Climate Change Resiliency in Colorado: Cropping Systems BMPs

Introduction

Authors:
Casey Shawver and Jim Ippolito: Department of Soil and Crop Sciences,
Reagan Waskom and Brad Udall: Colorado Water Institute and Water Center CSU,
Nolan Doesken: Colorado Climate Center (retired)

Concentrations of carbon dioxide in the atmosphere are projected to continue rising. In addition, crop related NO2 emissions in the Northern Plains region is the largest contributor to greenhouse gases. Elevated levels of greenhouse gases like CO2 and NO2 can lead to environmental impacts such as increased temperatures and varied patterns of precipitation. These environmental changes can causes changes in growing seasonality, pest and weed pressure, and sporadic precipitation. Preparing for uncertain and complex climatic conditions will require adaptations in land management that create resiliency. Diversification (agronomically and economically), fertilizer and irrigation best management practices, reducing/eliminating tillage, conserving soil with practices that reduce erosion, and any other methods that increases soil organic matter can increase overall resiliency. The culmination of these strategies can be boiled down to any practice that minimizes off-farm flow. This could be minimizing soil water evaporation, improving nitrogen application methods, or increasing carbon/organic matter through reducing tillage. This document outlines the above best management practices in detail that have been supported by research to potentially improve cropping systems in Colorado. Furthermore, this document is a continuous work in progress, with modifications made when required.

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Sustain Soil and Water Functions

Tillage Practices

- Convert management to no-till.
  - No-till avoids breaking up soil porosity which improves water infiltration. Improved infiltration rates are directly correlated to soil water storage.
    - Research in Colorado has shown that precipitation storage efficiency of 40-60-% are achieved when tillage is eliminated (Swanson et al., 2016).

  - Undisturbed surface residue from the lack of tillage is one of the most essential methods for reducing evapotranspiration and retaining soil moisture (Chambers et al., 2016; Delgado et al., 2011a).
    - Soils under no-till have increased water storage capacity compared to conventional stubble mulch systems.
      - These moisture savings are capitalized on when more intensive cropping systems are adopted (Croissant et al., 2014).
    - Surface residues capture snow to improve soil moisture retention.
      - Winter winds can remove snow from crop fields without residue, reducing opportunity to capture spring moisture.

  - Conversion to no-till can be economically and environmentally beneficial.
    - Eliminating tillage during fallow can increase winter wheat yield by 14% (Anderson, 2005).
    - A study by the USDA-ARS showed that converting from conventional, corn-corn production to a no-till corn-bean (in an irrigated cropping system) can increase annual average net returns by $288/ha-1 (Archer and Halvorson, 2010).
    - Water savings in no-till systems can be converted to profit if coupled with an intensified type cropping system (Croissant et al., 2014).
    - Converting to from conventional to no-till has the potential to save substantially in fuel savings. A 1,000 acre farming operation could save ~ $8,500 in diesel fuel (price dependent) (Elizabeth Creech, 2017).
    - Another study suggested that economic viability and environmental conservation (regarding N_2O and CO_2 emissions) can be achieved by minimizing tillage while using appropriate levels of fertilizer (Mosier et al., 2006).

  - No-till can improve water quality by reducing erosion, sediment loads, and runoff of fertilizers.
    - A study by Brooks et al. (2010) reported that converting from conventional tillage to minimum or no-tillage in wheat-fallow systems reduced sediment loads (Brooks et al., 2010).
    - Crop residues accumulated through no-till practices are the most effective practice for controlling wind erosion (Croissant et al., 2014; Delgado et al., 2011a).
      - Fine-strawed upright stubble is more effective that stalks lying flat on the soil surface.

    - Surface crop residues improve soil organic matter content which is directly correlated to soil quality and crop productivity (Delgado et al., 2011b).

    - The adoption of long-term no-till is the most significant mitigation potential of greenhouse gasses in cropping systems (Jarnes et al., 2009; Lal et al., 2011).
        - Reducing disturbance and increasing organic matter inputs can lead to a net removal of carbon from the atmosphere (Delgado et al., 2011a; Paustian et al., 2016).
        - According to the NRCS, no-till can sequester 0.15-0.27 Mg C ha-1y-1 (Chambers et al., 2016).

- Incorporate reduced tillage during summer fallow phase instead of herbicides preceding wheat planting.
    - Sweeps and rod weeders cause less moisture loss compared to one-way disks and chisels. However, there is still a moisture loss which can be found in a table in the 'Dryland Cropping Systems' factsheet link below.
    - At least 50% of residue needs to remain to reduce evaporation losses significantly. The general rule of 30% residual will only aid in erosion control (Bochicchio et al., 2015).
    - Strip-tillage can be more profitable than conventional tillage in corn and sugar beet cropping systems (Boulder County POS, 2015).

- Discontinue tillage on poor or marginal land and convert to perennial forage or native species (Bochicchio et al., 2015).
    - The second most significant opportunity for reducing GHG after converting to no-tillage is for farmers to retire low productivity, marginal soils from production (Bauder et al., 2003).
    - Perennial plants provide the opportunity for more significant carbon sequestration and erosion control.
        - Unmanaged grasslands typically allocate large fractions of C belowground supporting higher soil C stocks (Paustian et al., 2016).
        - A study by Brooks et al. (2010) showed that perennial grasses can aid in decreasing sediment loads (Brooks et al., 2010).

Links to Factsheets/Guides/Websites:
Dryland Cropping Systems (CSU Factsheet): https://extension.colostate.edu/docs/pubs/crops/00516.pdf
Best Mgmt Practices for CO Corn (CSU Guide): http://www.wyoextension.org/werawater/region8/PDFs/corn/tillage.pdf
Controlling Wind Erosion (CSU Factsheet): https://extension.colostate.edu/docs/pubs/crops/00518.pdf
CO Climate Plan (CDA, etc): https://www.climatehubs.oce.usda.gov/sites/default/files/COClimatePlan2015.pdf Conservation Tillage in a Winter Wheat-Fallow System (Pacific NW Case Study Series): http://cru.cahe.wsu.edu/CEPublications/PNW706/PNW706.pdf
Climate Change and Agriculture in the United States: Effects and Adaptation (USDA-ARS): https://www.esf.edu/glrc/library/documents/ClimateChangeandAgricultureReport_USDA_2013.pdf
Economics of No-Till Farming (USDA Article): https://www.usda.gov/media/blog/2017/11/30/saving-money-time-and-soil-economics-no-till-farming

Diversified Crop Rotations

- Diversify crop rotations to create resilience and reduce environmental and economic risk associated with extreme climate.
  - Improving spatial diversity and flexibility of a system can produce a resilience effect in the face of disturbance (Janowiak et al., 2016; Selvaraju, 2011).
  - Extended/diversified crop rotations can prevent or reduce many pest problems, especially by breaking life cycles of weeds and insects.
    - Rotations that include three or more crops usually have fewer problems with pests. This can ultimately lower inputs (Islam and Ashilenje, 2018).
  - According to a study by Peterson et al. (1993), winter wheat-corn-proso millet-fallow yields 25% more net return than a simple winter wheat-fallow rotation.
  - Incorporating legume species into a rotation can provide N credits reducing fertilizer input costs.
  - Strategic diversification provides multiple revenue sources which contribute to greater economic stability during commodity price swings (Bathke et al., n.d.; Roesch-Mcnally et al., 2017; SARE, 2004).
  - Rotations with various functional species (legumes with cereals, winter with summer crops, row crops with drilled crops, and annuals with perennials) can explore multiple soil strata, and use of nutrients, water, and light at different times of the year.
  - Incorporating perennial grain crops (i.e., Kernza) is a frontier idea that could lead to greater carbon sequestration, erosion control, and other soil and production benefits (Paustian et al., 2017).
    - https://landinstitute.org/our-work/perennial-crops/kernza/
  - Mix cover crops and annual crops to provide soil cover year-round and improve soil structure and organic matter.
  - Incorporate varied hybrid maturities to spread risk across the landscape.

- Intensify cropping in dryland systems to improve system productivity, soil quality and water-use efficiency.
  - In one study, cropping system intensity was positively correlated with SOC, organic matter, soil aggregation, and microbial biomass (Anderson, 2005; Rosenzweig et al., 2018).
    - Continuous rotations had 12-17% greater SOC concentrations than wheat-fallow.
    - Aggregate stability was approximately twice the amount in continuous cropping (intensified) compared to wheat-fallow.
    - Fungal biomass was 3x greater in intensified cropping system compared to wheat-fallow likely allowing for plants to utilize nutrients more effectively.
    - An 8-year study in Akron, CO increased organic matter by 20% in the top 5 cm of soil with continuous cropping systems compared with wheat-fallow (Bowman et al., 1999).
    - Reduced summer fallow was projected to have greater productivity and soil C sequestration under future estimated climate conditions (Robertson et al., 2018).
  - Intensifying cropping systems increases water efficiency and can improve yields.
  - Less than half of the precipitation received during the two years of winter-wheat/fallow is utilized by the winter wheat (Anderson, 2005).
  - Continuously cropped systems nearly doubled yield compared to wheat-fallow systems (Anderson et al., 1999).
  - One study showed that a winter wheat-fallow rotation tillage yielded 890 kg/ha while a winter wheat-corn-proso millet fallow yielded 2030 kg/ha, an increase of 128% (Anderson, 2005).

- Integrate livestock grazing into rotations to utilize forage cover crops or residues.
  - The use of crop/livestock integration is an important driver of on-farm diversity (NRCS, 2008).
    - These systems have often been isolated from each other but can provide multiple benefits when combined.
  - Cropping systems that include livestock invite the opportunity to incorporate perennial polycultures of forages, cereals, and legumes.
    - This integration has been shown to mitigate adverse effects of climate variability and increase profitability in dryland systems in the Great Plains (Nielsen et al., 2016).
  - Livestock in a no-till system can utilize corn stalks/residue in the fall/winter.
    - A Nebraska study observed an increase in bu/acre of corn with fields that were grazed.
  - Cattle can be grazed on cover crops resulting in dual use of the cover crop as well as income from livestock revenue.
    - If livestock is not part of the enterprise, lease agreements with nearby producers can be a beneficial way to utilize cover crop biomass in addition to receiving nutrient credits from cattle manure and extra income.

- Restore diversity in non-production areas near fields (Janowiak et al., 2016; Roesch-Mcnally et al., 2017).
  - Non-production areas can act as habitat for beneficial insects, reduce pest pressure, and act as a physical barrier for wind and water erosion.
  - Having perennial vegetation in these areas also provides soil carbon sequestration opportunities and other soil health benefits (Sherrod et al., 2018; Paustian et al., 2017).

- Integrate higher value cash crops into the farm enterprise to diversify crops and revenue sources (Janowiak et al., 2016).
  - Examples include: Vegetables, forest products, fruit, medicinal plants, wildflower seed, etc.

- Incorporate short-rotation woody crops onto less productive farmland for bioenergy production or other purposes (Eagle et al., 2012).
  - Poplar, willow, mesquite, alder, Chinese tallow, and other fast-growth woody perennials have a wide range of adaptability.
  - While growing, these perennial species can be planted in strategic locations to serve as windbreaks if and where appropriate.

- Employ a resource-conserving crop rotation promoted by the NRCS (Roesch-Mcnally et al., 2017; SARE, 2004).
  - This type of rotation includes one resource-conserving crop that increases soil organic matter, improves soil fertility and tilth, interrupts pest cycles, and reduces depletion of soil moisture/ reduces irrigation need in applicable areas (See NRCS Conservation Cropping factsheet below).

Links to Factsheets/Guides/Websites:
Understanding/Assessing Climate Change for NE (UNL Report): https://www.climatehubs.oce.usda.gov/sites/default/files/Nebraska%20ClimateChange%202014.pdf
Grazing Corn Stalks in No-till (UNL Cropwatch): https://cropwatch.unl.edu/grazing-corn-stalks-no-till-fields-unl-cropwatch-sept-20-2012
Conservation Cropping Rotation (USDA-NRCS Factsheet): https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_026682.pdf
Resilient Dryland Farming in the Semi-Arid High Plains (CSU): https://www.thelexicon.org/resilient/
Climate Change and Agriculture in the United States: Effects and Adaptation (USDA-ARS): https://www.esf.edu/glrc/library/documents/ClimateChangeandAgricultureReport_USDA_2013.pdf

Cover Crops

- Incorporate cover crops into a rotation to improve overall soil quality.
  - Decomposing cover crops improve soil quality factors and contribute to stable soil organic matter (Jarnes et al., 2009). Greater soil organic matter has a host of benefits for a production system:
    - Improved physical structure (water infiltration, porosity, aeration)
    - Multiple studies have shown the increases in SOM increases water holding capacity.
      - Every 1% SOM added can retain 20,000-25,000 more gallons of soil water per acre (one acre-inch) (Golden et al., 2016; Tellatin and Myers, 2017, 2018; USDA-NRCS, 2017, 2013).
    - Growing and decaying roots stimulate soil biology which increases microbial activity resulting in greater nutrient availability.
    - Increased carbon sequestration
      - According to the NRCS, cover crops can sequester 0.15-0.22 Mg C ha-1y-1 (Chambers et al., 2016).

- Utilize cover crops to protect soil and water quality during extreme rain events (SARE, 2004).
  - Living roots aid in soil aggregation and vegetation provides cover that reduces soil losses.
  - Cover crops can create root channels and surface porosity to aid in water infiltration during intense rainfall events.
  - In dryland systems, wheat or rye can be fall planted after harvest of low residue crops.

- Use low relative water use cover crops in situations with limited water availability.
  - Examples include: Barley, Phacelia, Field pea, Lentil, Lupin, Berseem clover, medic, chickpea, flax, amaranth, pearl millet, and foxtail millet (Emerson, 1995; Mengel, 2012)

- In sugarbeet production, utilize living mulch cover crops to improve overall production.
  - A 4-year study at the Western Colorado Research Center found that living mulch (barley) terminated at V2 stage had a positive impact on root quality by increasing sucrose concentration and decreasing root impurities. Yield was not impacted by the living mulch (Golden et al., 2016).
    - Yield could potentially be impacted if the mulch is not terminated early enough.
  - The living mulch provides a host of soil benefits as well as protecting sugarbeet seedlings from wind damage.

- Utilize cover crops to reduce inputs.
  - Cover crops can reduce costs of herbicides by outcompeting weeds at various times of the season.
  - Diversified systems often result in lower pest pressure due to varied plant species interrupting insect cycles.

- Plant cover crops with reduced seeding rates on land that is being fallowed due to drought.
    - Oats, wheat, triticale, and some millets at reduced seeding rates offer erosion control (Keshavarz Afshar et al., 2018).

- Utilize winter cover crops to capture snow to improve soil moisture retention.
    - Winter winds can remove snow from crop fields without residue, reducing opportunity to capture spring moisture.

Links to Factsheets/Guides/Websites:
Wind Erosion Factsheet (CSU): https://extension.colostate.edu/docs/pubs/crops/00518.pdf
Cover Cropping to Improve Climate Resilience (USDA): https://www.climatehubs.oce.usda.gov/archive/sites/default/files/covercropsfactsheet_feb2017_digital_tagged.pdf
Soil Health and Cover Crops (Soil Health Institute): https://soilhealthinstitute.org/wp-content/uploads/2017/12/10-ways-cover-crops-enhance-soil-health-FINAL.pdf

Dryland

- Shift towards more water efficient crops and varieties that fit viable markets (Bauder and Schneekloth, 2003).
    - Forage sorghum, sorghum x sudan hybrids, and forage millets can persist through weeks of heat and drought (Bauder and Schneekloth, 2003).
    - In 2012-15, Kansas State Agronomists reported on the performance of drought tolerant (DT) corn varieties. They concluded that DT hybrids could serve as an insurance policy to sustain yield potential under water-limited conditions. If water is not limiting, DT hybrids performed as well as non-DT varieties. (Ciampitti et al., 2015).

- Maintain stubble/residue on the surface of the soil to reduce evaporation and increase the time that water can infiltrate and move deeper into the soil profile (Schneekloth et al., 2009).
    - An experiment in Akron, CO showed that water losses were 1.5 times greater on bare soil than soil with 3,000 lbs of wheat straw (Croissant et al., 2014).
    - Stubble/residue captures snowfall which holds moisture and allows it to melt into the profile in the spring.

- Intensify cropping systems to increase water-use efficiency (Andales et al., 2003).
    - Less than half of the precipitation received during the two years of winter-wheat/fallow is utilized by the winter wheat (Anderson, 2005).

- Plant shelterbelts or windbreaks to mitigate the force of high winds and reduce crop transpiration in a dry climate (Delgado et al., 2011a).

- Utilize an undercutter sweep that has a narrow-pitched and overlapping V-shaped blade for primary tillage in the spring (Yorgey et al., 2018).
    - This method severs capillary pores and channels that would bring water to the soil surface which can deplete stored soil moisture.

- Alter seeding rates and spacing between rows (Bauder and Schneekloth, 2003).
    - Decrease plant populations for drier conditions that have less irrigation availability to match precipitation and stored soil water to crop ET (Janowiak et al., 2016; Selvaraju, 2011).

Irrigated

- Shift towards more water efficient crops and varieties (Bauder and Schneekloth, 2003).
  - Forages are flexible and can be harvested at any point to avoid drought-induced crop failure.
    - This type of crop can also re-initiate growth once water is available again.
    - In addition, forages have a linear water response relationship while most crops require a minimum quantity (Derner et al., 2015).

- Use variable rate irrigation by determining spatial variability in fields.
  - CSU research has demonstrated the spatial variability of soil water content in most fields. Accounting for this variability by using precision, variable rate irrigation can increase efficiency (Bauder and Schneekloth, 2003).

- Utilize field EC mapping to understand soil variabilities that aid in developing “management zones” for variable rate application of irrigation.
  - Areas with higher EC generally have higher clay and organic matter and greater water holding capacity than low EC sandy soils.

- Manage irrigation according to the growth stage of the crop (Swanson et al., 2016).
  - Some stages of growth will allow for a lower water depletion level than others without impacting yield and quality of the crop.

- Use limited irrigation management during times of restricted water supply (Al-Kaisi et al., 2014).

- Use evapotranspiration (ET) or crop water use to schedule irrigation.
  - This takes into account weather, soil, water, and plants.

- Schedule irrigation based on net return (income from the crop less the expense of irrigation) (Bauder and Schneekloth, 2003; Schneekloth et al., 2009).
  - Only applying the exact amount of water to achieve goals can increase water use efficiency.

- Utilize reclaimed or gray water as an alternative irrigation source (Broner, 2005) if feasible and legal

- Use less irrigation during non-drought years to “water-bank” resources for drought years (Derner et al., 2015).

- Manage reservoirs to accommodate earlier runoff
    - Snowpack levels are predicted to decrease and begin melting earlier in the season (Derner, 2015).

- Reduce the amount of irrigated land by converting partially to dryland (USDA, 2014).

- Create slopes in plant rows to increase water retention and reduce run-off (Bauder and Schneekloth, 2003).

Links to Factsheets/Guides/Websites:
Improving Water-use Efficiency (USDA-NRCS Webpage): https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/home/?cid=nrcs144p2_065174
Northern Plains Regional Climate Hub Assessment: https://www.climatehubs.oce.usda.gov/sites/default/files/NorthernPlains_Vulnerability_Assessment_2015.pdf
CO High Plains Irrigation Practices (CSU Guide): http://www.cwi.colostate.edu/media/publications/sr/14.pdf
Limited Irrigation Mgmt: Principles and Practices (CSU Factsheet): https://extension.colostate.edu/docs/pubs/crops/04720.pdf
Limited Irrigation Mgmt (CSU Agronomy News): http://www.extsoilcrop.colostate.edu/Newsletters/documents/2007/2007_irrigation.pdf
Crop Prod. With Limited Irrigation (CSU Agronomy News): http://www.extsoilcrop.colostate.edu/Newsletters/documents/2003/2003_drought.pdf
Crop Water Use and Growth Stages (CSU Factsheet): https://extension.colostate.edu/docs/pubs/crops/04715.pdf Deficit Irrigation of Diverse Irrigated Rotation (Pacific NW Case Study Series): http://cru.cahe.wsu.edu/CEPublications/PNW705/PNW705.pdf
Irrigation Scheduling (CSU Factsheet): https://extension.colostate.edu/docs/pubs/crops/04708.pdf
Maximizing the Value of Limited Irrigation (CSU County Newsletter): http://logan.colostate.edu/agri/agri_docs/Farm%20%20Ranch%20August%202016.pdf

N Fertilizer BMPS

- Create a nutrient management plan that addresses the amount, source, placement, form, and timing of application that can reduce N2O emissions and fertilizer cost.

- Apply nitrogen at the correct rate and time while using proper methods to reduce NO2 emissions (Bauder et al., n.d.; Lal et al., 2011; Walthall et al., 2013).
  - Crop-related N2O emissions in the Northern Plains region is the largest contributor to greenhouse gases at 40 Tg CO2 eq. (Doll and Pathak, 2015); 41% of these emissions are from corn production.
    - 35% of corn producers nationally did not meet the BMPs for N rate and 34% did not meet the N timing recommendations (Bochicchio et al., 2015).
    - According to a recent study, corn production in the Midwest could reduce N2O loss by 50% with conservative fertilizer practices (Paustian et al., 2016).
    - Reducing the flux of N2O from intensively managed croplands is a significant opportunity for reducing environmental impact (Paustian et al., 2016).

- Ribaudo et al. (2011) and Paustian et al. (2016) defined BMPs for rate, timing, and method of N application to reduce emissions.
  - Apply no more than 40% of the N that was removed with the crop harvested, based on the stated yield goal, and including any carryover from the previous crop.
  - Avoid applying large amounts of NO3-N fertilizer at a time. Split applications may be necessary (Waskom, 1994).
  - Apply variable rates of N based on patterns of soil fertility.
  - Align N application with the timing of crop need.
    - A study in Montana resulted in ammonia losses of 16.3, 11.4, 1.9% with late-fall, mid-winter, and spring applications (Ribaudo et al., 2011).
  - Band apply, inject, subsurface apply, or provide immediate incorporation of nutrients.
    - This puts the nitrogen as close to the area of root uptake as possible and reduces atmospheric losses.
    - In one study, precision fertilizer application reduced average N fertilizer by 22 lbs per acre which ultimately reduced N2O emissions (Engel, 2013).

- Use urease inhibitors to mitigate ammonia volatilization.
  - A study in Montana showed that NH3 losses were reduced by 64% using NBPT or Agrotain products compared to untreated urea (Morton et al., 2014).

- Utilize nitrification inhibitors to limit ammonium conversion to nitrates which can be lost through leaching (Eagle et al., 2012).

- Use polymer-coated urea to reduce N2O emissions (Eagle et al., 2012).
  - A USDA-ARS study concluded that polymer-coated urea (PCU) showed potential for reducing N2O emissions in irrigated cropping systems.
  - In multiple crop rotations, urea-ammonium nitrate had greater emissions spikes than any of the PCU applications (Halvorson et al., 2008).

- Incorporate leguminous species into rotations to reduce N inputs and increase N-use efficiency (Delgado et al., 2011a).

- Test soil, plant tissue, and irrigation water to determine plant nutrient needs and make more accurate fertility decisions (Waskom, 1994).
  - A survey done by the USDA showed that approximately 70% of farmers' nitrogen decisions are based on routine practice (Selvaraju, 2011).
  - Pre-sidedress-nitrate tests (PSNT) or plant tissue analysis can aid in that decision-making process by assessing previous years fertilizer recommendations.
  - Multiply ppm nitrate (expressed as mg L-1) in irrigation water by 2.7 lb/AF times the amount of effective water applied (in feet) to determine pounds of N per acre applied with the irrigation water (USDA-ERS and NASS, 2018).

- Switch to alternative or perennial crops to reduce leaching of N.
  - According to a nitrogen conservation assessment in Iowa, the land-use change will be necessary to substantially reduce water quality issues from N. In-field BMPs, though low-cost, will not make a big enough impact (Doll and Pathak, 2015).

- Use EC mapping and variable rate technology to reduce N application.
  - EC mapping helps to understand field variabilities that can help develop "management zones" for variable rate application of fertilizers (Engel, 2013).
    - Areas with higher EC generally have higher clay and organic matter
  - According to a Colorado State University study, combining soil and crop information for variable rate N application resulted in the highest NUE while maintaining productivity and decreasing environmental loads (Farahani et al., 2011).

- Experiment with biochar application to reduce N2O emissions.
  - A review of 56 studies found that biochar has been shown to decrease N2O emissions by 49% (Swanson et al., 2016).
  - Biochar is also considered a frontier technology for carbon sequestration (Paustian et al., 2017).

- Use winter cover crops to reduce N losses (Ramlow et al., n.d.).

- Restore riparian areas to improve water quality and mitigate non-point source pollution.
  - Vegetation in riparian areas can reduce NO_3 in groundwater through nutrient uptake (Hill, 1996).

Links to Factsheets/Guides/Websites:
BMPs for Colorado (CSU Guide): http://www.wyoextension.org/werawater/region8/PDFs/bmps_colorado/xcm171.pdf
BMPs for Ag N Mgmt (CSU Guide): https://aes-swcrc.agsci.colostate.edu/wp-content/uploads/sites/92/2019/03/Best-Management-Practices-Agriculture-Nitrogen-Management.pdf

Manure Management

- Test soil and manure using a representative sample to determine nutrient content.

- Determine manure rates based on crop N need (or P needs if soil test P concentrations are high) (Waskom and Davis, 1999).

- Apply manure/compost as a fertility source (Doll and Pathak, 2015).
    - Organic amendments can sequester soil carbon while improving soil and water quality (Delgado et al., 2011a).
        - A number of studies have shown that manure application increases soil carbon often greater than tillage changes or winter cover crops (Eagle et al., 2012).
    - Limit manure application on frozen or saturated soils.
    - Do not apply manure on steep slopes or areas prone to erosion.
    - Stockpiled manure should be kept at a minimum of 100 ft. away from any water supply or even farther during times of intense rain potential.

- Incorporate manure to minimize volatilization (Waskom and Davis, 1999).
    - Many findings support that injected manure in minimum-till and perennial systems is the best overall management practice for manure application (Lal et al., 2011).

- Apply liquid manures similar to the timing of N fertilizer, as close to the time of crop need as possible.

- Compost manure to reduce methane emissions (Eagle et al., 2012; Swanson et al., 2016).

Links to Factsheets/Guides/Websites:
Biochar (CSU Factsheet): https://extension.colostate.edu/docs/pubs/crops/00509.pdf
Field EC Mapping (CSU Factsheet): https://extension.colostate.edu/docs/pubs/crops/00568.pdf
N BMPs (CSU Guide): https://extension.colostate.edu/docs/pubs/crops/xcm172.pdf
Manure BMPs (CSU Guide): https://extension.colostate.edu/docs/pubs/crops/568A.pdf
Nutrient & Fertilizer Mgmt (CSU Website): http://coagnutrients.colostate.edu/ag-best-management-practices/nutrient-fertilizer-managment/
BMPs for Colorado (CSU Guide): http://www.wyoextension.org/werawater/region8/PDFs/bmps_colorado/xcm171.pdf
Resilient Ag (Sustainable Corn Report): https://sustainablecorn.org/PDF_download.php/doc/MAG_REV_4Web.pdf
Climate Change and Ag in the US: Effects and Adaptation (USDA-ARS): https://www.esf.edu/glrc/library/documents/ClimateChangeandAgricultureReport_USDA_2013.pdf

Other General Strategies

- Utilize strip cropping and/or contour farming to reduce erosion.
  - Innovative systems of strip cropping two or more crops provide erosion control, rotation patterns within the field, and windbreak contributions from taller crops such as corn (Colorado State University Extension and Colorado Dept. of Public Health & Environment, 2019).
    - Erosion reduces productivity. Systems that minimize erosion with conservation practices will sustain greater productivity over the long-term through extreme weather events that could substantially increase erosion rates (Lal et al., 2011).

- Create diversions, buffer strips, and/or conservation buffers to manage excess water and catch sediments from extreme rain events (Janowiak et al., 2016).
  - Grassed channels constructed across a slope, uphill of a tilled field, can divert excess water to areas where it can be adequately managed.

- Install windbreaks, hedgerows, or vegetative wind barriers to reduce wind exposure for sensitive crops (Jarnes et al., 2009).

- Use precision harvesting to reduce erosion potential and maintain soil health (Delgado et al., 2011b).

- Plant saline tolerant cultivars in areas at risk of this issue.
  - Rising temperatures and reductions in the water supply can exacerbate salinity issues in soils. The inability to flush salts below the root zone with quality water will leave few options. It's possible that certain crops will no longer be able to be grown in areas with increasing salt issues.

- Utilize a stripper header to harvest wheat to leave behind maximum amounts of residue (Yorgey, 2017).
  - Low disturbance drills can be used to penetrate high residue levels.
  - A study by Thomas et al. (2011) found that even with no-till practices, removing crop residue increased erosion rates (Thomas et al., 2011).

- Utilize drought damaged crops for other purposes such as green chop, silage, baled corn stover, or grazing.
  - Test plants for nitrate levels to avoid nitrate toxicities (LeValley, 2009).

        - If nitrate levels are too high, dilute with low-nitrate forages or other feed.
        - Cutting silage at a higher height (leaving 10” of stubble) can reduce nitrate toxicity as most nitrate accumulates in the bottom 10”.
    - Check labels of any chemicals that have been sprayed to ensure the crop has met minimum pre-harvest interval so that it is safe to be fed to livestock.

- Restore wetlands and riparian areas to improve water quality, create diversity, and mitigate erosion.
    - Riparian areas are essential to managing non-point source pollution from fertilizers (Lal et al., 2011).
    - Extreme weather events can cause stream bank erosion that can be mitigated with healthy vegetation in the riparian area (Lal et al., 2011).
    - Wetland restoration can reduce the impacts of extreme events due to higher water flow (Delgado et al., 2011a).
    - Restoring wetlands has the potential to sequester more C (Eagle et al., 2012).

- Make regular and consistent ecological investments into practices that increase soil moisture and organic matter (Carlisle, 2014).
    - These tactics allowed farmers to have greater resilience in the presence of drought according to a study by Carlise (2014).

- Employ multiple conservation practices to increase resilience.
    - Using various conservation practices enhances synergism which provides additional benefits of increased efficiency (Delgado et al., 2011a).

- Utilize integrated precision conservation practices (GPS, RS, GIS) for irrigation, fertilization, and other field applications.
    - These technologies can reduce off-site transport of nutrients and sediments as well as improve the efficiency of resource management (Berry et al., 2003).
    - Precision practices can increase soil quality and carbon sequestration (Berry et al., 2003).

Links to Factsheets/Guides/Websites:
Dryland Cropping System (CSU Factsheet): https://extension.colostate.edu/docs/pubs/crops/00516.pdf
Drought-tolerant Corn Hybrids (KSU Factsheet): https://www.bookstore.ksre.ksu.edu/pubs/MF3338.pdf
Drought-stressed Corn Opportunities (UNL Cropwatch):
(1) https://cropwatch.unl.edu/2018/drought-stressed-corn-feed-opportunity
(2): https://cropwatch.unl.edu/should-you-hay-or-cut-silage-drought-damaged-corn-fields
Soil & Erosion Mgmt (CSU Website): http://coagnutrients.colostate.edu/ag-best-management-practices/soil-erosion-management/
Stripper Header (WSU Publication): http://pubs.cahnrs.wsu.edu/publications/pubs/pnw694/
Conservation Tillage/Wheat-Fallow System (PNW Case Study Series): http://cru.cahe.wsu.edu/CEPublications/PNW706/PNW706.pdf
Colorado Climate Preparedness Project (Western Water Report): https://wwa.colorado.edu/publications/reports/WWA_ColoClimatePreparednessProject_Report_2011.pdf
Alternative Feeds for Cattle During Drought (CSU Factsheet): https://extension.colostate.edu/docs/pubs/livestk/01626.pdf

Reduce Existing Stressors

Weed Management

- Alter herbicide mode-of-action to avoid herbicide resistance (Jhala et al., 2014).
  - In all instances where resistance has evolved, continuous use of the same or similar mode-of-action was used with little to no diversity in crop rotation or herbicide type (Jhala et al., 2014).

- Diversify weed management strategies to slow herbicide resistance and prevent or mitigate unnecessary risks to natural resources and humans.
  - A combination of plant residue, strategic tillage, and herbicide application can be used as a multi-faceted weed control plan.

- Increase scouting for weedy species.
  - Species that previously did not exist in a particular region could begin shifting its distribution northward with future changing climatic conditions (Waskom and Davis, 1999).
  - Noticing noxious/invasive weeds early can increase chances of control.

- Reduce competition from weedy and invasive species and eradicate noxious weeds.
  - Climatic conditions may enhance the growth of non-native species.
  - Increasing atmospheric CO_2 can boost weed growth which can increase the ability for competition (SARE, 2018).

- Utilize winter residue or winter cover crops to suppress spring weeds.
  - Longer growing seasons can give winter annual weeds an early start on growth and compete with germinating crops (Grotjahn et al., 2014).

- Intensify crop rotations to reduce the amount of time that land is fallow.
  - Fallow land allows weed proliferation or input costs for herbicide treatments (Derpsch, 2001).

- Use auto-guidance technology with automatic boom controllers to avoid herbicide overlap, skips, applying to non-crop areas, and spraying non-infested areas (Adamchuk et al., 2008).

- Employ site-specific/variable rate herbicide management for pre and post-emergence applications to reduce herbicide inputs/cost.
  - Postemergence variable rate optical sensors use near-infrared light reflectance to distinguish green vegetation from soil or crop residue (Adamchuk et al., 2008).
  - Once the crop has emerged, utilize remote sensing (imagery) and scouting to map high-density weed areas (Adamchuk et al., 2008).
    - Optical sensors become no longer useful due to the inability to differentiate between weed and crop.
    - GPS can be utilized during weed scouting to mark areas of high weed density that warrant herbicide application.

Links to Factsheets/Guides/Websites:
Herbicide-Resistant Weeds (UNL Factsheet): http://extensionpublications.unl.edu/assets/pdf/ec1278.pdf
Weed Targeting Herb. Mgmt (UNL Factsheet): http://extensionpublications.unl.edu/assets/pdf/ec708.pdf

Pest and Disease Control

- Alter insect life cycles by creating longer, more diverse crop rotation that promotes natural enemies for pests and prevents disease.
  - Plant diversity can break life cycles in soil-born pests like nematodes.
  - Bob Quinn, a Montana farmer, converted to a five-year rotation which has led to the elimination of nearly all viral diseases and root rots that used to impact grain production (SARE, 2018).

- Enhance the use of integrated pest management and more frequent scouting.
  - Warming temperatures and longer growing seasons provide the potential for insects to shift their distribution or increase their abundance.
    - Scouting will be essential to have knowledge of new insects that may present themselves.
    - Increasing temperatures in an area could lead to larger populations of an insect than in prior years.

- Incorporate cover crops into rotations (SARE, 2004).
  - Cover crops attract insects like lady beetles, ground beetles, parasitoid wasps, spiders, etc. that prey on common cash crop pests like armyworms, slugs, and corn rootworm.

- Improve rapid response plans and regional monitoring efforts to allow for targeted control of new pests before they become established.
  - Noticing pests early can improve the effectiveness of control tactics.

- Use of crop varieties and species that are bred for resistant to targeted pests and diseases.

- Minimize the use of broad-spectrum herbicides that can eliminate beneficial insects.
  - Increasing the use of pesticides can cause more rapid resistance issues (SARE, 2018; USDA, 2014).

- Utilize disease-resistant crops.
  - Diseases will likely become more difficult to predict with changes in seasonal weather patterns (LaRose and Myers, 2019).

- Alter irrigation strategies to protect higher income crops from pest pressure due to water stress.
    - I.e. Fully irrigate some fields and reduce/remove irrigation from others to avoid pest stress/ pressure.

Reduce Vulnerability and Risk

Farm Assessment of Vulnerabilities

- Define management goals and objectives that improve enterprise resilience.

- Assess site-specific climate change impacts and vulnerabilities of production areas with the mindset of "whole farm risk management" (SARE, 2018).
  - This assessment helps identify attributes of the property that could make it more or less vulnerable to impacts of climate change conditions.

- Create a property map to note topography, soil types, mark drainages, and any other landscape information.
  - What areas are most vulnerable to drought (soil series, current crop rotation)?
  - What areas are most vulnerable to wind or water erosion (topography, aspect, current tillage practices)?

- Plan improvements or BMPs to employ to improve resiliency based on vulnerabilities.

- Monitor and evaluate the effectiveness of implanted practices over time.

Links to Factsheets/Guides/Websites:
Adaptation Resources (USDA Climate Hub pg 44-59): https://www.climatehubs.oce.usda.gov/sites/default/files/adaptation_resources_workbook_ne_mw.pdf

Drought Preparation

- Create a strategic drought contingency plan that provides management flexibility and the ability to respond quickly and effectively.
  - Strategies should be developed for preparing, responding, and recovering from drought. (Janowiak et al., 2016; Roesch-Mcnally et al., 2017)

- Purchase crop insurance (Averyt et al., 2011; Derner et al., 2018; Olsen et al., 1954).

- Sub-seasonal and seasonal climate forecasts are improving slowly and becoming more useful (https://www.cpc.ncep.noaa.gov/)

- Track and monitor dryness and drought across the country.
  - The Drought Monitor created each week by the National Drought Mitigation Center provides projected short and long-term drought conditions. https://droughtmonitor.unl.edu
  - The Colorado Climate Center at CSU provides weekly climate, water and drought updates specific to Colorado http://climate.colostate.edu/~drought/
  - The Evaporative Demand Drought Index (EDDI) is an experimental drought monitoring and early warning guidance tool that provides near real-time information on drought conditions. https://www.esrl.noaa.gov/psd/eddi/
  - Winter season predictions have become more accurate than summer precipitation. This can be an important source of moisture for operations that rely heavily on snowmelt. (Averyt et al., 2011; Morton et al., 2014)
  - Quick drought response index (QuickDRI) shows conditions relative to 4-week historical norms. (https://quickdri.unl.edu)
  - Colorado statewide drought response portal with information about snowpack, reservoir storage, U.S. drought monitoring, and drought updates. (http://www.coh2o.co)

Support for BMPs

- NRCS Environmental Quality Incentives Program (EQIP) is the most extensive USDA program that provides technical and financial assistance for implementing BMPs on cropland.

- Conservation Reserve Program (CRP) – Largest voluntary conservation program providing incentives to producers to take marginal of vulnerable cropland out of production for 10-15 years.

- Conservation Stewardship Programs (CSP) – This program rewards producers for practices that protect the environment and natural resources.

- Conservation Technical Assistance (CTA) – Technical assistance to promote activities to increase carbon sequestration.

- Biomass Crop Assistance Program (BCAP) – Provides incentives to producers to establish, cultivate, and harvest available biomass for heat, power, bio-based products, research, and advanced biofuels.

- Noninsured Crop Disaster Assistance (NCDA) – Provide emergency assistance to producers when drought and other disasters affect production.

- Farm Service Agency (FSA) provides a 9-month commodity loan that can be used by producers to obtain quick financial aid in times when markets are volatile due to climatic extremes.

- Agriculture Management Assistance (AMA) – Provides cost-share and incentive payments for producers to address issues associated with erosion control or water quality.
- Wetlands Reserve Program (WRP) – Voluntary conservation easement program offering landowners to increase the acreage of wetland to increase carbon sequestration.

- Emergency Conservation Program (ECP) – Provide financial assistance to restore conservation practices after a natural disaster.

- Risk Management Agency (RMA) – provides a variety of crop insurance products to help farmers manage risk including drought, excessive precipitation, hail, etc.

Links to Factsheets/Guides/Websites:
Northern Plains Regional Climate Hub Assessment: https://www.climatehubs.oce.usda.gov/sites/default/files/NorthernPlains_Vulnerability_Assessment_2015.pdf
Incentive Programs/Assistance for Producers (USDA-NRCS Website): https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/climatechangeresources/?cid=stelprdb1043608
Risk Mgmt Agency (Website): https://www.rma.usda.gov
Climate Change and Ag in the US: Effects and Adaptation (USDA-ARS): https://www.esf.edu/glrc/library/documents/ClimateChangeandAgricultureReport_USDA_2013.pdf

Infrastructure

- Expand or improve water systems to increase efficiency and storage based on the type of crop in production.
  - Climate change is predicted to bring longer, hotter growing seasons that will increase evapotranspiration, increase the plants' water need, and will require more extended periods of irrigation.
  - Eastern CO relies on the Ogallala aquifer which is declining and limited in water availability.
  - Upgrade to subsurface drip irrigation (SDI), gated pipe/furrow system, micro sprinkler, or sprinkler irrigation (Hawkes, 2018).
  - Expand water storage, irrigation, and drainage using deeper wells, cisterns, and farm ponds.
  - Line irrigation ditches or install pipe delivery systems (Reich et al., 2014).
    - Unlined ditches can lose water due to seepage through the soil.
    - Options include hard surface (paved), exposed membrane, and buried membrane. Hard surface in combination with a buried membrane reduces water seepage by 95%.
    - Pipelines reduce evaporation and seepage losses compared to lined or unlined ditches.
    - Use structures to increase environmental control for specialty crops.
  - Shorten row length in the field, pack furrows, use surge valves or manual surge rows and increase stream size and cutback (Barta et al., 2004).

- Match infrastructure and equipment to new and expected conditions
  - Consider purchasing/leasing/utilizing precision nutrient and pesticide application systems.
  - Upgrade building facilities to handle expected increased snow or wind loads.

- Have equipment that can plant successfully through residue.
  - Surface residue is essential for moisture retention and erosion control. Having equipment that can plant through that is vital (Bauder and Schneekloth, 2003).

Links to Factsheets/Guides/Websites:
Subsurface Drip Irrigation (CSU Factsheet): https://extension.colostate.edu/docs/pubs/crops/04716.pdf

Alter Management Strategies for the Future

Adjust Timing and Seasonality

- Adjust on-farm activities to account for a longer growing season.
    - In the Northern Great Plains, the growing season is expected to increase by 20-30 days (Yorgey et al., 2018).
        - Specifically, in Colorado, frost-free days are expected to increase by 19 days (SARE, 2018).
    - Adjust the timing or sequencing of cropping operations, such as altering planting, irrigation, or fertilizer application.
        - Adjust synchronization of crop nitrogen (N) needs and application for improved nitrogen use efficiency.
            - Early season N application may need to be reduced with projected drought.
    - Adjust the timing of planting, such as earlier planting dates, to avoid heat stress during critical periods of plant development.
    - Prepare for altered plant phenology due to earlier onset of spring and advanced reproduction of plants (Swanson et al., 2016).

Alternative Crops

The crops listed below are general recommendations and ideas. Successful incorporation of these crops into a rotation is dependent on location and available markets. However, some of the obstacles encountered with these crops can be overcome by marketing and alternative approaches found in some of the literature below.

- Plant perennial crops (hay production, forages, grains) to sequester CO2 (SARE, 2018).
  - Kernza is a perennial grain crop that is native to the Great Plains. It has a deep root system, twice as deep as annual wheat and uses less water. It has the potential to sequester greater carbon and improve soil health. Markets are niche at this present time, but research and larger entities are working on commercializing this crop.
    - https://landinstitute.org/our-work/perennial-crops/kernza/
  - One study found that after several years of drought, the active C pool was greater for grass systems than in the cropping systems (Sherrod et al., 2018).

- Incorporate more warm season species in cropping rotations.
  - Increased severity of drought, warmer temperatures, and elevated atmospheric CO2 is more conducive to C4 plants.

- Seek out longer-season varieties of corn, soybeans, and wheat (Bochicchio et al., 2015).
  - Early-planted, longer season soybean cultivars have had increased yields over the past few decades (Walthall et al., 2013).
  - Seek out wheat cultivars with modified flowering times to match changed planting dates and temperature regimes (Walthall et al., 2013).

- Incorporate varied hybrid maturities to spread risk across the landscape.

- Camelina (Bathke et al., n.d.)
  - Spring planted, annual camelina production fits into Eastern Colorado’s dryland crop rotation and is more drought/heat tolerant than other brassica types.
  - Camelina uses the same type of equipment as wheat which wouldn’t require greater investment.
  - Camelina is a low fertilizer requirement crop that works well in no-till and dryland systems.
  - This crop is relatively disease/insect resistance in Eastern Colorado.

- Proso millet
  - Proso millet is a relatively low water use crop (Enjalbert and Johnson, 2011).
    - Proso millet has a shallow root system that doesn't generally rely on subsoil moisture.
    - It requires the least amount of water of the cereal crops grown in Colorado and is extremely efficient at removing water from topsoil and converting it to dry matter.
  - This crop fits well in a winter wheat rotation and helps control winter annual weeds.
  - Proso millet can be utilized when the producer is wishing to avoid summer fallow.
    - Because of its shallow root system, it can be followed by a deep-rooted crop like sunflower which would typically require a fallow period.
  - This crop is more adapted to "poor soils" or soils that have lower water-holding-capacity.

- Pearl millet (Lyon et al., n.d.)
  - This crop has drought resistant characteristics that have a short maturing season.
  - The market is growing within cattle and poultry production for pearl millet as a feed source due to its levels of protein and lysine.

- Grain Sorghum (SARE, 2004)
  - This crop is suited for areas too hot and dry for corn production and is more saline tolerant than corn.
  - Self-pollination reduces the risk of poor seed set which provides an advantage over corn during dry years.

- Grain Amaranth (SARE, 2004)
  - The grain is high in protein and lysine which is lacking in cereal grains.
  - This crop is generally drought and heat tolerant and adapted to a wide range of conditions.

- Dry edible beans/peas
  - Dry edible beans and peas can be used for double cropping or pulse crops.
  - They can provide nearly year-round ground cover to reduce soil exposure to water and wind erosion.

- Winter triticale (SARE, 2004).
  - This crop can be used as a dryland forage.
  - Triticale does not become weedy like rye because it is harvested as hay well before seed formation.
  - Due to its hybrid vigor, triticale will produce greater yields than rye of wheat (in terms of forage).
    - In a two year study in NE CO, the mean forage yield was between 5400-5600 lbs/acre.

    - Winter varieties outperform spring varieties in Colorado climate.

- Winter canola (Moncada et al., n.d.; Vigil et al., 2016).
    - According to Canola producers in the Great Plains regions, yields of winter wheat following canola resulted in a 10-25% increase compared to wheat following wheat. Yield trials can be found in the link below.
    - There is significant demand for canola oil in the United States with large amounts still being imported annually.
    - OSU and KSU performed enterprise budgets that showed wheat-wheat-canola rotations were 51% more profitable than continuous wheat in Oklahoma.
    - Canola water requirements are similar to that of wheat.

- Winter Pea
    - This crop germinates well in tilled and no-till systems as well as adds N credits to the cropping system.
    - The crop type allows for grass-type weeds to be sprayed that would normally impact winter wheat.
    - A regular head can be used for combining due to its upright growth habit.
    - In one study, winter pea used significantly less soil water than winter wheat (Meyer, 2011; Stamm et al., 2018).

- Dry field pea (Yorgey et al., 2018)
    - Pea can be grown for grain or forage. Both are high in protein and suitable for livestock feeding.
    - Field pea requires similar amounts of water as a cereal grain.
        - Early rains followed by dry periods for pod fill and ripening are ideal.
    - Peas can contribute 25-50 pounds of N per acre.

- Flax (Moncada et al., n.d.)
    - Yields well on soils that also produce wheat but will have reduced yields if there are drought conditions during pollination and grain fill.

- Sunflower
    - This plant can yield reasonably well in soils with low moisture or high salinity.
        - It can extract water from deeper regions of the soils due to its root structure.

- Replace fallow periods with annual forages.
  - In a study from the Kansas State University Southwest Research-Extension Center found that although most cover crops resulted in less profit than fallow, growing annual forages instead often increased profit compared to fallow (Moncada et al., n.d.).
  - Flex-fallow is another strategy that utilizes cover crops/forages in place of fallow during years with average/higher projected moisture.

- Miscellaneous Specialty Crops
  - Markets are expanding for various products, and more opportunities may be present where they weren't before.
  - Distribution bottlenecks may be a challenge.
  - The link below has case studies of farmers/ranchers that have diversified their operations with specialty crops, what challenges they faced, and ultimately their successes.
    - https://www.sare.org/Learning-Center/Bulletins/Diversifying-Cropping-Systems/Text-Version

- Explore additional marketing options for alternative/specialty crops to increase profits (Holman et al., 2017).
  - Direct marketing can be more profitable.
    - A farmer that produces flaxseed in North Dakota increased his crop value 50x by direct marketing to stores/hospitals instead of the local grain elevator.
  - Continue to search and explore marketing avenues.
    - According to Robert Beguin (Nebraska farmer), "the first two or three years are difficult, but avenues begin to open up."
  - Utilize long distance channels like the internet for sales.
  - Seek third-party verification to market sustainable production practices.
  - Some alternative crops can and are grown under contract. Information on agricultural production contracts can be found here: https://conservancy.umn.edu/bitstream/handle/11299/199823/agricultural-production-contracts.pdf?sequence=1&isAllowed=y

- Apply for funding to test alternative crops through SARE producer grants.

Links to Factsheets/Guides/Websites:
Proso Millet (UNL Guide) http://extensionpublications.unl.edu/assets/pdf/ec137.pdf
Camelina Prod. (CSU Factsheet): https://extension.colostate.edu/docs/pubs/crops/00709.pdf
Adaptation Resources (USDA Climate Hub): https://www.climatehubs.oce.usda.gov/sites/default/files/adaptation_resources_workbook_ne_mw.pdf
Fallow Replacement Crop Effects (KSU Report): https://newprairiepress.org/cgi/viewcontent.cgi?article=7389&context=kaesrr
Great Plains Canola Prod. (KSU Handbook): https://www.bookstore.ksre.ksu.edu/pubs/mf2734.pdf
National Winter Canola Variety Trial (KSU): https://www.agronomy.k-state.edu/services/crop-performance-tests/canola-and-cotton.html
Canola Production (CSU Guide): https://extension.colostate.edu/docs/energy/canola.pdf
Winter Triticale as a Dryland Forage (CSU County Newsletter): http://logan.colostate.edu/agri/agri_docs/Farm%20%20Ranch%20August%202016.pdf
Alternative crops (UMN Guide): https://organicriskmanagement.umn.edu/sites/organicriskmanagement.umn.edu/files/alternative_crops.pdf

- COMET-Farm is a whole farm and ranch carbon and greenhouse gas accounting system that guides you through management practices and alternative future management scenarios. http://cometfarm.nrel.colostate.edu
- Cool farm tool is an online greenhouse gas, water, and biodiversity calculator for farmers. http://www.coolfarmtool.org/
- The Ogallala Agro-Climate Tool is an application that estimates irrigation demand and crop water use over the aquifer region. https://www.lbk.ars.usda.gov/wewc/Ogallala_Ag_Tool/index.php
- Water Irrigation Scheduler for Efficient Application (WISE) is a cloud-based tool for irrigation scheduling that can be used on a computer or through a cell phone application. http://wise.colostate.edu or https://erams.com/documentation/wise-irrigation-scheduler/
- Western extension risk management education center is partnered with extension educators, public, and private sector partners to provide risk management resources. Their website offers resources, tools, and training to support producers in establishing long-term risk management. https://westrme.wsu.edu/risk-management-resources/
- The Colorado Agricultural Meteorological Network (CoAgMet) is a network of automatic weather stations distributed across the state. This resource also provides useful information like evapotranspiration (ET) reports growing degree days (GDDs), and raw weather data. https://extension.colostate.edu/docs/pubs/crops/04723.pdf
- http://coagmet.colostate.edu/
- The Community Collaborative Rain, Hail and Snow network (CoCoRaHS) provides detailed subcounty-scale precipitation data for current and past years (cocorahs.org)
- Colorado State University Extension has a center pivot evaluation and assessment tool. https://extension.colostate.edu/topic-areas/water/irrigation-assessment-tools/commercial-sprinkler-irrigation-assessment-tools/
- ‘Weather Ready Farms’ is an initiative by Nebraska Extension that focuses on climate and weather literacy and strategic scenario planning. They have a cropping system scenario planning tool developed in partnership with the Northern Plains Climate Hub. http://agritools.unl.edu/management-strategies/
- Nebraska Extension publishes a monthly series of articles about dealing with drought in crop production. https://cropwatch.unl.edu/tags/drought
- AgriTools is a mobile phone app that is designed to provide location-specific climate/weather data, forecasts, and maps related to agriculture. https://weather-ready.unl.edu/
- Nebraska has a Hail Know Team and a website that has resources for this type of natural disaster. https://cropwatch.unl.edu/hailknow
- A farmer-researcher-industry coalition has created a website that disseminates information to growers and links them with handlers and processors of value-added grains. www.oatlink.com

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