Regional Legume Cropping Assessment as it pertains to Nitrogen Budgeting and Climate Forcing

By Peterson et al.

Introduction

The Northern High Plains of the United States is diverse in both climate and agricultural aspects. Establishing a tried and true method of input application for farmers and ranchers is made difficult due to the changing elevation, precipitation variability and diverse soil profiles within the region. Inputs are the driving force, other than water, that guarantee a yield and profit for a producer. However, as sustainability becomes a readily used buzz word in grant applications and mainstream agriculture, producers have to be prepared to operate in a manner that will ensure the life of the soil, their lands and their livelihood. Sustainability is a concept that has many facets. Soil fertility, life form diversity, input management and global impact are just a few facets that make up sustainable practices in agriculture. Optimization of nitrogen budgeting and a solid picture of greenhouse gas emissions (GHG) from carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) would allow producers to manage their farm ecosystems for the long term.

In the Northern High Plains winter wheat/fallow systems are readily cropped utilizing a 14 month fallow period to store water and mineralize nitrogen. This system is chemically and mechanically intensive resulting in nutrient leaching (Cassman et al., 2002). Intensive agricultural practices deplete soil organic matter, microbial life, fertility, nutrient use efficiency, water use efficiency and increase greenhouse gas emissions (GHG) (Tilman et al., 2001; Gregorich et al., 1998); resulting in yield depression and profit loss. These systems have been shown to use excessive synthetic nitrogen inputs to make up for soil depletion; little is publicized about Northern High Plains winter wheat contributions to GHG emissions or assessment of alternative cropping methods to fallow in the region.

Alternative approaches to land management (i.e. reduced tillage and diversified crop rotation) can greatly increase yield, soil health and sustain farming (Collins et al., 2000; Doran et al., 1998; Larney et al., 1997). The addition of a legume into a crop rotation affords the ability to fix atmospheric nitrogen (N_2); increasing the natural nitrogen inputs into the system and decreasing economic burden on the producer (Barton et al., 2011). To date 16.8 million bushels of wheat are expected in the region in 2011 (NASS). Currently in the region it is advised to apply 2.3 lb of Nitrogen (N) to achieve 12% protein in winter wheat. If more protein is desired then more N is applied (Prairie Grains). On an average 60 bushel winter wheat production, a producer uses 138 lbs/N per acre; economically that translates to $33.05 an acre (ERS). Depending on the scale of a producer's winter wheat production fertilizer costs could be in the thousands of dollars for one application. Nitrogen cost extrapolation on the expected bushels of wheat in the region translates to $9.3 million dollars. Nitrogen application has shown to benefit crop production in depleted soils provided water is available. N fertilizer application has also been shown to affect nitrous oxide emissions (N_2O) (Pattey et al., 2008); one of three greenhouse gas (GHG) contributors to climate forcing. Coincidently with the change in cropping structure also changes nutrient dynamics (Moore, 1994) leading to the change in gas emission. Depending on the management of the cropping structure change the GHG mitigation can occur reduce GHG emissions to the atmosphere.

Despite political ambiguity, climate data shows that there is a global warming trend that has occurred since the industrial revolution and could very well be linked to land use;

specifically agricultural production (Brovkin et al., 1999, and Gameda et al., 2007). Agricultural practices rank third in GHG production in the world (IPCC, 2001a). This trend indicates that there is a bigger shift in minimum and maximum temperatures with maximum temperatures increasing (Chase et al., 2000). This shift greatly affects precipitation and cropping schemes ending in new plant varieties being bred to tolerate the changing climatic conditions (Gameda et al., 2007). Global warming is the effect of an increase in CO_2, CH_4, and N_2O being released from the Earth's surface and affecting how solar rays enter and exit the atmosphere (Brovkin et al., 1999; Matthews et al., 2003). In tilled systems stored carbon in the form of soil organic matter is brought to the surface, transformed to CO_2 and released to the atmosphere (Baggs et al., 2006). Methane released from agriculture soils most likely is oxidized to CO_2 before it reaches the atmosphere (Wassmann et al., 2000). In agricultural systems the major contributor of N_2O emissions is denitrification of microbial mediated processes (Groffmann et al., 2000) usually resulting from excessive fertilization of crops (Naqvi et al., 2000). Schlesinger established that the addition of fertilizers and tillage can considerably add to nitrous oxide emissions however, dryland systems have decreased emissions (Smith et al., 2004) due to water filled pore space (Pattey et al., 2008).

Industrialization and conversion of forest lands to large scale agricultural productions results in an increased GHG concentration (IPCC, 1996; Brovkin et al., 1999; Matthews et al., 2003; Oleson et al., 2004). Management practices of tillage, summerfallow, pesticide addition, burning of weeds and irrigation affect the release of GHG from the Earth's agriculture lands (Gameda et al., 2007). In Canada 9.5% of GHG emissions have been linked to agriculture as of 2004 (Smith et al., 2004). Of this 9.5%, 60% is from the soil (cropping systems). This goes to show that the management practices of the soil are vital to storing and trapping climate forcing gases. As arable land continues to decrease and global warming persists it is imperative that researchers, producers and consumers better understand the implications of farming practices to ensure the future and health of our lands and food supply. The following review of wheat/fallow alternative cropping systems will look at GHG emissions from legume crops utilized in rotation. To date little is published about the effects of summerfallow conversion to legume crops on GHG emissions and nitrogen budgeting in the Northern High Plains. However, comparable work has been done in other parts of the world; mainly Canada and Australia.

Nitrogen Fixation

Addition of legumes to a cropping system can contribute large amounts of nitrogen through atmospheric nitrogen fixation either through intercropping or conversion of summerfallow to a legume crop cover (Gregorich et al., 2005, Tanaka et al., 2005). Legumes are atmospheric nitrogen fixers and can increase nitrogen levels within soil. These crops can be grown as a cover crop, crimped and tilled in prior to maturity to reduce erosion, evaporation, fix nitrogen, increase soil organic matter (SOM), soil organic carbon (SOC) and increase water use efficiency and nutrient cycling (Tonitto et al., 2006; Nyefeler et al., 2011; Tanaka et al., 2005).

When converting to a legume cover crop is it vital to understand the potential impacts of the conversion and how those impacts work into the overall goal of the farm. Research shows that crop rotation that includes more than 3 crops, one being a nitrogen fixing crop (pea), tend to be healthier and more sustainable due in part to diversity in microbes, less pesticide application and increased SOM, SOC and soil inorganic nitrogen (Naudin et al., 2010; Tonitto et al., 2006). Conventional systems, defined as cereal crop with a fallow period, rely heavily on N fertilizer inputs. This combination of practices decreased living plant material, carbon fixation, N assimilation, SOM and increases soil erosion (Matson et al., 1997). Introduction of a legume crop into rotation increases diversity of the overall system however, if a legume is intercropped with a cereal crop weeds and pests are managed and diversity in space increases; leading to greater yields, yield stability, increased nitrogen in cereal grain and a reduction of pesticide application and nitrogen leaching (Naudin et al., 2010). These results were congruent with that of Hauggaard-Nielsen et al., (2001). Many intercrop yields can go to market as silage for livestock or cereal can be harvest and sold to grain markets. Each option has increased protein and biomass due to synergistic mechanisms of legume with cereal (Naudin et al., 2010).

Research has indicated that niche optimization is key to success of nitrogen use efficiency, decrease in non-renewable natural resources and chemical inputs while decreasing the environmental impacts linked to overuse of inorganic N supplements (Naudin et al., 2010, Altieri et al., 1989, Tilman et al., 2002, and Crews and People, 2004). Increased N-fixation has been improved when legumes are grown in cold temperature regions (Tonitto et al., 2006). Conversely other research has shown that N-fixation is impractical because of a wide-spread misperception that legume cropping systems will reduce yield by 50%; but many still believe that legumes fertilization is possible when optimized (Cassman et al., 2002; Smil, 2000; Sinclair and Cassman, 1999; Tonitto et al., 2006). This reduction in yield, in comparison to a cash crop is due to:

1.) a legume crop/green manure is grown for a full year, reducing cash crop cycling.
2.) legume managed land can incur costs due to crop up-keep.
3.) legumes cannot produce enough N to ensure maximum cash crop yield (Tonitto et al., 2006).

Each of these issues is viable but at the cost of manmade N fertilizers any decrease in chemical inputs should be seen as a benefit.

The Northern High Plains doesn't have an extensive index of nitrogen fixing potential of legume crops in the region. Regionally speaking, alfalfa is readily cropped for livestock forage. Beans are cropped in rotation with barley and beets but as sole crops and not intercrops in Wyoming. Currently there is research and breeding occurring for pea, medic, lupin and others. These crops need to be assessed for nitrogen fixing potential in varying environments under dryland and irrigated systems to determine their place in Northern High Plains farming. Table 1 gives an index of potential nitrogen fixing ability of crops from Western and Eastern Canada and Australia.

Table 1- Average nitrogen fixed by legume crops and emitted nitrous oxide from around the world under both irrigated and dryland conditions. Dryland is only rainfed water. Annually 50-70 Tg of atmospheric nitrogen are fixed every year around the world.

Crop	Location	Nitrogen Fixing Potential	Irrigated (I)/ Dryland (D)	Author	Nitrous Oxide Emissions
Pea	France Australia	30-45 kg N ha^{-1} 150 kg N ha^{-1}	D I and D	Naudin et al., 2010 Unkovich et al., 2010	5.6 kg N_2O-N ha^{-1}Pattey et al., 2008)
Clover or Vetch	Canada Australia	50-370 kg N ha^{-1} 17-47 kg N ha^{-1}	I and D	LaRue and Patterson, 1981; Peoples et al., 1995 Unkovich et al., 2010	
Medicago spp.	Australia	95 kg N ha^{-1}	I and D	Unkovich et al., 2010	4.9 N_2O-N ha^{-1} (Ellert et al. 2008)
Annual Medic	Australia	25 kg N ha^{-1}	I and D	"	
Annual Clovers	Australia	47 kg N ha^{-1}	I and D	"	
Lupin	Australia	9-48 kg N ha^{-1}	I and D	"	-0.5-24 N_2O-N ha^{-1}(Barton et al., 2011)
Soybean	Australia	64 kg N ha^{-1}	I and D	"	
Annually	World	50-70 Tg N	I and D	Smil, 2001	

Potential Legume Crops

Wyoming is mainly based in perennial legume systems such as alfalfa/grass for livestock forage. Annual crops such as beans and peas are used in rotation throughout the state but peas are not regularly used at this time. The addition of a perennial or annual legume can considerably increase the diversity of a cropping system especially dryland systems (Tanaka et al., 2005). By switching converting fallow ground to a legume crop, SOM, fertility, water holding capacity and erosion control can be increased while adding N to the soil profile (Tanaka et al., 2005). Most annual legume crops are terminated before maturity is reached. This ensures the maximum N fixation benefit to the succeeding crop as the biomass returns immobilized N to the soil profile (Tanaka et al., 2005).

Legumes in a system react differently depending on soil type and amendments. Irrigated verse dryland legumes tend to react differently in N_2 fixation rates (Table 1), biomass and efficiency use of N (Corre-Hellou et al., 2011). A review of the literature indicates that legumes that are cropped in a nitrogen rich soil or have nitrogen applied become lazy and they reduce nitrogen fixation; in an N depleted system legumes tend to fix nitrogen efficiently (Naudin et al., 2010). This research also shows that the succeeding crop or crops planted with the legumes benefit favorably. The niches of the legume is optimized allowing the system to become a higher productive land mass (Tonitto et al., 2006; Tanaka et al., 2005).

To optimize nitrogen fixation a few characteristics should be looked at: ease of cropping legume, benefits (N_2 Fixation) to system and cost. Legumes should be able to be easily planted and taken care of to reap the benefit of nitrogen fixation for cash crops. These crops should also be cheap to grow, monetarily and resource wise to not be a burden. Currently there needs to be an understanding of the legumes present in Wyoming and how they affect cropping systems. Peas are readily cropped north and south of the Northern High Plains, as is chickpea, beans, lentils and black medic. One would presume that these crops could be established and nitrogen fixation assessed to determine the maximum nitrogen benefit to the rotation and succeeding. Obtaining an assessment of nitrogen fixation according to Wyoming seasonality is vital in determining if legumes are a possible alternative to fallow ground.

Nitrous Oxide Emissions of Legumes

Despite legumes interest for nitrogen fixation as an alternative to chemical nitrogen inputs, legumes have been shown to have excessive nitrous oxide emissions. This could be very detrimental to a cropping system that is managed for trace gas emissions. The key according to research for proper nitrous oxide emissions is regular and often sample taking to ensure proper estimates. Many models utilize linear interpolation for estimates which may underestimate values. These values also usually miss wetting events and winter emission (Parkin et al., 2006; Hergoualc'h et al., 2009). The main nitrous oxide emissions that are derived from soils are associated with nitrification and denitrification (Gregorich et al., 2005). Climatic factors, uncontrollable in field settings, can also drive N_2O emissions: temperature, water content and freezing/thawing events (Burton and Beauchamp, 1994). Farming practices such as: tillage, residue management, legume cropping and N mineral fertilizer application can effect N_2O emissions greatly (Gregorich et al., 2005). Most research for N_2O emissions in conjuncture with cropping practices of legumes have occurred in Eastern Canada.

The results of these studies indicated that major N_2O fluxes occur in winter/spring due to freeze thaw events which lyse microbial cells releasing nutrients (Ivarson and Sowden, 1970). This process enhances organic carbon which promotes denitrification (Ellert et al., 2008). During these freeze thaw events saturation of the soil with water is likely to occur, favoring denitrification of soil mineral N, producing N_2O (Gregorich et al., 2005). Research on perennial verse annual legume systems solidifies that annual systems tend to have greater emissions in freeze/thaw situations than perennial systems (1.19 +/- 0.79 kg N_2O-N per hectar per year annual, 0.29 +/- 0.39 kg N_2O-N per hectar per year). Authors indicated that this differences is due to inorganic N content under perennial crops is less and the active decay of roots and uptake of nutrients is slower (Gregorich et al., 2005). Legumes are suggested to contribute 0.4 Mt N_2O-N per year to the 10% nitrous oxide emissions that are produced via agricultural activities (Barton et al., 2011).

The use of tillage and residue incorporation has shown to increase emissions upon breakdown of legume residues and this breakdown can occur very close to freezing temperatures and should be monitored throughout the year (Gregorich et al., 2005; Chantigny et al., 2002). No-till systems like dryland, perennial systems have shown to be much lower in emissions than those that are tilled. In an alfalfa/grass system, the predominate legume system in Wyoming, no-tillage, dryland management practices could be used to mitigate the emissions produced from the crop. However, to optimize emissions one must manage the system for health and profit. Alfalfa systems produce more N_2O emissions than annual systems like soybeans cropped with corn (Ellert et al., 2008). Ellert et al. establishes that emissions of nitrous oxide are highly linked to peak growth rather than water pulse, temperature, or harvest. These statements are different than other research which indicates emissions being linked to multiple cuttings of the perennial crop throughout the year, water pulses and temperature of the soil (Rochette et al., 2004a). This is concurrent with research concerning emissions of alfalfa due to the dieback of nodules after harvest (Vance et al., 1979); another potential source of emissions in the perennial system could be due to the amount of residue that falls on the ground during the growing season (~13 kg per hectar per year, (Tomm et al., 1995).

Gregorich et al., (2005) established that residue plays a vital role in emissions from cropping systems. The practice of tilling in residue into the soil increases emission 2.41 kg N_2O-N per hectar than if the residue is kept on the surface and allowed to decompose. Some research suggests that this flux in nitrous oxide offsets stored carbon (Barton et al. 2011); management practices must be known to make simple decisions when assessing trace gases! Table 1 provides nitrous oxide fluxes of a few crops.

The literature doesn't calculate emissions using a universal method. Many papers indicate that the IPCC over estimates N_2O emission for a growing year due to universal constants which are not regional specific. It might be imperative to establish a method to calculate emissions from crops within the Northern High Plains region so that data can easily be assessed. This will also allow annual and perennial systems to be assessed equally within the region; values will be truly comparable!

Conclusion

Ultimately for the Northern High Plains use of legumes in place of summerfallow, cropping system optimization must occur. This can only occur after legumes are assessed in the region. Annual and perennial legumes that are likely to grow in the region: Austrian winter pea, soybean, bean, clovers, alfalfa, and medic need to be assessed for greenhouse gas emissions, nitrogen fixation and soil indices to assess health of system. These initial assessments will allow cropping schemes to be optimized for mineral N additions, water use and productivity to ensure sustainability in the region and determine if fallow conversion to legume cropping is viable.

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