MAD AGRICULTURE

GMO TRANSITION TRIALS REPORT 2020

Executive Summary

Mad Agriculture is helping Boulder County with a transition program that involves an extension of the GMO ban deadlines, during which Mad Agriculture would provide support and opportunities for structured learning for farmers navigating future production without GMO crops and neonicotinoid (neonic) seed coatings. This included GMO vs. non-GMO crop comparison trials, exploring new market development for alternative crops, and testing the implementation of additional soil health practices. The extension allowed for use of GMO corn and neonic pesticide seed coatings through 2021, and GMO beets to 2025[1].

The goal of this 2-year program is to build trust with affected producers and rapidly identify economically and ecologically viable alternatives to GMO crops and neonic pesticides while simultaneously scaling back existing GMO production acres. Another major goal is to bring the energy and progress being made across the USA in regenerative agriculture and the re-regionalization of commodity agriculture to affected farmers on Boulder County agricultural lands.

Corn and beets are the primary crops these farmers grow using GMO technology. The Western Sugar Co-op is the only available market for sugar beet production and will only purchase GMO sugar beets. As members of the Co-op, farmers are legally bound to deliver their beet shares. Helping farmers remove their beet share obligation is very challenging because of the complex relationship between farmers and the Co-op. Transitioning away from GMO sugar beets will require legal expertise that creates a strategy to sell or retire sugar beet shares, which is not the responsibility of Mad Agriculture. Because of this, we focused on helping farmers conduct side-by-side corn trials to explore potential differences in the management and agronomic performance of GMO and non-GMO corn.

The corn trials demonstrated that GMO corn and neonicotinoid seed coatings are not absolutely necessary for corn production. The long term profitability of the non-GMO alternatives remains to be determined, with reason for optimism. Our 2020 trials show that non-GMO corn production can generate a viable harvest with an equal to slight reduction in yield, slight increase in the cost of herbicide, and equal to slight reduction in seed cost, relative to GMO corn production.

[1] A proposed extension for GMO sugar beets differs by tenant based upon the number of beet shares owned relative to the portion of that producer's private farm land.

Shifting to non-GMO crops did not reduce the frequency of herbicide use, and glyphosate continued to be used outside of the growing window of non-GMO corn. The primary alternative herbicides used were Dual and Status; these herbicides tend to be more expensive than glyphosate. There was no increased tillage or cultivation reported for non-GMO corn relative to GMO corn. There were no reports of insect pest pressure on non-GMO corn, which does not include the Bt gene for insect resistance. Fertilizer usage was very similar for GMO and non-GMO corn on each farm.

Alternative markets have signs of early success and positive momentum across the region. There is relatively strong regional demand for legumes and grains from local mills, institutions and food hubs. Priority should continue to be made for crops that can be sold at higher prices than commodity crops and have the potential to scale at the regional, and possibly domestic, levels. Rebuilding regional supply chains and establishing supply relationships with institutional, retail, and distribution partners will be vital to successful market development.

In the regenerative practice trials, we learned the importance of developing systems that regenerate soil health. The adoption and use of cover crops, new crops and practices work most effectively as a system. The combination of work presented here - alternatives to GMO crops, new crops and soil health practices - can advance the good work that Boulder County farmers have already done in creating sustainable farm systems. However, we learned that farmers would rather continue to develop soil health and regenerative systems outside the purview of this project. Therefore, this tier of work will not be repeated in 2021.

Introduction

In November 2016, Boulder County elected to phase out genetically modified (GMO) crops and use of neonicotinoid (neonic) pesticides on County-owned Open Space. As a result, tenant farmers who grew GMO crops on Boulder County Open Space land were faced with the challenge of transitioning from GMO corn by the end of 2019 and GMO sugar beets and neonic pesticides by the end of 2021. The GMO ban has caused consternation and fractured the local agricultural community. Most tenant farmers who grow GMO crops on Boulder County land are unhappy with the decision to ban the use of GMO crops.

This transition program is for farmers affected by the ban who want to retain their Open Space leases and whole-heartedly pursue economically viable alternatives to GMO crop production and use of neonic seed coatings. This program is not an effort to "kick the can down the road" on the GMO ban, but rather a roadmap to pursue viable alternatives to GMO crops.

We began 2020 by deepening our understanding of each farmer's operation, gained a more nuanced familiarity with the primary barriers, consequences and opportunities of adapting to the new regulations, and trialled alternative management practices, crops, and markets. After building relationships and understanding the farm operations, we designed non-GMO and GMO comparison corn trials, discovered and integrated new crops for new markets, and explored regenerative production practices in field trials with the farmers. Nine farmers performed nineteen trials across their Boulder County leased land. These trials included the following practices: non-GMO corn production, forage sorghum production, cool season forage cover crops, in-season cover crop establishment, heritage wheat, grain sorghum (milo), buckwheat, garbanzo beans, and edible dry beans. In addition to the trials, farmers attended 6 workshops and 3 field days related to the transition to non-GMO and neonicotinoid-free farming practices and new markets. Every farmer has met the minimum criteria of participation.

Findings and observations from the 2020 trials are provided in this document, organized into three tiers of work, listed below. Separately, we provide specific outcomes of trials on a farm-by-farm basis within the Farm Vision Plan documents, which includes personal and financial information as it relates to the trials.

Tier 1: Successful transition away from GMO crops and use of neonicotinoid pesticide coatings on seeds.

Tier 2: Help develop alternative crops and cropping systems, and new markets for those crops.

Tier 3: Help develop regenerative practices that restore soil health.

The corn trials were generally successful from planting to harvest. In order to explore management and profitability implications of GMO and non-GMO grain and silage corn production, Mad Agriculture collected qualitative and quantitative data from these trials to include in an enterprise budget analysis that compare GMO and non-GMO corn production production and profitability.

Overall, we had success in the production and marketing of new crops, especially for heritage wheat and dry beans. Production of white grain sorghum (milo) for gluten-free flour, buckwheat, and garbanzo beans were not as successful for a variety of reasons, discussed below. Several key market partnerships were developed this year, including with East Denver Food Hub, ARAMARK, Moxie Bread Co., Dry Storage Mill, Freshly Milled, and others. We worked closely with Tessa Hale of Boulder County to orchestrate the sale of edible dry beans for local procurement.

It is clear that infrastructure is critical to the development of regional food production, particularly in the mid-scale production (5-25 acres per variety) level. Regional markets demand a variety of grains, yet existing infrastructure in the area is best suited for small (<1-5 acre field size) or large (100+ acre field size) production systems. Regional markets also prefer organically-produced crops, and buyers are willing to pay premium prices. However, tenant farmers are not interested in shifting to organic agriculture, due to a variety of management and cultural factors. It remains unclear whether markets will be viable at the volumes needed to influence crop management decisions. Further discussion on the appropriate scale of production and type of market is included in the Market Report document.

Our trials provide early indicators that there are alternative crops to corn. However, it is important to note that field trials are just that, trials. A success or failure in one year doesn't mean success or failure in the future years. Agriculture has a slow innovation cycle: a farmer can only test a new crop or technique once per year. A farm business has a web of suppliers and markets that are established over years or decades. A given crop, practice or market can be successful one year and fail the next due to weather, pests, and market conditions. The 2-year term of this project is a finite window of opportunity to introduce new crops and build new markets. Most importantly, new crops do not have established markets at the scale required to displace corn production. Scaling markets in tandem with supply is challenging, but Mad Agriculture plans to build upon the successes of 2020 to create durable market opportunities in 2021.

This project provides an opportunity to explore how regenerative practices, cropping and livestock systems can restore and sustain soil health. Practices of regenerative agriculture can help reduce long-term input costs and restore the soil resource base of Boulder County Open Space. Our work focuses on integrating new practices that fit the five guiding principles of regenerative agriculture for commodity-oriented producers, which are: 1) Minimize Disturbance, 2) Leave No Bare Soil, 3) Maximize Diversity, 4) Keep a Living Root in the Soil for as Long as Possible and 5) Livestock Integration.[2]

[2] "Soil Health." *Natural Resources Conservation Service*, Natural Resources Conservation Service, 12 Mar. 2021, 11:12AM, www.nrcs.usda.gov/wps/portal/nrcs/main/nd/soils/health/.

In Year 1, we focused on integrating cover crops into farm operations and rotational patterns for all of the farmers. The lack of late-season water severely limits the establishment of cover crops in the fall season, when cover crops are most often planted. In order to integrate cover crops into rotations, we focused on two techniques: co-planting the cover crop along with the cash crop through overseeding, and planting a cover crop that can be used as a forage to encourage livestock integration. Forage-oriented cover crops often present the highest and most direct opportunity for profitability amongst cover crop approaches, meeting soil health and forage production goals. After an assessment of all farm operations, we focused on five cover crop trials with six of the nine farmers, which included a pea-oat cover crop, overseeding rye-into-alfalfa, interseeding cover crop into corn, fall cover crop with rye, and integrating livestock into row cropping systems using forage cover crops. We had moderate to high success with each of these trials, with no outright failure. Specific results are shared below.

Tier 1: Non-GMO Corn and Beets

Tier 1 addresses the immediate need to transition farmers away from GMO corn and neonic pesticides. The most direct alternatives to GMO corn are non-GMO corn and forage sorghums. These crops have clear markets and prices and are largely sold through feed markets to dairy producers in Weld County or fed to the producers' own animals.

Beet Production

For beets, there is no replacement for this crop due to the legal obligation of some tenants to deliver beet shares to Western Co-op. Failing to grow and deliver sugar beets under contract with the co-op creates a non-delivery fee that would bankrupt any farmer. Retiring beet shares is not possible due to the legal structure of member obligations, and selling shares is currently impossible because there is no market demand for beet shares for the foreseeable future. Transitioning away from sugar beets is a legal issue that is outside the scope and expertise of Mad Agriculture to address. We designed an extension of the ban for farmers moderately to severely affected by the ban because transitioning away from GMO beets may be impossible or take years to complete. We refer to the original program design for more details on this.

Corn Production - Trials and Enterprise Budget Analysis

Introduction

Other than beets, corn is the crop most commonly grown in Boulder County with GMO technologies. For this reason, trial comparisons of GMO and non-GMO corn was the focus of crop trials for the majority of farmers.

The common objectives for the farmers and the number involved allowed for a comparative analysis of GMO and non-GMO corn production and profitability. Mad Agriculture aggregated information from these trials to understand the difference in agricultural practice associated with this transition, as well as its impact on farmer profitability with an associated enterprise budget analysis across all farms. Additionally, the aggregation of multiple farmer trials with a range of financial experiences allows for identification of trends and opportunities for farmers in their transition to non-GMO corn production.

The key questions addressed through the trials and resulting enterprise budgets are:

- Will a shift to non-GMO corn increase tillage and/or reduce herbicide use?
- How does non-GMO corn hold up to potentially higher weed and pest pressure?
- What are the differences in costs and revenues for non-GMO and GMO corn?
- Is non-GMO corn more or less profitable than GMO corn?
- Is neonic seed coating critical for the agronomic success of corn production?

Methods

The purpose of the trials was to allow the farmers to explore the agricultural questions they needed to be successful at transitioning from GMO to non-GMO crop production without the use of neonicotinoid seed coating. Since farmers were encouraged to trial what would be specific to their own farm, farmers chose their own seeds and varieties to reflect their current agricultural practice, and so purchased seed from their established seed sources with relative maturities and other attributes that they are accustomed to growing, or interested in growing in the future. This created some inherent variability in the varieties that were grown and compared. For instance, within the group of farmers who conducted corn trials, some compared GMO and non-GMO corn with the same genetic backgrounds, and others explored the performance of varieties of different genetic backgrounds. Broadly, the emphasis for these trials was on GMO and non-GMO corn variety comparisons and largely did not incorporate comparisons of seeds with and without neonicotinoid coating, with the exception of two trials (trials 4 and 8). All corn trials predominantly consisted of a side-by-side comparison of a small plot of non-GMO corn grown (4-30 ac) next to a larger acreage of GMO corn (20-155 ac). One trial was a comparison between GMO corn silage and alternative silage crops; the GMO cost, revenue and profitability was reported in this overall GMO analysis, but is not included in the analysis of on-farm differences between GMO and non-GMO corn, since it was not paired with a non-GMO corn plot for comparison (trial 8). Another trial had a GMO crop without a non-GMO comparison because the non-GMO crop was lost due to the misuse of herbicide: Roundup was accidentally applied to non-GMO corn due to a miscommunication between a farmer and AgFinity, who contract sprays for many of the farmers in Boulder County (trial 7). Similarly, the data from this trial, so far as it was complete, was included in the overall analyses, but could not be included in any on-farm comparison analysis for revenue or profitability between GMO and non-GMO crops.

The 2020 growing season had generally favorable growing conditions for corn. Hail damage and major drought were not factors that affected comparisons of agronomic performance between varieties and did not restrict harvest. There were also no reports of weed, insect, disease or other pest pressure that affected yield or harvest.

To collect data from farmers, Mad Agriculture created an enterprise budget form and shared it with farmers to input their management practices and costs of production. Tracking field-specific costs is not common for many broadacre farmers across the United States, and are generally difficult to measure. This level of detail proved unsuitable to the accounting practices of most of the participating farmers. To simplify the process, Mad Agriculture requested management details and the three ‘primary costs’ of production, which were the agronomic system inputs: costs of seed, herbicide, and fertility. For the remaining ‘additional costs’ of production, including field preparation, planting, insecticides and fungicides, irrigation, cultivation, harvest, hauling, crop scouting, crop insurance, capital interest, fuel, equipment maintenance, machine ownership, and general overhead, Mad Agriculture used the average costs of production from pivot and furrow irrigated corn production in Colorado and Nebraska[3,4,5,6]. 'Additional costs' tend to be more consistent across farms, and are inherently difficult for any individual farm to monitor. These factors are also similar for non-GMO and GMO corn production. Items like fuel cost may have the potential to diverge if field activities differed for non-GMO and GMO corn, but this year the number of field passes on any farm trial did not differ. The sum of the averaged costs, excluding 'primary costs' (already accounted for in the data collection), and excluding rent and property taxes, was the 'additional cost', which amounted to $401.01. All values considered in the calculation of 'additional costs' are shown in Appendix Table 1. The total cost of production was a sum of the 'primary costs' and the 'additional costs'.

Revenue was a product of crop yield and sale price. Most farmers kept accurate receipts at the field level for yields and pricing, but if the trial occurred within a larger field area, the farmer had to make sure that area-specific yield data was captured. Most modern combines for grain harvest have real-time yield monitors, and silage harvest is typically performed by a contractor that can also capture area-specific data upon request.

In a few cases, some farmers did not provide the basic numbers requested for 'primary costs' or sale price. This created data gaps in the enterprise budget accounting. When this occurred, specific averages for GMO and non-GMO silage and grain were created from values of the other trials. This was done for seed bag cost, herbicide cost, fertilizer cost, and sale price. When seed price was reported on a $/bag basis without the associated plant population, a plant population of 35,000 seeds/ac was used for grain and 40,000 seeds/ac for silage to calculate the seed price on a $/ac basis.[7] All substitutions are noted in Table 1.

Net profitability at the field level was determined as the difference between revenue and total cost of production.

Results & Discussion

A summary table of costs, revenues and net profitability is shown in Table 1. The aggregated findings for all farmers for each of the parameters considered in the enterprise budget analysis are shown below.

---

[3] "*NE Irrigated Corn 2018*. Colorado State University. (2018). 12 Mar 2021. http://www.wr.colostate.edu/ABM/ne-irrigated-corn-18.pdf.

[4] *Irrigated Corn Silage 2018*. Colorado State University. (2018). 12 Mar 2021. http://www.wr.colostate.edu/ABM/2018W-CornSilage.pdf.

[5] Klein, R. (2020). *2020 Corn Irrigated. University of Nebraska*. 12 Mar 2021. https://cropwatch.unl.edu/Budgets/2020/2020-Corn-Irrigated.pdf.

[6] Klein, R. (2020). *2021 Corn Irrigated. University of Nebraska*. 12 Mar 2021. https://cropwatch.unl.edu/Budgets/2021/2021-Corn-Irrigated-121620.pdf.

[7] R. Keshavarz and S. Urbanowitz. *Optimizing Corn Plant Population for Maximum Benefits: Things to Consider*. Colorado State University Extension. (2020). 12 Mar 2021, 11:20AM. https://extension.colostate.edu/topic-areas/agriculture/optimizing-corn-plant-population-for-maximum-benefits-things-to-consider-0-312/.

Table 1. A summary of costs and revenues that influenced net profitability at the field scale for non-GMO and GMO corn trials.

Trial	Corn Type	GMO Status	Irrigation	Coating	Population (seeds/ac)	Herbicide Cost ($/ac)	Fertilizer Cost ($/ac)	Seed Cost ($/ac)	Total Cost ($/ac)	Yield (Grain: bu/ac) (Silage: ton/ac)	Corn Value ($/bu)	Gross Revenue ($/ac)	Net Profit* ($/ac)
1	Grain	GMO	Pivot	Neonic	40,000	$26.00	$126.00	$117.50	$670.51	175.0	$4.30	$752.50	$81.99
1	Grain	Non-GMO	Pivot	Neonic	40,000	$37.87	$126.00	$110.00	$674.88	131.3	$4.30	$564.38	-$110.51
2	Grain	GMO	Flood	Neonic	35,000	$30.95	$86.58	$113.75	$632.29	169.1	$4.20	$710.22	$77.93
2	Grain	Non-GMO	Flood	Neonic	35,000	$36.58	$86.58	$109.38	$633.55	154.6	$4.20	$649.36	$15.82
3	Grain	GMO	Flood	Neonic	35,000	$26.14	$89.86	$96.01	$613.01	170.0	$4.10	$697.00	$83.99
3	Grain	Non-GMO	Flood	Neonic	35,000	$33.48	$89.86	$92.16	$616.50	175.0	$4.10	$717.50	$101.00
4	Grain	GMO	Flood	Neonic	33,000	$26.14	$89.86	$103.31	$620.31	242.2	$4.10	$993.02	$372.71
4	Grain	Non-GMO	Flood	Uncoated	35,000	$33.48	$89.86	$93.89	$618.24	235.3	$4.10	$964.73	$346.49
4	Grain	Non-GMO	Flood	Uncoated	35,000	$33.48	$89.86	$132.75	$657.10	253.9	$4.10	$1,040.99	$383.89
4	Grain	Non-GMO	Flood	Uncoated	35,000	$33.48	$89.86	$60.48	$584.83	238.7	$4.10	$978.67	$393.84
5	Silage	GMO	Pivot	Neonic	48,000	$26.00	$150.00	$144.00	$721.01	28.7	$27.50	$789.25	$68.24
5	Silage	Non-GMO	Pivot	Neonic	48,000	$37.87	$150.00	$132.00	$720.88	25.6	$26.80	$686.08	-$34.80
6	Silage	GMO	Pivot	Neonic	40,000	$40.76	$40.96	$123.20	$605.93	27.2	$28.10	$765.16	$159.23
6	Silage	Non-GMO	Pivot	Neonic	40,000	$40.76	$40.96	$117.04	$599.77	27.2	$28.10	$765.16	$165.39

7	Silage	GMO	Pivot	Neonic	40,000	$21.60	$45.74	$105.25	$573.60	25.0	$27.00	$675.00	$101.40
7	Silage	Non-GMO	Pivot	Neonic	26,667	$21.60	$45.74	$46.17	$514.52	0.0	$27.00	nan	nan
8	Silage	GMO	Flood	Uncoated	40,000	$26.14	$89.86	$70.17	$587.17	20.1	$27.00	$542.70	-$44.47

Assumed Values and Sources

Values not provided by the farmers are indicated in grey.

Planting populations were assumed according to whether they were corn grain or corn silage, using 35,000 seeds/ac for grain and 40,000 seeds per acre for silage.[7]

When values were not disclosed, the average for GMO or non-GMO costs were used to populate the respective GMO and non-GMO values.

Total cost includes seed, fertility, and herbicide costs as given, as well as additional costs determined to be $401.01/ac for field preparation, planting, insecticides and fungicides, irrigation, cultivation, harvest, hauling, crop scouting, crop insurance, capital interest, fuel, equipment maintenance, machine ownership, and general overhead.[3,4,5,6]

Costs

Costs include 'primary costs' like seed, herbicide, fertility, and 'additional costs'. Overall, fertility was the same for GMO and non-GMO corn for each farm, but varied greatly between farms. Herbicide was generally more expensive in non-GMO corn than in GMO corn, owing to the general use of more expensive herbicides in place of glyphosate. Seed cost accounted for the greatest potential difference in cost between GMO and non-GMO corn, with non-GMO corn tending to be the same or less expensive than GMO corn seed.

Seed

On average, a bag of GMO seed was $11 greater than non-GMO seed. This equated to GMO seeds costing about $10 more per acre than non-GMO seed. On-farm differences ranged between $9 and $72/bag or $4 and $59/ac. Figure 1 shows the distribution of costs for GMO and non-GMO seed. Most savings with the same genetics in non-GMO and GMO were around $10-$20 per bag.

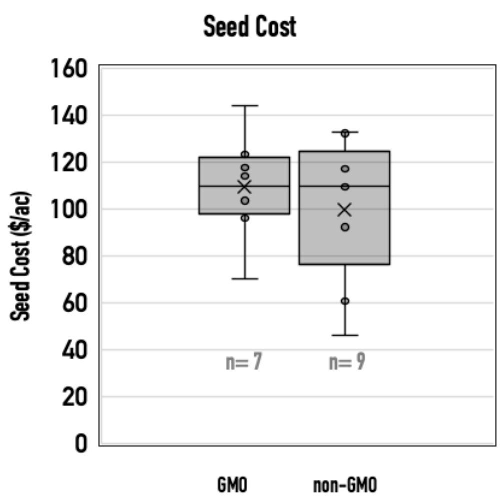

Figure 1. Comparative cost of non-GMO and GMO corn seed.

Seed cost was the cost with the greatest potential to affect corn profitability, which must be weighed with its yield potential. Most producers choose their seed from suppliers with whom they hold long-term relationships. Large, corporate seed suppliers such as DeKalb and Pioneer offer the latest, and most expensive non-GMO and GMO genetics with small seed cost and yield potential differences between non-GMO and GMO corn seed. It follows then, that these companies do not offer as great of an opportunity to reduce seed cost in the overall profitability of corn production, especially when the genetic potential of the seed for yield is similar.

Most corn seed suppliers offer non-neonic coated seeds if requests are made well in advance of the growing season. In 2020, Mad Agriculture provided the tenant farmers a comprehensive list of new seed suppliers for non-GMO and non-neonic coated seeds, and held a workshop on seed sourcing. We found more than seven seed suppliers, including corporate suppliers that offer naked or non-neonic coated corn seed. Early ordering of seed may involve less flexibility to wait closer to the season to order seeds, but often comes with an additional discount of between 5-10%.

Of all seed sources, Revolution Soil & Seed offered a wide variety of non-GMO corn genetics at a significantly lower cost that are suited to the region and market, and they provide access to 'naked seed' or a range of biological coatings. Unlike neonics, which are intended to protect corn seed from pests, biological seed coatings support the germination and health of the seed. Only two farmers incorporated non-neonic coated seeds in their trials this year. With ample time the following season to procure uncoated seed, and resources that Mad Agriculture provided for the farmers to do so, farmers should have had sufficient time to request uncoated seed to include neonicotinoid comparisons in future trials.

2020 Observations:

- Farmers tended to procure seeds within their existing seed supply relationships.
- Cost of seed per unit yield gain is perhaps the most important single factor in profitability.
- There are generally cost savings in non-GMO seed, though the magnitude of savings varies tremendously.
- Greater savings can be found in non-GMO seed with older corn genetics, but seed cost must be optimized with yield potential.
- Additional seed cost savings can be had when ordering seed early, as would need to be done to request seed without neonic coatings.

Herbicide

Costs associated with weed management in GMO/non-GMO corn typically depend on the herbicides used. In addition to Bt traits for insect pest resistance, among the primary technologies that GMO corn enables is the resistance of the corn crop to the use of glyphosate to kill weeds growing amongst the corn. With non-GMO corn varieties, in-season use of glyphosate was replaced with alternative herbicides. The primary alternatives to glyphosate as a post-emergent herbicide were Status, Dual, Status + Dual, or no spray. Farmers often still used glyphosate in their non-GMO management before planting. Glyphosate is cheaper than herbicide alternatives, therefore costs tend to go up when alternative herbicides are used.

Herbicide costs went up between $6/ac and $12/ac, on average for non-GMO corn relative to GMO corn. There were no reports from farmers that they needed to perform extra passes for tillage or weed cultivation in non-GMO plots relative to GMO plots. The comparative costs of the herbicide program between non-GMO and GMO corn managements are shown in Figure 2.

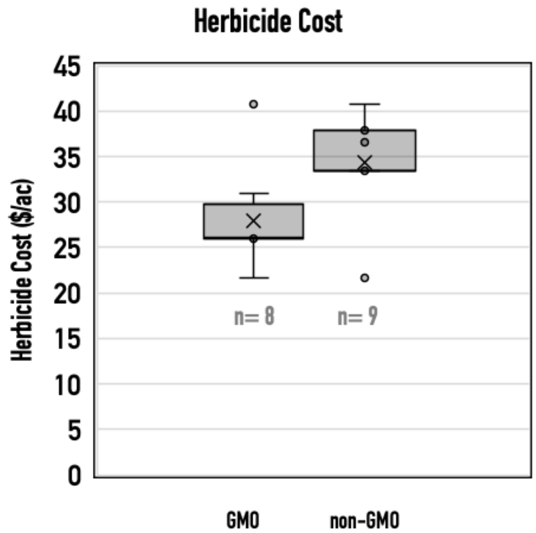

Figure 2. Comparative cost of herbicide for non-GMO and GMO corn trials.

When no herbicide was used, farmers generally observed higher weed pressure, but this pressure was not great enough to affect yield. There were also no substantial weed or pest pressure differences observed in this first year, though this may be a legacy of past chemical practices in the field. In a few cases, farms used no herbicide or less herbicide on non-GMO plots than GMO plots. While support for chemical-free weed management has been offered, tenant farmers have not expressed interest in these practices. Farmers prefered chemical weed management to mechanical cultivation of weeds because chemicals potentially require fewer passes, less fuel per pass, and reduces physical disturbance of the soil.

2020 Observations:

- Glyphosate is cheaper than herbicide alternatives.
- When no herbicides were used, farmers observed higher weed pressure.
- Weed pressures due to changes in chemical use did not compromise yield.
- Relatively low weed pressures in non-GMO likely results from herbicide use in prior years.
- Farmers often use glyphosate prior to the establishment of non-GMO corn.
- While support for chemical-free weed management has been offered, farmers are not interested in mechanical cultivation or other practices for weed control.

Fertility

Farmers tended to use the same fertility inputs regardless of GMO or non-GMO management. The fertilizer costs did range widely from $40 to 150/ac, however these costs were essentially the same within farmer trials of GMO and non-GMO corn, as shown in Figure 3. Farmers determine their fertility inputs based on soil tests and targeted yield. Some producers have different yield targets based on their soil types, and economic goals.

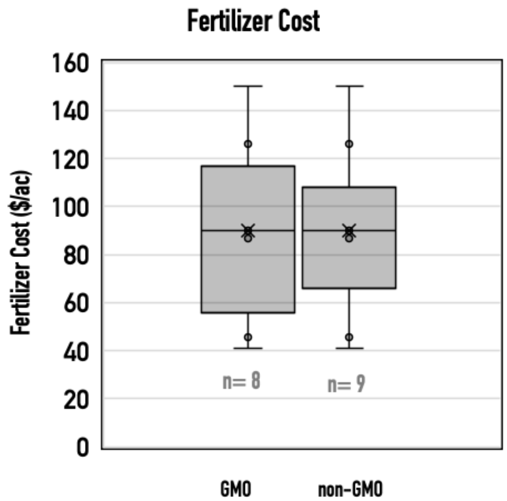

Figure 3. Comparative cost of fertilizer for non-GMO and GMO corn trials.

2020 Observations:

- Farmers did not change their fertility inputs for GMO and non-GMO corn.
- Fertility costs varied widely among producers.

Revenue

Corn yield and price determine revenue. There were generally few differences in corn yield between GMO and non-GMO corn for each farmer. Corn prices were the same for GMO and non-GMO corn, as premium markets for non-GMO seed were not established in this region.

Yield

There were no appreciable differences in corn yield between non-GMO and GMO corn grain and silage varieties. Yield ranged from 131 to 254 bu/ac for grain corn, and from 20 - 29 tons/ac for silage corn. Variability in yield differences between GMO and non-GMO crops was high among farms, with non-GMO yields ranging from 12 bu/ac greater, to -43bu/ac less for grain and between 5 and -3 tons/ac, relative to GMO yields. However, on average, yields for GMO corn were 10 bu/ac and 0.6 tons/ac greater in non-GMO than GMO corn. We found more variability in yield for corn varieties with different genetic backgrounds than with GMO and non-GMO varieties with similar genetic backgrounds. Figure 4 shows the comparative yield of grain (Fig. 4A) and silage (Fig. 4B) corn yield.

2020 Observations:

- There was little overall difference between GMO and non-GMO corn yields for grain or silage.
- Base genetics more strongly determine yield potential than GMO traits.
- Base genetics influence yield as much or more than GMO traits.

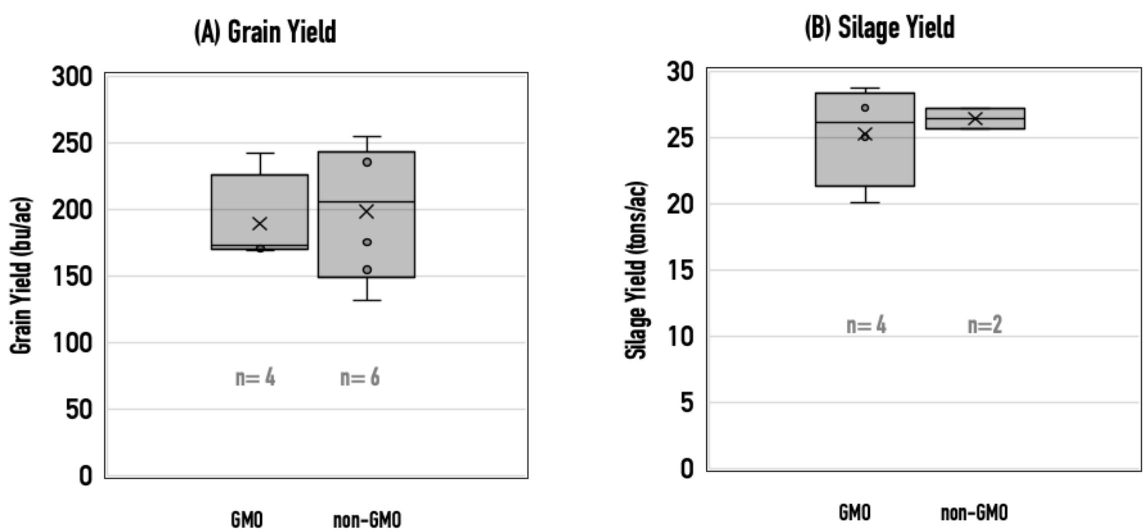

Figure 4. Comparative yield of non-GMO and GMO grain (A) and silage (B) corn.

Corn Price

As a commodity, the price for corn is largely set by the Chicago Board of Trade (CBOT). Corn pricing has been highly volatile over the period of the project (Figure 5). In early 2020, commodity market prices were low, trading at ~$3.80/bu to, and fell to $2.86/bu in August, which was an 18-year low. By January 2021, corn was trading at $5.56/bu, which is the highest value since early 2013. This pricing doesn't affect the comparative enterprise analysis of non-GMO vs. GMO corn, however, it does affect the farmer's appetite to grow corn, and in turn, influences the desire to increase diversity of crops and new markets. From 2020 to 2021, the market has shifted to make corn more financially attractive.

Personal relationships, timing of sale (including future contracts), proximity to market (e.g. freight costs), and differentiation in the marketplace (organic, non-GMO, specialty varieties) further affect the price a producer can receive for their crop.

We have found that farmers have long-standing relationships with buyers in the area that have established logistics and pricing systems with no supply ceiling. These existing market relationships to livestock and dairy feedlot operations in nearby Weld County, CO already offer premiums over CBOT prices, largely from reduced freight costs. Most of the farmers were able to sell their 2020 grain corn harvest for over $4/bu, which was higher than commodity prices.

In this region, markets that offer non-GMO corn premiums are limited. Markets for non-GMO corn generally have smaller volume demand, and markets in the Front Range (i.e. Ranchway Feed) already have adequate supply. Alternative markets that would offer premiums for non-GMO corn are over 100 miles away (i.e. western Kansas and California), and added freight costs would negate potential premium gains.

In some cases, crop quality can factor into the sale price (e.g. RFV, relative feed value). The price of silage is less determinate than grain, and often is more dependent on factors like feed quality, and relationships between the producer and buyers in the community. One farmer that grew silage with a side-by-side comparison trial, sold their GMO and non-GMO corn at the same price, and the other sold their non-GMO silage for $0.70 less.

Figure 5. Commodity corn prices 2012-2021 (350 = $3.50/bu)

2020 Observations:

- Farmers are reluctant to move to new markets.
  - There is a high degree of social investment between farmers and buyers.
  - There is security in current markets, which have no supply ceiling.
  - Current markets are nearby and have established logistics and pricing systems.
- Current market relationships enjoy premiums over base commodity pricing.
  - Close proximity to livestock markets in Weld County allows for associated delivery benefits.
- Markets that offer non-GMO premiums in the Front Range are limited and have low volume demand.
  - Other opportunities are over 100 miles away (i.e. western Kansas and California), and freight costs would negate price premiums.

Net Profitability

Net profitability was the difference between revenue and total costs. Values for profitability ranged widely between farmers, from $393/ac to $-110/ac (Figure 6). Profitability comparisons also varied greatly between farms, with GMO corn profitability between $21 less and $192 greater than non-GMO corn. On average overall profitability was $45 greater for non-GMO than for GMO corn. Four trials were more profitable with non-GMO corn, while four other trials were more profitable with GMO corn. Non-GMO corn was only unprofitable for one farmer (on both of their trials). GMO corn was only unprofitable for one farmer. The use of GMO corn or non-GMO corn was not a factor that affected farm profitability.

There was greater variability in the profitability of non-GMO corn than that of GMO corn. The driving factors in determining net profitability were cost of seed and corn yield. In general, when a low cost of non-GMO seed coincided with moderate yields, profits were greater for non-GMO varieties than for expensive GMO varieties with high yields. Such profitability increases were realized predominantly in trials where baseline genetics of GMO/non-GMO varieties were different, since non-GMO/GMO corn with similar genetics tended to yield similarly, with herbicide cost increases that nearly offset small price differences in seed. Opportunities to increase profitability with non-GMO corn seed are in varieties that perform moderately well and have a lower seed price.

Though only one farmer incorporated non-neonic seeds in their GMO/non-GMO comparison trials, the absence of neonics on three non-GMO seed varieties did not affect their profitability, as these varieties fetched a greater profit than any of the corn grown in any of the other farmers' trials.

2020 Observations:

- Corn profitability was not affected by GMO and non-GMO traits.
- Corn seed price (primary) and corn yield (secondary) were the most important factors affecting net profitability.
- Moderately producing varieties of non-GMO corn with less expensive genetics were more profitable than the most expensive GMO varieties with the greatest yield.

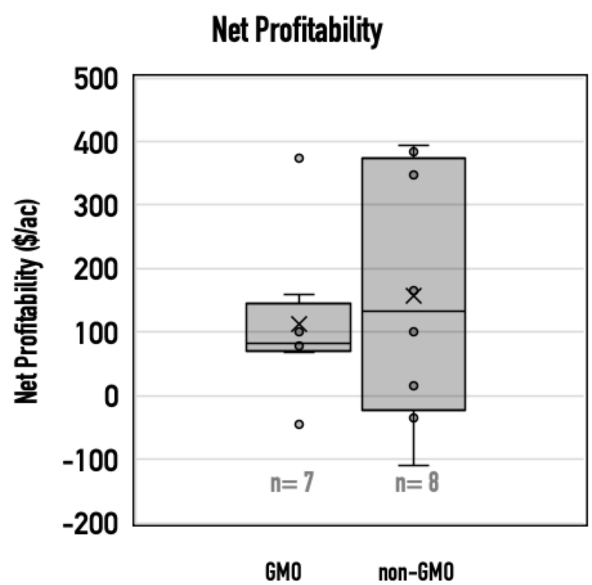

Figure 6. Net Profitability of grain and silage corn.

Farmer Concerns

Despite a range of yield and profitability outcomes in 2020, there remains significant long-term concern among farmers that comparative yields and profitability will worsen for non-GMO corn in the long term. The following perspectives shared by the farmers showcases their concerns and desire for continuing the same trials again in a new year:

- *Farmer Concern*: Previous years of management with GMO traits and glyphosate created field conditions in which non-GMO corn could perform well, but over time these conditions may worsen (i.e. weed and pest pressures may mount and amplify).
    - Other herbicides exist and will be used, but farmers question the relative safety and toxicity of other herbicides and pesticides relative to Roundup and the use of pest resistant traits in their corn. Effectiveness of alternative herbicides is also in question.

- *Farmer Concern*: The 2020 crop season had generally favorable conditions for production and the region had a 'good water year', not limiting irrigation for crops. It is not entirely surprising, then, that non-GMO corn performed as well as it did. It has yet to be seen how non-GMO corn will perform in less favorable crop years.
    - Many of the same corn genetics can be purchased with or without GMO traits, and therefore have the same yield potential. The purpose of GMO traits is to protect the plant from pest pressure, and thereby increase the health and yield potential of the plant. There was no difference in pest pressure between GMO and non-GMO corn trials, so the use of traited corn provided no additional benefit to yield in 2020.
    - The net profitability of corn was mainly influenced by seed cost and yield. In some trials the highest profitability was observed in a non-GMO seed, despite a slightly lower yield. In some trials, the lower cost of non-GMO seeds was unable to make up the economic difference for associated yield loss.
- *Farmer Concern*: Neonicotinoid seed coatings were used in most non-GMO seed trials this year, and are understood to only have a potential benefit during conditions favorable for insect pests, like a wet spring.
    - Neonicotinoids are effectively an insurance measure: not always needed, but when the right conditions arise, crop failure could occur. For example, if corn is planted, and then the weather turns cold and wet, pests can attack the seed before germination. This is a bigger problem in wetter climates. However, with Colorado's dry climate and ability to partially control climate through irrigation, we hypothesize that the need for neonics is diminished.
    - Crop rotations, planting timing, and pre-plant field preparations are the most reliable management approaches to reduce the need for neonicotinoid seed protection. These methods all take several seasons to refine and tune to each year's unique conditions.
    - Biological seed coatings take an alternative approach by boosting seedling health to fend off pest pressure. This emerging technology shows promise but has yet to achieve widespread adoption. Return on Investment projections show value, but this must be borne out further to earn trust.
- *Farmer Concern*: Cost savings for non-GMO compared to GMO seeds are exaggerated and sufficient volumes of non-coated non-GMO seed do not exist.
    - Non-GMO seed cost savings vary by region, seed company, and genetic variation and do not necessarily apply to all situations.

- Non-GMO seed cost savings can be found with different genetic lines and suppliers. Though higher seed prices are often linked with higher yields or other favorable characteristics, some seed suppliers prefer slightly older genetics at a much cheaper cost.
- Untreated seed can be found from different suppliers and sometimes within current supply markets, but often requires earlier purchasing decisions (i.e. seed orders may need to be made as early as December or January.

Tier 1 Conclusions

Year 2020 was a successful year in helping transition farmers away from GMO crops and neonicotinoid pesticides. The corn trials demonstrated that GMO corn and neonicotinoid seed coatings are not absolutely necessary for corn production. The long term profitability of the non-GMO alternatives remains to be determined, with reason for optimism. Our 2020 trials show that non-GMO corn production can generate a viable harvest with an equal to slight reduction in yield, slight increase in the cost of herbicide, and equal to slight improvement in seed cost.

Neonicotinoid seed coatings can be more reliably removed from the operations of farmers, particularly when another crop is grown between corn years. One farmer ran a GMO vs non-GMO comparison trial that also incorporated seeds without neonic coatings in their trial and also had the highest net profitability, suggesting that neonic seed coatings did not negatively affect corn profitability. The biggest difficulty will be in the supply of uncoated seed. While neonicotinoid-coated seeds dominate the market, increasing numbers of producers are interested in purchasing non-coated seed. Numerous companies currently supply non-coated seed. Year-to-year fluctuations in field and climate conditions, market pricing, and crop rotation diversity will affect the profitability of corn production.

Shifting to non-GMO crops did not reduce the frequency of herbicide use, and glyphosate continued to be used outside of the growing window of non-GMO corn. The primary alternative herbicides used were Dual and Status; these herbicides tend to be more expensive than glyphosate. There was no increased tillage or cultivation reported for non-GMO corn relative to GMO corn. There were no reports of insect pest pressure on non-GMO corn, which does not include the Bt gene for insect resistance. Fertility was very similar for GMO and non-GMO corn on each farm.

Corn profitability was influenced primarily by seed price, and secondarily by yield. Non-GMO corn seed tends to be the same or less expensive than GMO corn seed. Corn prices were the same for GMO and non-GMO corn, as premium markets for non-GMO seed are not established in this region. The average profitability of non-GMO corn across all farms was greater than for GMO corn, though profitability differences varied by farmer.

Tier 2 - Future Crops and Markets

In this phase of work, we are introducing new crops and developing new markets to help shift the production of crops from animals to food for human consumption. We are seeking a balance of higher values for specialty crops and a volume of demand that suits broadacre production. Our trials with alternative crops include legumes, warm-season specialties, and heritage/ancient small grains, especially wheat. The crops are intended to be sold as food-grade products, yet can be sold into animal feed markets as a fallback at considerably lower rates. Diversification is central to integrated management of pests and weeds, particularly without the tools of genetically engineered traits and neonicotinoid seed coatings. We have taken a metered approach to experimenting with alternative and additional crops, focusing on rising opportunities for specialty crops that can be purchased at medium-to-high volume.

These crops also have the potential to advance soil health goals through added crop diversity for diversification of rotations, small grain crops that require less synthetic inputs compared to corn, and crops that directly build soil organic matter (i.e. small grains), suppress weeds (i.e. buckwheat), use less water (i.e. sorghum) and naturally fix nitrogen (i.e. garbanzos and dry beans). Our region currently lacks strong market access for annual legumes, thus alfalfa, which is important for the regional animal feed market, is the primary regional legume. Northern Feed and Bean offers offtake for pinto beans, however pinto beans for commodity production are often not financially competitive with other commodities in rotation. We supported the re-introduction of dry beans into local and regional value added markets in collaboration with ongoing efforts of Boulder County staff, and worked to introduce chickpeas into the farm rotation system.

Adding new crops into a farm's rotation requires development across several parts of the food system from field to consumer. The crop must grow well in this climate, soil, and geography; trialling different varieties and management techniques takes several seasons to refine and learn the adaptations to variable conditions. The crops and varieties that grow well must align with market demand; no matter how well a crop grows and how beneficial that plant may be to a crop rotation, the product must be sold (and sold at the right price and volume) to be a viable part of the farm system. In simple terms, the right supply (crop type and variety) must meet the right demand (price and volume). Buyers often want product samples to determine the utility and value for a given crop, and producers need offtake in order to justify dedicating land and effort to raise a crop. This trialling phase is necessary to develop markets but involves risk and takes commitment to a potential reward that may or may not be realized. For this reason, crop and variety trials have been selected according to highest viability for success through and after the trialling phase.

Building regional food systems is complex, and requires an ecosystem of participants. Through this project, Mad Agriculture has identified and collaborated with many regional partners to stitch together new regional supply sheds. Regional food development and alternative markets for human crops are multi-year projects that never stop evolving. 2020 has seen promising beginnings, but there is a long way to go for growing and selling staple crops at the scale, volume and pricing needed to transform land use.

Local, regional, and national scale consumer packaged goods (CPG) brands have shown interest in procuring more regenerative and organic ingredients. These brands' complex supply webs require coordination at several levels to shift their purchasing source and maintain farmer identity. Before committing to that shift, CPG brands (like most other markets) need crop quality characteristics and/or a sample of the desired crop grown by the farmer. Beginning with a portion of a single crop can reduce supply risks for the brand, while establishing a relationship with the farmer for future crops and higher volumes. In 2020, Boulder County-based CPG company, Quinn Snacks, wanted to investigate whether a local sorghum could meet the specifications for their gluten free pretzels. One participating farmer planted five acres of milo grain sorghum, but unfortunately, the crop was overtaken by weed pressure, compromising the trial, and the milo was 'turned in' as a cover crop. In the end, the farmer decided this pursuit was no longer worth the effort to develop the relationship with the market (i.e. Quinn Snacks). This is an example of a trial that generated an understanding of misalignment between the desired ingredient and the context of growing that crop at a given scale and growing environment.

Long-term success in the effort to produce regional food and enhance cropping and productive diversity will require stable markets and robust supply webs. As land owner and co-financial partner in agricultural production and revenues, Boulder County may find it to be a worthwhile investment of personnel and infrastructure to share the burden and reward of the logistics involved in higher value regional food markets for the long term. Tessa Hale from the public health division of the County and Cassandra Schnarr within the agriculture division of Parks and Open Space have already been instrumental in developing markets and coordinating logistics. Continued internal effort and, certainly, external partnerships hold the potential to make this effort a lasting and significant portion of Boulder County's agricultural production and central pillar to regional resilience and prosperity.

There is no 'silver bullet' market solution for enhancing profitability and soil health in non-GMO commodity farm markets; any future will require and benefit from diversity. 2020's Tier 2 Trials included:

- Dry Beans
- Heritage Spring Wheat
- Buckwheat
- Milo Sorghum
- Garbanzo Bean/Chickpea

Dry Beans

Five different bean varieties were grown and observed for their vigor, productivity, and market value. The trial comprised 4 acres grown on a furrow irrigated property. There were also 50 acres of pinto beans grown under pivot across from the small trial plots. The varieties were small Cayenne Red, Etna Cranberry, Jet Black, Pinto, and Navy

In addition to these small-scale trials, a 50 acre pinto bean trial was conducted in parallel to the GMO Transition project. Having two production systems at different scales and irrigation systems provided useful learning across production, harvest, processing, and marketing phases. While small scale trials reduce risk, there are major efficiencies of scale to be had within the field as well as at bean cleaning, processing, and sale. Harvesting larger plots aligns with existing combine harvesting equipment and harvesting fewer varieties at once enables a more consistent product to be cleaned and sorted. Institutional and other mid-to-large volume purchasers are only able to participate if a sufficient volume is available. Sophisticated bean cleaning and bagging becomes viable only at a certain scale (as low as 25,000 pounds, but preferably 50,000 pounds or more of a single crop variety). Some key purchasers require production and processing certification (like GAP) that is cost-prohibitive at smaller scales.

All bean varieties grew moderately very well in this trial. The highest yielding varieties were Jet Black and Small Cayenne Red. Expected yields would be higher under pivot irrigation.The upright Pinto bean and the Black bean were the best beans at harvest (least loss). Cranberry beans grew reasonably well and were the most attractive aesthetically, but were most susceptible to pre-harvest and in-harvest loss, which can be attributed to an earlier maturity than other varieties. The farmer didn't have harvesting equipment easily available, so some beans 'underperformed' because of yield loss due to over-maturity.

Markets show the highest demand for Pinto and Black beans, because of their familiarity and multiple uses across food types and volumes. There exists a market interest for 'mixed beans' which involves several varieties. This attractive combination may be best created by combining appropriate proportions of varieties also grown for individual sale, rather than combining pre-processing. All markets prefer or demand non-dessicated beans: beans that are not preemptively sprayed with herbicide to maximize uniform stand maturity for harvest.

In summary, Black beans and Pinto beans, grown in fields of at least 10 acres, offer the best short and long term viability. Investment in specialty bean harvesting equipment will offer a more efficient yield capture. Beans for human consumption should not be desiccated pre-harvest for both health concerns and economic opportunity. Identifying a processing facility that can clean and bag beans while preserving identity is vital.

All 98,000 pounds of beans have been sold in a competitive landscape for procurement, with more demand than supply. The cleaned and bagged beans were sold at $0.80 -$1.00/pound.

Heritage Spring Wheat

Across the world, we are witnessing a revival in ancient, heritage and whole grains. There is a growing frustration with industrial grain products and the production systems from which they originate. Consumers are drawn to this market because heritage and modern whole grains are flavorful, nutritious[8], and easier to digest[9]. In the Front Range of Colorado, we are beginning to see a shift in what grain markets value, particularly in the health of the human digestive system and the health of the soil. The agricultural community and the public continue to gain understanding of the role of soil in healthy ecosystems[10], in healthy foods[11], and in healthy lifestyles; as consumers, this drives value towards production systems that improve soil health and towards crop varieties that focus on nutrition and flavor over quantity or shelf life. Mad Agriculture is playing a role in figuring out what varieties grow well in the Front Range of Colorado, how they can be grown regeneratively, and what the best uses for different grains are. We are working closely with many partners in the region to explore the fit between grain and product, farmer and market, seed and regeneration of soil and ecosystems.

Wheat varieties are categorized based on their physical characteristics. Wheat (Triticum *aestivum*) has been divided into several general classes based on kernel texture (soft, hard), and kernel color (white, red), and seasonal habit (fall/winter, spring). Hard red spring wheats are highest in protein with medium-strong gluten, the protein that provides elasticity to dough, so are used for yeast breads and hard rolls. Hard red winter wheats have the strongest gluten and are used primarily for pan breads and buns. Soft red winter wheats have medium protein and weak gluten for flat breads, pastries, and crackers; and low protein, weak gluten soft winter and spring wheats are used for pastries, noodles, and batters. High protein and strong gluten durums are preferred for pasta, macaroni, and spaghetti.

In 2020 we worked with a participating farmer to grow three varieties that are well-suited for baking artisan bread, including Khorasan, Red Fife and Rouge de Bordeaux.

Trial Setup, Performance and Product Quality

Three heritage wheat varieties were tested, along with a control non-heritage variety. Each heritage variety was grown in 1.25 ac strips. The plots were surrounded by Jefferson, a modern hybrid variety. All of the varieties performed successfully.

---

8 Brand Khorasan Wheat (2021). *Research*. 14 Jul 2021. https://www.kamut.com/en/health/research.

9 Martineau, C. (2016). *Gluten Free? These Heritage Grain Will Lure You Back*. Vogue Magazine. https://www.vogue.com/article/gluten-free-heritage-grains-change-your-mind.

10 Chester, J. (2018). The Biggest Little Farm. http://www.biggestlittlefarmmovie.com.

11 Bush, Z. (2021). 12 Jul 2021. https://zachbushmd.com.

We also conducted tests to determine the functional qualities of these heritage wheat, in order to help determine product value and to provide information to potential buyers. Ardent Mills was gracious enough to provide nutrient and grain characteristic testing to help this local cause.

The basic details and results of the trial are listed below.

Rouge de Bordeaux	Khorasan	Red Fife	Jefferson
2.5 Acres (2 Strips) Rate: 115#/ac Planted: 4/27/2020 Yield: 8470 lbs. Protein: 13.41% Moisture: 9.6%	.625 Acres (½ Strip) Rate: 115#/ac Planted: 4/27/2020 Yield: 1650 lbs. Protein: 13.49% Moisture: 9.5%	2.5 Acres (2 Strips) Rate: 115#/ac Planted: 4/27/2020 Yield: 8890 lbs. Protein: 12.74% Moisture: 10.2%	3.3 Acres (Border) Rate: 115#/ac Planted: 4/27/2020 Yield: Not Measured Protein: 13.36% Moisture: 13.2%

Blake Cooper, former Manager of the Agricultural Division of Boulder County Parks and Open Space, evaluated all of the fields for disease and pest pressure. In all plots, disease pressure was largely absent and didn't affect yield or harvest. The harvest of the grains was supported collaboratively by the farmer, Boulder County Open Space staff, AgFinity and Mad Agriculture.

Markets & Barriers

All three varieties of the wheat were sold at $0.35/pound for uncleaned grain into the local milling market. Heritage wheat value can vary from $0.20 - $1.00 per pound for cleaned grain. Non-GMO modern wheat typically sells for ~$0.05-$0.10 per pound, uncleaned.

Our main buyers locally are Moxie Bread Company (Louisville, CO), Dry Storage mill (Boulder, CO) and Hearth Bakery (Denver, CO). These mills are not certified organic, but prefer organic grains. Regional and larger scale markets have been slow to commit to purchasing heritage grains. We are in active conversation with Ardent Mills and Bay State Milling, however they have been far more cautious in making purchasing commitments and contracts. This may change in the future as we gain success, however we cannot currently rely on larger scale offtake above 10+ acres. Ten acres is also the minimum scale to access effective processing, thus creating a narrow optimal scale.

In our work to market these grains, we learned that there is greater and growing demand for heritage grains that are produced organically. Marketing and sale of the heritage wheat was limited by the use of herbicide and synthetic fertilizer in production methods. Fertilizer was used at planting and herbicide was used early in the season, however, lab tests showed no residual herbicide on the wheat berries themselves. The clean test results enabled sale of the crop, giving the buyer confidence that no residual pesticides were on the grain. However, this sort of transaction depends on relationships as there is no 'chemical-free' certification available.

We also learned that there is a lack of regional infrastructure to clean grain grown between 3 to 10 acres. A grain crop below 3 acres can be cleaned manually using small-scale machines like a Farmstead 150HD seed cleaner. Crops above 10 acres can reach minimum requirements for industrial cleaning at Twin Peaks Seed and Grain in Longmont, CO. Crops grown between these scales are too large to cost-effectively clean manually and too small for industrial cleaning. Going forward, this gap will need to be addressed with infrastructure acquisition, or avoided by matching the production scale to meet the available processing options.

There is similarly a lack of on-farm storage to create a major impact on diversifying current rotations on broadacre farms. Storage in grain bins can allow farmers to more effectively navigate the tendency of regional markets to prefer purchasing smaller quantities multiple times per year, rather than the entire crop all at once. Storage before processing can allow farmers to harvest a crop from the field at the right time and maintain flexibility on the timing of cleaning the crop, industrially or manually.

Garbanzo Beans (Chickpea)

Garbanzo beans comprise an increasing share of the domestic diet[12], with versatility from whole raw beans to processed foods like hummus or as a roasted and seasoned snack. The pulse crop is often grown in more northern climates but has potential in this region. Colorado is a region that can grow both cool season (i.e. lentils, garbanzos) and warm season (i.e. dry beans) pulses. There is enough market demand and growth potential from local and regional institutions to processing facilities and distribution hubs.

The garbanzo beans were planted on dryland and a dry early summer resulted in partial germination, and we were not able to complete a marketable harvest. This dryland field was in production in 2019, so there was not a water-recharge fallow season that often occurs in the dryland setting. The garbanzo beans were planted in early May, which is toward the end of the optimal planting window and may have contributed to the low germination rate. While this single year experience did not perform well, there are many reasons to try again in a small acreage. Replacing the fallow season with a complementary pulse crop between wheat or small grain production is one of the attractive qualities of garbanzo beans in Boulder County.

In future trials, this crop is best suited to an irrigated setting to increase the likelihood of successful production and improve yields. Growing a harvestable crop to sell and provide

[12] *Whole Foods Predicts 2021 Food Trends: Chickpeas, Upcycled Foods, and Vegetable Jerky*. 24 Jul 2021. Whole Foods Market. https://vegconomist.com/market-and-trends/whole-foods-predicts-2021-food-trends-chickpeas-upcycled-foods-and-vegetable-jerky/.

samples for continued market development is critical to begin the process of establishing viable garbanzo bean production on Boulder County land.

Milo (Grain) Sorghum & Buckwheat

Milo sorghum and buckwheat are gluten free grains with growing markets in the region and worldwide. Each crop also involves productive characteristics that can support the farm system; buckwheat rapidly builds organic matter while suppressing weeds and milo can replace corn in a rotation while using less water. In 2020, 2 acres each of milo and buckwheat were grown side by side in a field under pivot irrigation. This field is subject to overwatering due to its location, and has historically received a lower degree of weed management than other fields in the area. Unfamiliarity with the crops created challenges in field management, the crops became overrun with weeds, were not managed in a timely manner, and were ultimately terminated mechanically without harvest. The weed pressure was primarily pigweed, which has similar sized seed to milo and buckwheat, eliminating the possibility of viably cleaning the harvested seed off the field.

The buckwheat withstood weed pressure greater than milo, which was to be expected, as buckwheat is often used as a weed suppressing cover crop. Both crops were able to reach reproductive stages before being terminated, showing their ability to grow seed. The yields were low and not worth harvesting amongst weed pressure. A few ounces of buckwheat were hand harvested from the field for testing. Due to a lack of infrastructure to process buckwheat and relatively less demand for the crop, these tests have yet to be performed. There remains little market interest from local mills for either of these crops, and an interested producer has yet to be identified as reliable demand volume remains low (less than 25,000 pounds).

Forage Sorghum - An Alternative Feedstock for Cows

Forage Sorghum provides a regionally-viable annual forage crop option with similar rotational and market/utility characteristics to corn. Forage sorghum is non-GMO and could provide an alternative crop to corn. Forages in the sorghum sudangrass family tend to require less water and fewer inputs than corn, but also provide less relative weight gain potential. Therefore, sorghum tends to involve lower costs and lower revenues than corn; relative profitability remains an important factor to observe over years of trials. Corn is familiar to the farmers, whereas sorghum-sudangrass crops are less commonly grown, so there is less experience with its cultivation. Sorghum-sudangrass is a common alternative to silage corn across the nation, particularly in semi-arid regions to Colorado's south (Oklahoma and Texas). Regionally adapted seeds and local expertise are less commonly available than corn.The primary barriers to sorghum, sudangrass, and sorghum-sudangrass forage are different field management techniques and nutritional profiles than corn.

- Sorghum pricing is based on corn in most markets and earns less than corn per ton.
- Sorghum is sensitive to glyphosate so other, more expensive herbicides need to be used on warm season grasses and weeds during the growing season.
- There is a lot of genetic variety in the sorghum-sudangrass family, so selecting the right variety is important.
- Management of sorghum is different: familiarity with planting practices, weed management, and timing two cuts for optimal feed quality at harvesting are still being practiced by farmers that are new to growing sorghum-sudangrass.

There were 2 sorghum trials in 2020 and both involved struggles. One trial did not germinate well and had to be re-planted while the other was planted late, received no fertilizer and the first cutting was missed. We will be repeating sorghum trials in 2021 and optimizing field management and harvesting.

Tier 2 Conclusions

Alternative markets have signs of early success and positive momentum across the region. There is relatively strong regional demand for legumes and grains from local mills, institutions and food hubs. Priority should continue to be made for crops that can be sold at higher prices than commodity crops and have the potential to scale at the regional, and possibly domestic, levels.

Rebuilding regional supply chains and establishing supply relationships with institutional, retail, and distribution partners will require continued effort, outreach, and time. Existing cleaning and processing infrastructure in the region best serves small (<1-3 acre field size) or large (10+ acre field size) production systems. Infrastructure for mid-scale production (3-10 acres field size) is needed, or for this production scale to be avoided.

In addition to improving regional infrastructure and increasing domestic markets, the diversification of marketable crops is the most important lever to continue growing alternative markets. Market potential for the following cereal grains and legume crops include:

Cereal Grains	Legumes
Barley	Black eyed peas
Buckwheat	Dry beans
Heritage corn	Garbanzo beans
Milo (grain sorghum)	Lentils
Rye	Yellow Peas (animal feed)
Spelt	
Wheat	

Early successes with market alternatives were encouraging, however farmers would rather develop such opportunities outside the purview of the GMO and neonic ban.

Tier 3 - Advancing Soil Health with Regenerative Practices

This project provides an opportunity to explore how regenerative practices, cropping and livestock systems can restore and sustain soil health. Practices of regenerative agriculture can help reduce long-term input costs and restore the soil resource base of Boulder County Open Space. Our work focuses on integrating new practices that fit the five guiding principles of regenerative agriculture are:

1) Minimize Disturbance
2) Leave No Bare Soil
3) Maximize Diversity
4) Keep a Living Root in the Soil for as Long as Possible
5) Livestock Integration

Many of the Boulder County Open Space tenants are using practices such as conservation tillage, crop rotations, livestock integration, minimizing chemical use and actively managing residue. There is, however, much to be learned and enhanced. Wind erosion and limited water infiltration are indicators that soil health can be improved. This project provides an opportunity to test crops and additional regenerative practices, including companion cropping, cover crops, compost and manure applications, and more. Participating farmers are not required to test these practices within this project. The following discussion has been shared with participating farmers and is intended to provide context for present and future integration of these practices.

Integrating new regenerative practices can have associated challenges and the economic incentive is not always immediately apparent. For farmers operating on thin financial margins, making an investment into practices that might not yield a positive return on investment is a hard argument to make. Also, integrating cover crops can pose a risk to the main crop, and therefore influence the net profitably. For example, interseeding cover crops beneath growing corn can introduce more plants that compete for water and nutrients, thereby reducing the resource availability to maximize corn production. Corn is a mainstay crop with secure offtake and pricing mechanisms in place for the animal feed market, and corn revenues represent a major revenue stream for many of the Boulder County row-crop farmers. Potential reductions in yield could affect a farmer's capacity to provide enough forage for raising animals at the customary number of animals, expected weight gains, and seasonal feeding routines. Moreover, the environmental or soil fertility benefits of cover crops are often difficult to quantify within the annual crop-enterprise perspective, which is a key barrier to adoption. It is more appealing to plant a cover crop whose growth meets financial and management goals simultaneously.

It is often easy for a non-farmer to think that using new tools and technology, like a roller crimper, is an easy way to make advancements. However, there may be hurdles to consider when applying any new practice, especially in this region. Most years, establishing a rye cover to be crimped can be challenging because late season irrigation water is often unavailable, and fall precipitation can be variable, which is critical for establishing the crop. The adoption of a roller crimper in an operation, then, takes trialling to be incorporated as an effective weed management strategy. All of this is to say, regenerative practices that improve soil health and work agronomically take time and practice to develop with a farmer.

In 2020, we focused on integrating cover crops into various cropping systems. Compost and manure are often expensive because the Boulder county community doesn't have a local compost provider. We are tracking progress on a separate compost project with another Boulder County producer, in partnership with Colorado State University, examining the agronomics and carbon-sequestration potential of compost application in a row-cropping scenario.

Water is the limiting factor for establishing cover crops in Boulder County. The lack of late-season water limits the establishment and growing window (between harvest and first frost or between last frost and cash crop planting), and reduces motivation to justify the investment. Soil water is more abundant in spring after winter recharge, but there is not always enough left for cash crops. Irrigation water in spring into summer can supplement soil water. Irrigation water is typically unavailable in the fall, but late summer and fall monsoons are possible. The cover crop needs the right soil temperature and moisture to germinate, and enough water and sunlight exposure to grow.

This year, we spent a lot of time learning the various farm operating and rotational patterns for all of the farmers. Cover crops are chosen to fit the environmental conditions and one or more of these common goals: weed suppression, insect suppression, nitrogen fixation/fertility, water infiltration, deep nutrient scavenging, living root, erosion control, animal forage, or saleability as crop or seed. After an assessment of their operations, we focused on five trials with six of the nine participating farmers.

1) Pea-Oat Cover Crop
2) Rye-into-Alfalfa Overseeding
3) Cover Crop Interseeding into Corn
4) Fall Cover Crop with Rye
5) Integrating Livestock with Cover Crops

With those conditions for cover cropping in mind, 2020 Trials focused on forage-oriented plants in a few different scenarios: cool-season dryland setting (pea-oat, 2 locations), perennial overseeding (rye into sparse alfalfa stand, 1 location), and annual overseeding (rye-radish-clover into v5 corn, 3 locations).

Trial Results

Pea-Oat Cover Crop

The pea-oat mixes were planted in mid-March to utilize winter soil water and spring precipitation with soil health goals of nitrogen fixation (i.e. pea) soil aggregation and carbon sequestration (i.e. oat) and productive goals of forage bales for cows (because properties were both unfenced eliminating grazing option). In both trials, the oats germinated and grew well; peas were less successful in germination, often due to inadequate seed-soil contact and planting depth. One farmer noted high variability in seed size contributing to poor consistency in planting depths. Both trials were terminated prematurely, one by accidental herbicide spray from a contracted service, the other as collateral damage to address rising kochia weed pressure on the field. Pea-oat is a common cover crop mix because it provides fertility, diversity, and forage, but would be better suited for fields where adequate fencing and water infrastructure enable grazing to occur. Early planting seemed to benefit this crop. This trial provided enough intrigue to try again, on the right field.

Overseeding Rye-into-Alfalfa

Ryegrass is complementary and adds diversity to a sparse or struggling alfalfa stand. Alfalfa provides nitrogen for the rye; rye fills in the bare areas to suppress weed growth and increase per-acre forage production. This technique is particularly relevant when alfalfa is fed to the producer's own livestock as alfalfa markets often prefer a purer alfalfa bale. Other producers in the area have had success with this approach, which encouraged this trial. The rye was seen to establish adequately in the field and provide additional forage, but the ultimate benefit was overshadowed by an invasion of cheatgrass. Managing cheatgrass involved a grass-targeting herbicide, collaterally terminating the rye. This trial was successful enough to try again in the right context.

Interseeding Cover Crop into Corn

Interseeding cover crops into a standing corn crop is intended to address the 'no-late-water' barrier to cover crop implementation. The practice involves broadcasting seeds between corn rows when the corn is between the V3-V7 stages, allowing the seeds to germinate before the corn canopy closes. The low stature cover crops' growth decreases significantly without direct light as the corn canopy increases, reducing competition with the crop. After the corn is harvested and the canopy reopens, the short-but-established cover crops get a head-start on fall growth for a robust stand.

Each location had a different experience with this trial, a testament to the value of diversity and a signal that further trials are necessary to understand and refine this practice. In two fields, clover emerged while the rye and radish showed no signs of emergence. In the third field, minimal clover and no rye were seen but the radish was abundant. In two fields, the corn was harvested for silage, then the corn stalks were incorporated into the soil, destroying the cover crop The post-harvest growth period was thus unable to be observed. The third field, with radish, was raised for grain allowing sunlight to reach the small radish plants as corn leaves dried down toward harvest.

The intended benefits of these cover crops are to:

- Maintain a living root through a greater duration of the year to promote beneficial soil biology and increase soil organic matter (SOM).
- Provide soil cover to reduce wind erosion, moderate temperatures and reduce soil evaporation.
- Clovers can fix nitrogen for the next crop and provide forage.
- Radish improves soil structure, scavenges nutrients and can provide forage for livestock.
- Rye reduces incoming weed pressure and can provide forage for livestock.

On one farm, cows grazed the corn stalks after grain harvest and had access to the area of radishes as an additional forage. All forage cover crops are best suited for fields where animal integration and grazing occur. Cutting and hauling bales from a forage cover crop is costly and eliminates the benefit of animal impact on the crop field. A field with fencing, pivot irrigation, and animal water infrastructure presents the optimal setting for successful forage cover cropping.

Fall Cover Crop with Rye

One strategy to integrate cover crops is to plant a winter grain in the fall, which will survive the winter, grow vigorously in the spring, and can be terminated mechanically or chemically before spring or summer planting. This is the most common form of cover cropping within row-cropping systems. We chose to work with annual ryegrass, which can germinate at low temperatures and is highly drought tolerant.

We planted several acres of rye with one producer, following edible dry bean trials. We planted the rye by broadcasting the rye into freshly worked soil directly before a snowstorm. The rye germinated in the days following a 3 inch snowfall. The rye is now dormant during the winter. We will use a roller crimper in the spring to terminate the rye before planting corn through the residue if there is enough biomass to warrant the practice.

Tier 3 Conclusions

In the regenerative practice trials, we learned the importance of developing systems that regenerate soil health. The adoption and use of cover crops, new crops and practices work most effectively as a system. The combination of work presented here - alternatives to GMO crops, new crops and soil health practices - can advance the good work that Boulder County farmers have already done in creating regenerative farm systems. However, we learned that farmers would rather continue to develop soil health and regenerative systems outside the purview of this project. Therefore, this tier of work will not be repeated in 2021.

Appendix

Table 1. Aggregated University Corn Enterprise Budgets

Cost	CSU 2018 - Grain Corn Pivot Irrig- NE Colo.[3]	CSU 2018 - Silage Furrow Irrig- NE Colo.[4]	Neb 2020 Pivot Irrigation 235 bul target -grain corn[5]	Neb 2021 Pivot Irrigated 235 bu target - grain corn[6]	Average
Field Preparation		$74.00	$21.99	$21.92	$39.30
Seed	$121.02	$109.83	$114.10	$114.10	$114.76
Planting		$15.00	$14.58	$20.71	$16.76
Fertility	$110.15	$148.86	$98.70	$85.50	$110.80
Herbicide	$25.19	$27.22	$52.91	$45.15	$37.62
Insecticide + Fungicide	$20.02	$37.18	$10.00	$9.99	$19.30
Irrigation	$205.55	$65.00	$127.16	$105.80	$125.88
In-Season Cultivation			$11.06	$11.43	$11.25
Consultant/ Scouting	$12.00		$12.00	$12.00	$12.00
Crop Insurance	$44.94		$9.00	$9.00	$20.98
Fuel	$12.82				$12.82
Equipment Maintenance	$8.03				$8.03
Harvest	$11.37	$16.00	$49.06	$50.72	$31.79
Hauling	$40.20	$50.00	$25.85	$25.85	$35.48
Capital Interest	$17.49	$17.89	$13.31	$12.17	$15.22
General Overhead	$10.10	$25.00	$20.00	$25.00	$20.03
Machine Ownership	$54.37	$10.00			$32.19
Property Taxes	$15.57	$19.30	$80.60	$76.56	$48.01
Rent/ Land Payment	$184.00	$160.00	$179.10	$183.75	$176.71
Total Cost	$892.82	$775.28	$839.42	$809.65	$888.91