| *O. tortispina* | 28.2a[1] | 27.3a | 7.3 | 5.7a |
| *O. polyacantha* var. *hystricina* | 29.2a | 24.8a | 6.6 | 1.4b |
| *O. polyacantha* var. *rhodantha* | 24.0b | 25.8a | 6.3 | 1.4b |
| *O. polyacantha* var. *juniperina* | 24.2b | 19.1b | 5.7 | 0.9b |
| Ave. | 26.4 | 24.2 | 6.5 | 2.3 |

[1]Numbers within a column with different letters are significantly different at the 0.05 level of probability.

Table 2 (continued). Fat, fiber, lignin, starch, and sugar content of *Opuntia polyacantha* varieties when grown under agricultural conditions at the Colorado State University, Western Colorado Research Center. Fruita, Colorado.

| *O. polyacantha* variety | Fat | Fiber | Lignin | Starch | Sugar |
|---|---|---|---|---|---|
| | % | % | % | % | % |
| *O. tortispina* | 1.12b | 20.9 | 6.9 | 0.29b | 0.59b |
| *O. polyacantha* var. *hystricina* | 1.85a | 23.9 | 7.6 | 0.49b | 0.93a |
| *O. polyacantha* var. *rhodantha* | 1.67a | 23.7 | 5.6 | 0.72b | 0.65b |
| *O. polyacantha* var. *juniperina* | 1.15b | 20.2 | 6.5 | 4.80a | 0.87a |
| Ave. | 1.45 | 22.2 | 6.7 | 1.57 | 0.76 |

[1]Numbers within a column with different letters are significantly different at the 0.05 level of probability.

# Western Colorado Alfalfa Variety Performance Test at Fruita 2012-2014

Calvin H. Pearson[1, 2]

**Summary**

Numerous alfalfa varieties are available for commercial planting on farms and ranches. With so many varieties available in the marketplace, selecting a variety to plant can be challenging. Agronomic performance data of alfalfa varieties provides quantitative information to aid producers in deciding which varieties to plant. Testing all available alfalfa varieties at one location is not feasible; thus, information obtained in alfalfa variety performance tests can be valuable to those who live in other areas with similar environments and growing conditions. An alfalfa variety performance test was conducted at the Western Colorado Research Center at Fruita in which selected alfalfa varieties were evaluated over a three-year testing period from 2012-2014. The performance of these varieties was evaluated under local field conditions; thus, the results obtained from these trials are relevant to grower production operations. Averaged across the four cuttings and the twenty varieties, alfalfa yields in 2012, 2013, and 2014 were 8.73, 10.22, and 9.38 tons/acre, respectively. The average three-year total yield was 28.33 tons/acre. Three-year total yields ranged from a high of 30.54 tons/acre for Ameristand 445NT to a low of 26.63 tons/acre for FGI 48W201. Four of the eighteen varieties (Ameristand 445NT, Gunner, DK50-18, and WL363HQ) had high three-year total yields.

## Introduction

**Evaluating** varieties under local production conditions provides site-specific information that is useful to local producers and others who grow alfalfa in similar environments and growing conditions. Local variety performance information is also valuable to breeding and seed companies to guide them in developing and marketing seed of their varieties. Alfalfa variety performance tests at the Western Colorado Research Center (WCRC) at Fruita are conducted over a three-year testing period.

Prior to planting test plots, alfalfa breeding and seed companies are solicited for varieties to enter into the test. Company representatives determine which of their varieties to include in the test. They pay a fee to the University for each entry tested.

The alfalfa variety performance trial being irrigated at the Western Colorado Research Center at Fruita. Photo by Calvin H. Pearson.

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This report contains test results for the commercial alfalfa variety performance evaluation. The data are for 2012-2014 and are a complete three-year testing period for eighteen alfalfa varieties.

**Materials and Methods**

The commercial alfalfa variety performance test was conducted at Colorado State University, WCRC at Fruita. The elevation at Fruita, Colorado is 4510 feet. Average annual precipitation is 8.4 inches. Average frost-free days are 181. Alfalfa was furrow-irrigated with water from the Colorado River. Irrigation water is delivered to farms through a canal system.

The alfalfa variety performance test was a randomized complete block experiment design with four replications. Plot size was 10 feet wide x 15 feet long. The soil was a Billings silty clay loam. Fertilizer applied to plots in this study was 300 lbs $P_2O_5$/acre and 63 lbs N/acre broadcast as 11-52-0 on August 10, 2011 and plowed down prior to planting. Planting occurred on August 30, 2011 at 15 lbs seed/acre.

Intensity herbicide at 12.0 oz/acre (plus 1 qt/acre crop oil concentrate and 1 qt of urea ammonium nitrate (UAN) fertilizer in 100 gallons of water) was applied on Sept 28, 2011 in 22 gallons water/acre at 30 psi. Raptor herbicide at 6 oz/acre acre (plus 1 qt/acre crop oil concentrate and 1 gallon of UAN fertilizer was applied on Oct. 10, 2011 in 60 gallons of water) using 22 gallons water/acre at 30 psi. Warrior at 3.84 oz/acre plus Lorsban 4E at 1 pint/acre was applied on May 8, 2014 in 22 gallons/acre of water at 25 psi to control alfalfa weevil.

Alfalfa was furrow-irrigated with gated pipe. Ten irrigations were applied during the 2014 growing season with an average set time of 19.6 hours per irrigation.

Plots were harvested using an automated forage plot harvester (Pearson, C.H. 2007. An updated, automated commercial swather for harvesting forage plots. Agron. J. 99:1382-1388).

Yields were calculated on an air-dry basis. The cut forage was green chopped no later than 24-36 hours after plot harvest and within 2-3 days after harvest the alfalfa was irrigated.

Statistical analyses were performed by analysis of variance using Statistix 10 (Analytical Software. 2013. Tallahassee, FL). Differences among treatments were considered significant at $P \leq 0.05$ using an F-protected LSD.

**Results and Discussion**

The last spring frost in 2012 occurred on April 16, 2012 and the first fall frost occurred on October 7, 2012, thus, the frost-free days in 2012 was 174 (28°F base).

The last spring frost in 2013 occurred on April 19, 2013 and the first fall frost occurred on October 16, 2013, thus, the frost-free days in 2013 was 180 (28°F base).

The last spring frost in 2014 occurred on May 1, 2014 and the first fall frost occurred on October 29, 2014, thus, the frost-free days in 2014 was 181 (28°F base).

Eighteen alfalfa varieties were tested for three years from 2012 through 2014. Data for each of the four cuttings for each of three years are presented in this report.

The 2012 yield data are for the first of the three-year testing period. Hay yield in the first, second, third, and fourth cuttings, and total yield

Automated weighing system on a commercial swather being used to harvest alfalfa forage plots at the CSU Western Colorado Research Center at Fruita. Photo by Calvin H. Pearson.

in 2012 averaged across all eighteen varieties was 1.84, 2.05, 2.99, 1.85, and 8.73 tons/acre, respectively (Table 1). There were no statistically significant differences among the eighteen alfalfa varieties for yield in any of the four cuttings or the 2012 total yield.

Yield data obtained in 2013 are for the second year of the three-year testing period. Alfalfa stands were excellent. Hay yield in the first cutting in 2013 averaged across all eighteen

Swather with automated weighing system used for harvest alfalfa plots. Photo by Calvin H. Pearson.

varieties was 3.62 tons/acre (Table 2). There were no statistically significant differences among the eighteen alfalfa varieties for yield in the first cutting. Hay yield in the second cutting averaged 2.33 tons/acre. Yields ranged from a high of 2.57 tons/acre for DKA43-13 to a low of 1.95 tons/acre for 6431. Eight varieties had high second cutting yields. Hay yield in the third cutting averaged 2.64 tons/acre. There were no statistically significant differences among the eighteen alfalfa varieties for yield in the third cutting. Hay yield in the fourth cutting averaged 1.64 tons/acre. Yields in the fourth cutting ranged from a high of 1.81 tons/acre for Ameristand 445NT to a low of 1.46 tons/acre for FGI48W201. Three varieties (Ameristand 445NT, DKA50-18, and FSG 429SN) had high fourth cutting yields.

Averaged across the four cuttings and the eighteen varieties, the 2013 total alfalfa yield was 10.22 tons/acre and the average two-year total was 18.95 tons/acre (Table 2). Six of the eighteen varieties had high 2013 total yields. Seven varieties had high two-year total yields. The varieties that had high 2013 total yields also had high two-year total yields.

Yield data obtained in 2014 are for the third year of the three-year testing period. Hay yield in the first cutting in 2014 averaged across all eighteen varieties was 3.25 tons/acre (Table 3). Yields ranged from a high of 3.56 tons/acre for Ameristand 445NT to a low of 2.86 tons/acre for FGI 48W201. Eleven varieties were high yielding in the first cutting in 2014. Hay yield in the second cutting averaged 2.54 tons/acre. There were no statistically significant differences among the varieties for yield in the second cutting in 2014. Hay yield in the third cutting averaged 2.08 tons/acre. Yields ranged from a high of 2.32 tons/acre for Ameristand 445NT to a low of 1.88 tons/acre for 6431. Seven alfalfa varieties had high third cutting yields. Hay yield in the fourth cutting averaged 1.51 tons/acre. There were no statistically significant differences among the varieties for yield in the fourth cutting in 2014.

The 2014 total yield, averaged across the four cuttings and the eighteen varieties, was 9.38 tons/acre (Table 3). The 2014 total yields ranged from a high of 10.39 tons/acre for Ameristand 445NT to a low of 8.33 tons/acre for FGI 48W201. Five of the eighteen varieties had high 2014 total yields.

The average three-year total yield was 28.33 tons/acre (Table 3). Three-year total yields ranged from a high of 30.54 tons/acre for Ameristand 445NT to a low of 26.63 tons/acre for FGI 48W201. Four of the eighteen varieties (Ameristand 445NT, Gunner, DK50-18, and WL363HQ) had high three-year total yields. Non-yield characteristics of current alfalfa varieties available in the United States can be obtained at https://www.alfalfa.org/varietyLeaflet.php.

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We thank CSU Western Colorado Research Center staff (Fred Judson and Kevin Gobbo) and also Calvin Rock, Anna Mudd, and Ben Steele (CSU summer hourly employees) who assisted with this research.

Table 1. Forage yields of 18 alfalfa varieties at the Western Colorado Research Center at Fruita in 2012.

| Variety | Source/Brand | 1st cut May 21 | 2nd cut June 26 | 3rd cut Aug 8 | 4th cut Sept 24 | 2012 total |
|---|---|---|---|---|---|---|
| | | | | tons/acre[1] | | |
| Gunner | Croplan Genetics | 2.06 | 2.19 | 3.06 | 1.92 | 9.23 |
| Ameristand 445NT | America's Alfalfa | 1.84 | 2.18 | 3.20 | 1.96 | 9.18 |
| FGI 48W203 | Forage Genetics | 1.93 | 2.20 | 3.06 | 1.82 | 9.01 |
| Ameristand 407TQ | America's Alfalfa | 1.99 | 2.04 | 3.05 | 1.86 | 8.94 |
| FSG 639ST | Allied Seed | 2.11 | 2.06 | 2.90 | 1.87 | 8.94 |
| WL363HQ | W-L Research | 1.87 | 2.01 | 3.15 | 1.91 | 8.93 |
| Rebound 6.0 | Croplan Genetics | 1.89 | 2.13 | 3.10 | 1.79 | 8.90 |
| WL354HQ | W-L Research | 1.85 | 2.06 | 3.13 | 1.80 | 8.84 |
| DKA50-18 | Monsanto | 1.78 | 2.12 | 3.02 | 1.85 | 8.77 |
| DKA43-13 | Monsanto | 1.78 | 2.11 | 2.89 | 1.90 | 8.68 |
| FGI 48W202 | Forage Genetics | 1.65 | 2.06 | 3.10 | 1.83 | 8.64 |
| FSG 429SN | Allied Seed | 1.94 | 2.07 | 2.73 | 1.86 | 8.59 |
| 6431 | Nexgrow | 1.89 | 1.86 | 2.97 | 1.84 | 8.56 |
| 6305Q | Nexgrow | 1.79 | 1.89 | 2.91 | 1.84 | 8.44 |
| FGI 48W201 | Forage Genetics | 1.72 | 1.97 | 2.90 | 1.84 | 8.43 |
| 6422Q | Nexgrow | 1.64 | 1.94 | 2.95 | 1.83 | 8.36 |
| Archer III | America's Alfalfa | 1.63 | 2.04 | 3.01 | 1.67 | 8.35 |
| FGI 48A179 | Forage Genetics | 1.75 | 1.93 | 2.78 | 1.83 | 8.30 |
| Ave. | | 1.84 | 2.05 | 2.99 | 1.85 | 8.73 |
| CV (%) | | 11.3 | 7.4 | 7.8 | 6.6 | 5.6 |
| LSD (0.05) | | NS | NS | NS | NS | NS |

[1]Yields were calculated on an air-dry basis from samples that were air-dried for approximately one week inside on a drying rack. Varieties are listed in the table by descending yield for the 2012 total yield.

Table 2. Forage yields of 18 alfalfa varieties at the Western Colorado Research Center at Fruita in 2013.[1]

| Variety | Source/Brand | 1st cut May 20 | 2nd cut June 24 | 3rd cut Aug 13 | 4th cut Sept 29 | 2013 total | 2-yr total |
|---|---|---|---|---|---|---|---|
| | | tons/acre[2] | | | | | |
| Ameristand 445NT | America's Alfalfa | 3.87 | 2.40 | 2.88 | 1.81 | 10.96 | 20.14 |
| DKA50-18 | Monsanto | 3.87 | 2.38 | 2.87 | 1.70 | 10.82 | 19.59 |
| Gunner | Croplan Genetics | 3.62 | 2.50 | 2.51 | 1.63 | 10.27 | 19.50 |
| WL354HQ | W-L Research | 3.77 | 2.35 | 2.87 | 1.63 | 10.62 | 19.45 |
| DKA43-13 | Monsanto | 3.63 | 2.57 | 2.72 | 1.66 | 10.58 | 19.26 |
| Rebound 6.0 | Croplan Genetics | 3.73 | 2.34 | 2.58 | 1.66 | 10.31 | 19.22 |
| WL363HQ | W-L Research | 3.67 | 2.30 | 2.60 | 1.66 | 10.22 | 19.16 |
| FGI 48W203 | Forage Genetics | 3.43 | 2.42 | 2.52 | 1.60 | 9.96 | 18.98 |
| FGI 48W202 | Forage Genetics | 3.63 | 2.50 | 2.54 | 1.60 | 10.26 | 18.91 |
| Ameristand 407TQ | America's Alfalfa | 3.52 | 2.18 | 2.56 | 1.62 | 9.88 | 18.81 |
| FSG 639ST | Allied Seed | 3.54 | 2.06 | 2.58 | 1.65 | 9.83 | 18.77 |
| FSG 429SN | Allied Seed | 3.60 | 2.22 | 2.67 | 1.68 | 10.17 | 18.76 |
| Archer III | America's Alfalfa | 3.62 | 2.34 | 2.59 | 1.62 | 10.17 | 18.52 |
| 6422Q | Nexgrow | 3.58 | 2.34 | 2.58 | 1.62 | 10.13 | 18.50 |
| 6305Q | Nexgrow | 3.63 | 2.22 | 2.62 | 1.54 | 10.02 | 18.46 |
| FGI 48A179 | Forage Genetics | 3.56 | 2.44 | 2.50 | 1.63 | 10.14 | 18.43 |
| 6431 | Nexgrow | 3.40 | 1.95 | 2.76 | 1.65 | 9.76 | 18.32 |
| FGI 48W201 | Forage Genetics | 3.43 | 2.39 | 2.58 | 1.46 | 9.87 | 18.30 |
| Ave. | | 3.62 | 2.33 | 2.64 | 1.64 | 10.22 | 18.95 |
| CV (%) | | 7.6 | 6.3 | 8.6 | 5.8 | 4.8 | 4.2 |
| LSD (0.05) | | NS | 0.21 | NS | 0.14 | 0.70 | NS |

[1]Yields were calculated on an air-dry basis from samples that were air-dried for approximately one week inside on a drying rack. Varieties are listed in the table by descending yield for the 2-year total yield.

Table 3. Forage yields of 18 alfalfa varieties at the Western Colorado Research Center at Fruita in 2014.[1]

| Variety | Source/Brand | 1st cut May 29 | 2nd cut July 9 | 3rd cut Aug 12 | 4th cut Sept 24 | 2014 total | 3-yr total |
|---|---|---|---|---|---|---|---|
| | | | | tons/acre[2] | | | |
| Ameristand 445NT | America's Alfalfa | 3.56 | 2.88 | 2.32 | 1.63 | 10.39 | 30.54 |
| Gunner | Croplan Genetics | 3.33 | 2.66 | 2.15 | 1.68 | 9.82 | 29.32 |
| DKA50-18 | Monsanto | 3.36 | 2.66 | 2.22 | 1.47 | 9.70 | 29.29 |
| WL363HQ | W-L Research | 3.46 | 2.72 | 2.21 | 1.68 | 10.06 | 29.22 |
| Rebound 6.0 | Croplan Genetics | 3.47 | 2.62 | 2.11 | 1.58 | 9.78 | 29.00 |
| WL354HQ | W-L Research | 3.21 | 2.50 | 2.19 | 1.49 | 9.39 | 28.84 |
| FGI 48W202 | Forage Genetics | 3.18 | 2.69 | 2.10 | 1.51 | 9.48 | 28.39 |
| DKA43-13 | Monsanto | 3.14 | 2.35 | 2.10 | 1.39 | 8.98 | 28.24 |
| FGI 48W203 | Forage Genetics | 3.00 | 2.63 | 2.10 | 1.38 | 9.11 | 28.08 |
| FSG 429SN | Allied Seed | 3.24 | 2.53 | 1.99 | 1.56 | 9.32 | 28.08 |
| 6422Q | Nexgrow | 3.13 | 2.64 | 2.11 | 1.64 | 9.53 | 28.02 |
| FSG 639ST | Allied Seed | 3.24 | 2.49 | 1.98 | 1.50 | 9.21 | 27.98 |
| Ameristand 407TQ | America's Alfalfa | 3.29 | 2.30 | 1.96 | 1.54 | 9.08 | 27.90 |
| 6305Q | Nexgrow | 3.28 | 2.44 | 2.10 | 1.54 | 9.37 | 27.82 |
| FGI 48A179 | Forage Genetics | 3.21 | 2.59 | 2.01 | 1.42 | 9.23 | 27.66 |
| Archer III | America's Alfalfa | 3.17 | 2.45 | 1.94 | 1.45 | 9.00 | 27.53 |
| 6431 | Nexgrow | 3.35 | 2.32 | 1.88 | 1.47 | 9.02 | 27.35 |
| FGI 48W201 | Forage Genetics | 2.86 | 2.21 | 1.93 | 1.33 | 8.33 | 26.63 |
| Ave. | | 3.25 | 2.54 | 2.08 | 1.51 | 9.38 | 28.33 |
| CV (%) | | 7.6 | 11.5 | 7.2 | 11.3 | 6.4 | 3.4 |
| LSD (0.05) | | 0.35 | NS | 0.21 | NS | 0.85 | 1.36 |

[1]Yields were calculated on an air-dry basis from samples that were air-dried for approximately one week inside on a drying rack. Varieties are listed in the table by descending yield for the 3-year total yield.

# Winter Wheat Variety Performance Trial at Craig, Colorado 2014

Calvin H. Pearson[1,2] and Scott Haley[2]

**Summary**

A winter wheat variety performance test was conducted at Craig, Colorado in 2014 to identify varieties that are adapted for commercial production in northwest Colorado. Twenty-two varieties and breeding lines were evaluated in the trial. Growing conditions during the 2014 cropping season in the Craig area were favorable for winter wheat production compared to many other years. Grain yield in the winter wheat variety performance trial averaged 2966 lbs/acre (49.4 bu/acre). The highest yielding variety was CO11D346 at 3680 lbs/acre (61.4 bu/acre). Several winter wheat varieties were higher yielding than other varieties, with six varieties in the top statistical (LSD) yield group (CO11D346, CO11D174, Cowboy, Deloris, IDO1215, and IDO1213). Protein concentration in 2014 averaged 9.4%. Protein concentration ranged from a high of 10.8% for Brawl CL Plus to a low of 8.8% for Cowboy and Farnum.

## Introduction

**Winter** wheat variety performance testing has been conducted in northwest Colorado for many years (Pearson and Haley, 2010, 2011, 2012; Pearson et al., 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2013; Golus et al., 1997). Winter wheat variety performance tests are conducted each year in northwest Colorado to identify varieties that are adapted for commercial production in the region. The 2014 winter wheat variety performance test was conducted at Craig, Colorado.

## Materials and Methods

Twenty-two winter wheat varieties and breeding lines were evaluated during the 2014 growing season at the Wayne Counts Farm near Craig. The experiment design was a randomized complete block with four replications. Plot size was 4-ft. wide by 40-ft. long with six seed rows per plot. Planting occurred on Oct 2, 2013 at a seeding rate of 680,000 seeds/acre. An application of Ally at 1/10 oz/acre plus 5 oz/acre of Sword plus 2 oz/acre of Fitness fungicide was applied in 5 gal. water/acre at 30 psi with a ground sprayer on May 28, 2014. No fertilizer was applied as is often the case for growers in northwest Colorado. Plant height and lodging were evaluated just prior to harvest. Harvest occurred on Aug. 18, 2014 using a Hege 140 small plot combine (Figs. 1, 2). Grain samples were cleaned in the laboratory using a small

Fig. 1. Winter wheat plots at the Wayne Counts Farm at Craig, Colorado just prior to harvest. Photo by Calvin H. Pearson.

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Clipper cleaner to remove plant tissue that remained in the grain sample following threshing. Grain moistures and test weights were determined using a DICKEY-john GAC2100b™ Grain Analysis Computer. Grain yields were calculated at 12% moisture content. Grain protein concentration was determined by whole grain near infrared reflectance spectroscopy with a Foss NIRSystems 6500 (reported on a 12% moisture basis).

Statistical analyses were performed by analysis of variance using Statistix 10 (Analytical Software, 2013). Differences among treatments were considered significant at $P \leq 0.05$ using an F-protected LSD.

**Results and Discussion**

The results of the soil test analysis for the 2014 plot area at Craig were: a sandy clay loam soil with a pH 7.6, 0.8 mmhos/cm, 1.3% organic matter, 5.5 ppm $NO_3$-N, 5.0 ppm P, 193 ppm K, 2.03 ppm Zn, 9.03 ppm Fe, 4.72 ppm Mn, and 2.98 ppm Cu.

Weather information for the growing season is typically included in this report, but much of the data from the Craig weather station were missing, thus, it was not possible to include information about Craig weather during the 2013-2014 cropping season.

Generally speaking, precipitation in the Craig/Hayden area is often a major limiting factor for crop production. Precipitation varies considerably from month to month and year to year. If timely precipitation occurs, grain yields of winter wheat will be good. If precipitation does not occur in a timely fashion, wheat yields will be low. Because the amount of precipitation is so variable and spotty during the growing season in the Craig/Hayden area, wheat yields often vary considerably from year to year.

Grain moisture in the winter wheat variety performance test at Hayden averaged 9.9% (Table 1). Grain moisture content ranged from a high of 10.8% for CO09W009 to a low of 9.2% for IDO1213.

Plots were weed-free and overall growth and productivity was good (Figs. 1, 2) compared to our wheat trials in many other years in northwest Colorado. Grain yield for the winter wheat varieties averaged 2966 lbs/acre (49.4 bu/acre) (Table 1). Grain yield ranged from a high of 3680 lbs/acre (61.4 bu/acre) for CO11D346 to a low of 2576 lbs/acre (42.9 bu/acre) for IDO1103. Several winter wheat varieties were higher yielding than others, with six varieties having grain yields in the top group according to LSD (0.05) mean separation (CO11D346, CO11D174, Cowboy, Deloris, IDO1215, and IDO1213). According to the Colorado Agricultural Statistics Service, the average wheat yield in northeast Colorado in 2012 was 40.1 bu/acre (Colorado Department of Agriculture, 2013).

Fig. 2. Harvesting the winter wheat variety performance trial at Craig, Colorado on Aug 18, 2014. Fred Judson is shown operating the Hege 140 combine. Photo by Calvin H. Pearson.

Test weights averaged 60.1 lbs/bu (Table 1). Test weights ranged from a high of 63.6 lbs/bu for Weston to a low of 57.0 lbs/bu for IDO1213.

There was no lodging in the winter wheat variety performance test in 2014. Plant height averaged 26.4 inches (Table 1). Plant height ranged from a high of 33.2 inches for Weston to a low of 22.4 inches for CO11D446.

Protein concentration averaged 9.4% (Table 1). Protein concentration ranged from a high of 10.8% for Brawl CL Plus to a low of 8.8% for Cowboy and Farnum.

Statistical analyses were performed by analysis of variance using Statistix 10 (Analytical Software, 2013). Differences among treatment were considered significant at $P \leq 0.05$ using an F-protected LSD.

### Acknowledgments

The farmer-cooperator for this trial was Wayne Counts. We thank Wayne for his willingness to participate with us in conducting this research. We also thank the Western Colorado Research Center staff (Fred Judson and Kevin Gobbo) and Ben Steele (summer research assistant) who assisted with this research. Appreciation is also extended to the Colorado Wheat Administrative Committee for funding this research.


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Table 1. Winter wheat variety performance test at Craig, Colorado 2014. Farmer-Cooperator: Wayne Counts.

| Variety | Market class[1] | Grain moisture | Grain yield | | Test weight | Plant height | Protein |
|---|---|---|---|---|---|---|---|
| | | (%) | bu/acre | lbs/acre | lbs/bu | in. | (%) |
| CO11D346 | HRW | 10.2 | 61.4 | 3680 | 58.7 | 25.6 | 8.9 |
| CO11D174 | HRW | 10.0 | 55.0 | 3302 | 60.4 | 25.4 | 9.2 |
| Cowboy | HRW | 10.6 | 54.5 | 3272 | 60.4 | 24.3 | 8.8 |
| Deloris | HRW | 9.8 | 53.7 | 3224 | 61.3 | 31.5 | 9.3 |
| IDO1215 | HWW | 9.4 | 53.4 | 3209 | 57.8 | 26.4 | 9.3 |
| IDO1213 | HWW | 9.2 | 53.3 | 3199 | 57.0 | 26.6 | 9.0 |
| Farnum | HRW | 9.8 | 52.2 | 3132 | 60.1 | 27.7 | 8.8 |
| Hatcher | HRW | 9.8 | 51.6 | 3100 | 59.6 | 22.7 | 10.1 |
| Golden Spike | HWW | 10.0 | 51.3 | 3080 | 60.1 | 28.1 | 8.9 |
| CO11D446 | HRW | 10.0 | 49.7 | 2984 | 59.0 | 22.4 | 9.0 |
| UI SRG | HRW | 9.8 | 49.1 | 2947 | 60.1 | 30.0 | 9.7 |
| CO09W009 | HWW | 10.8 | 48.3 | 2899 | 61.6 | 23.7 | 9.1 |
| Curlew | HRW | 9.7 | 48.0 | 2880 | 60.3 | 28.7 | 9.6 |
| Snowmass | HWW | 9.8 | 47.5 | 2851 | 60.1 | 25.6 | 9.4 |
| Brawl CL Plus | HRW CL2 | 9.6 | 46.5 | 2791 | 60.6 | 25.5 | 10.8 |
| Byrd | HRW | 10.2 | 46.4 | 2785 | 60.0 | 22.9 | 9.5 |
| Antero | HWW | 10.1 | 46.0 | 2758 | 58.9 | 24.6 | 9.9 |
| Weston | HRW | 10.2 | 45.9 | 2756 | 63.6 | 33.2 | 9.9 |
| CO09W040-F1 | HWW | 10.0 | 43.7 | 2620 | 61.0 | 22.9 | 9.3 |
| Promontory | HRW | 10.2 | 43.3 | 2599 | 59.8 | 26.8 | - |
| Lucin CL | HRW CL | 9.6 | 43.3 | 2601 | 61.3 | 32.6 | 9.7 |
| IDO1103 | HRW | 9.7 | 42.9 | 2576 | 59.6 | 24.3 | 9.7 |
| AVE. | | 9.9 | 49.4 | 2966 | 60.1 | 26.4 | 9.4 |
| LSD (0.05) | | 0.3 | 8.5 | 509 | 2.2 | 1.5 | |
| CV (%) | | 2.2 | 12.1 | 12.1 | 2.6 | 4.0 | |

[1] HRW = hard red winter wheat; HWW = hard white winter wheat; CL = Clearfield* wheat; CL2 = two-gene Clearfield* wheat.

## Research Projects/Publications

### Dr. Calvin H. Pearson

**2014 Research Projects***

Winter wheat cultivar performance test – Craig (Wayne Counts, Dr. Scott Haley)
Alfalfa variety performance test (2012-2014) – Fruita (seed companies, breeding companies, private industry)
Evaluation of basin wildrye as a biomass resource – Fruita (Dr. Steven Larson and Dr. Kevin Jensen, USDA-ARS Logan, UT)
Application of Foliar Blend by Agri-Gro in alfalfa on alfalfa yield and hay quality – Fruita (Bio-Tech Solutions)
Application of Ignite$S^2$ by Agri-Gro in pinto bean – Fruita (Bio-Tech Solutions)
Performance of sub-surface drip irrigation in alfalfa for improved irrigation efficiency and environmental enhancement – Fruita (Wayne Guccini, NRCS)
Evaluation of canola varieties – Fruita (Dr. Mike Stamm, Kansas State University)
Evaluation of alfalfa genetic material 2009-2011 – Fruita (Dr. Peter Reisen, Forage Genetics)
Evaluation of RR alfalfa genetic material 2012-2014 – Fruita (Dr. Peter Reisen, Forage Genetics)
Evaluation of RR alfalfa genetic material 2013-2015 – Fruita (Dr. Peter Reisen, Forage Genetics)
Evaluation of RR alfalfa genetic material 2014-2016 – Fruita (Dr. Peter Reisen, Forage Genetics)
Evaluation of perennial plant species and production input for sustainable biomass and bioenergy production in Western Colorado – (Fruita, Rifle, and Meeker)
Evaluation of corn hybrid breeding material for grain and silage – Fruita (DOW Agrosciences)

**2015 Research Projects* (Continuing, New, or Planned)**

Winter wheat cultivar performance test – Craig (Wayne Counts, Dr. Scott Haley)
The potential of winter rye production in the Grand Valley – (KWS Cereals)
Evaluation of alfalfa genetic material 2011-2013 – Fruita (Dr. Peter Reisen, Forage Genetics)
Evaluation of RR alfalfa genetic material 2013-2015 – Fruita (Dr. Peter Reisen, Forage Genetics)
Evaluation of RR alfalfa genetic material 2014-2016 – Fruita (Dr. Peter Reisen, Forage Genetics)
Evaluation of RR alfalfa genetic material 2015-2017 – Fruita (Dr. Peter Reisen, Forage Genetics)
Evaluation of corn hybrid breeding material for grain and silage – Fruita (DOW AgroSciences)
Evaluation of canola varieties – Fruita (Dr. Mike Stamm, Kansas State University)
Performance of sub-surface drip irrigation in corn for improved irrigation efficiency and environmental enhancement – Fruita (Wayne Guccini, NRCS)

*Cooperators/collaborators/sponsors are noted in parentheses.

**2014/2015 Publications**

Pearson, C.H., S.R. Larson, C.M.H. Keske, and K.B. Jensen. 2015. Native grasses for biomass production at high elevations. pps.101-132 . *In*: Cruz, V.M.V., and D.A. Dierig, (ed.) Industrial Crops: Breeding for Bioenergy and Bioproducts. Springer. New York, NY.

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