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Climate Smart Precision Nitrogen Management

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Abstract. Climate Smart Agriculture (CSA) aims at improving farm productivity and profitability in a sustainable way while building resilience to climate change and mitigating the impacts of agriculture on greenhouse gas emissions. The idea behind this concept is that informed management decision can help achieve these goals. In that matter, Precision Agriculture goes hand-in-hand with CSA. The Colorado State University Laboratory of Precision Agriculture (CSU-PA) is conducting research on CSA practices that can help increase crop productivity, profitability, build resilience to climate change and mitigate the effect of agriculture on greenhouse gas emissions. Nitrogen fertilizer is the most widely used nutrient on the planet and the most important anthropogenic contributor of nitrous oxide emissions from agricultural sources. With increasing pressure to produce more food globally, many economies have been increasing nitrogen consumption. The global nitrogen use efficiency (NUE) estimates are in the proximity of 40%, which indicates that a lion share of nitrogen is lost in the biosphere every year. For farmers, to practice climate smart agriculture mandates enhancement of NUE. Long-term research at Colorado State University since 1997 has developed and demonstrated site-specific management zones as an effective tool for CSA. This research observed a reduction of up to 46% in nitrogen loadings without impairing grain yields. Coupling site-specific management zones with more recent innovations such as active proximal sensors enables the management of both, macro- and micro-variability in farm-fields and may result in further improvement of nitrogen use efficiency and reductions in N loadings in the biosphere. Increasing NUE with such advanced decision making process decreases the dependence on fossil fuel costly conversion of N_2 to urea and reduces the unused amounts of nitrates in the field contributing to N_2O emissions. Improving NUE through precision agricultural techniques has great potential to mitigate climate change. On the other hand, it is expected that most of the impacts of climate change will be related to water. At CSU-PA, research is also being conducted to better understand the mechanisms determining the basis of precision irrigation. It has been demonstrated that spatial variability of soil water content exists even in leveled fields. Addressing this variability using precision irrigation could help farmers build resilience to climate changes by increasing their water productivity. Overall, research at CSU-PA confirms that more informed decision can help achieve the goals of CSA.

Keywords. *Climate-smart agriculture, variable-rate N management, precision irrigation, nitrous oxide*

Agriculture is fundamentally associated with the environment and climate where it takes place. Farmers, since the dawn of agriculture, pay a close look at the weather and weather patterns because they know quite well the impact it could have on their earning potential. It is thus important for farmers to prepare and plan for changes associated with climate by adopting mitigation practices and building resilience to climate change. Over the last few years, humankind has witnessed several 1-in-a-1000 year weather events such as droughts in California, Russia and Southwest Australia; flooding in Pakistan and South-Carolina or fires in Alberta, Canada and so forth. Colorado witnessed a 1000 year flood event on September 13, 2013, which greatly impacted many farmers in the state. With the accumulating numbers of unusual weather events, there is little doubt anymore that the climate is changing. In this changing paradigm, farmers have a choice, either to react to such events or to prepare to respond to such changes, irrespective of the cause of the changes. With the advent and accessibility of precision farming technologies, farmers today can prepare better than before by harnessing the wealth of data and translating that into informed management decisions now and in the future.

Climate Smart Agriculture (CSA) is a term that was coined by the United Nation's Food and Agriculture Organization (FAO) and is defined as "*an approach to developing the technical, policy and investment conditions to achieve sustainable agricultural development for food security under climate change. It contributes to the achievement of national food security and development goals with three objectives: (i) sustainably increase agricultural productivity and incomes, (ii) adapt and build resilience to climate change, and (iii) reduce and/or remove greenhouse gas emissions where possible*" (FAO 2015). The CSA initiative is FAO's response to the growing number of farmers challenged worldwide by the effects of climate change on their farm and by the threat that it poses for global food security. Climate-Smart Agriculture aims at helping farmers sustainably increase their profitability, build resilience to climate change and contribute to the mitigation of greenhouse gas emissions.

Precision agricultural techniques and technologies have a significant role and potential for the achievement of CSA goals. In fact there are similarities with precision agriculture. The concept of CSA is based on taking informed decisions for crop management. Because of the great diversity of contexts that exists in agriculture, CSA is not a one-size-fits-all approach, rather a suite of concepts and guidelines to help farmers find the tools, techniques, technologies and sources of information best adapted to local farming context and to use them for the achievement of the CSA goals. Such goals and objectives of CSA are similar to the goals of Precision Agriculture, which is best described by five “R’s”. Application of Right input, at the Right time; in the Right amount; at the Right place; and in the Right manner. When these five “R’s” are brought together, that is when Precision Agriculture comes to fruition. In addition, success of precision agricultural practices relies on being site-specific, locally adaptive, and operationally feasible.

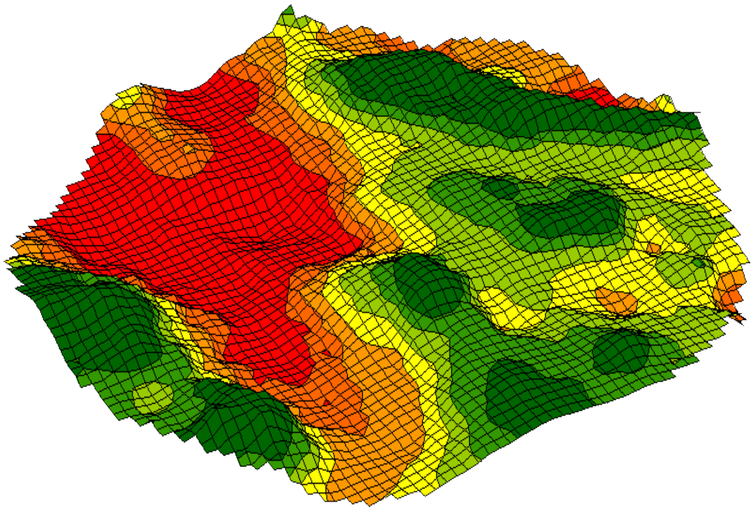
Figure 1. In-field spatial variability and potential nitrogen fertilizer prescription map with differential rates of fertilizer application.

In traditional farming systems, producers apply nitrogen (N) fertilizer at a uniform rate across a given field. However, due to inherent spatial variability in fields, not all areas require the same level of N (Figure 1). Because N fertilizer is inexpensive relative to the value of the crop produced, farmers choose to apply inputs such that a fairly high proportion of the field receives an adequate level of N (Frasier et al., 1999). This results in various areas of the field receiving greater N than necessary and other areas receiving lower N than necessary. The significance is three-fold: 1) excess N is prone to offsite degradation of the environment through runoff, leaching and greenhouse gas emission, 2) additional N is purchased at a cost that may be unnecessary, and 3) certain areas of the field do not reach their full productivity potential. There is a pressing need to improve N use efficiency (NUE) in crops and particularly in cereals (Cassman et al., 2002). Excess N fertilizers often volatilize in the form of nitrous oxide (N_2O) (Eichner, 1990). Because of high amounts of N fertilizers applied but not absorbed by the crop, agriculture is the biggest source of N_2O emissions, which is a gas that has a 298 times more potent greenhouse gas effect than CO_2 (Figure 2). Variable rate N management (VRN) has the potential to improve NUE by better adjusting N rates to crop needs. The objective of this study was to assess the potential of precision N management techniques to improve N use efficiency and reduce N_2O emissions.

Materials and Methods

A case study conducted at Colorado State University’s Agricultural Research Development and Education Center, located in Fort Collins, Colorado (40° 40’ N, 104° 58’ W) in 2010 aimed at comparing three different N management practices in maize: (1) a farmer’s approach which consists of a uniform N application, (2) a variable-rate N application approach based on management zones, and (3) a variable-rate N application approach based on crop-sensing adapted for each management zone (MZRS). Management zones highlighting soil productivity potential were delineated using bare-soil imagery, topography and historical yield (Fleming et al., 1999). A higher N rate was applied in high productivity management zones than in the lower productivity zones. This technique aims at increasing the yield in the high productivity zones and lowering N losses in the low productivity zones where soil factors other than N may limit the yield. Remote sensing (NDVI) was acquired at the V8 (8-leaf) growth stage of maize using a Greenseeker (Trimble Navigation Limited, Sunnyvale, California, USA). The NDVI obtained at the V8 growth stage of maize gave an indication of the crop N status. A pale crop canopy (i.e. low NDVI) was considered as requiring higher N rate than dark green canopy (i.e. high NDVI) where N available to the crop was sufficient. These two approaches (i.e. management zones and proximal canopy sensing) were considered to be complimentary because the management zones approach provided information about the soil and the macro-variability existing in the field while the proximal canopy sensing provided information about the crop and the micro-variability existing in the field. The N rates for the three approaches are detailed in Table 1.

The three N management approaches were compared on the basis of grain yield, N use efficiency and N_2O emissions. Grain yield was acquired at the end of the season using a Case IH model 1660 6-row combine harvester (International Harvester, Racine, Wisconsin) equipped with an AgLeader 2000 yield monitoring system (AgLeader Inc., Ames, IA). Nitrogen use efficiency was calculated in the form of Partial Factor Productivity, which is the ratio of kilograms of grain harvested per kg of N applied in one hectare.

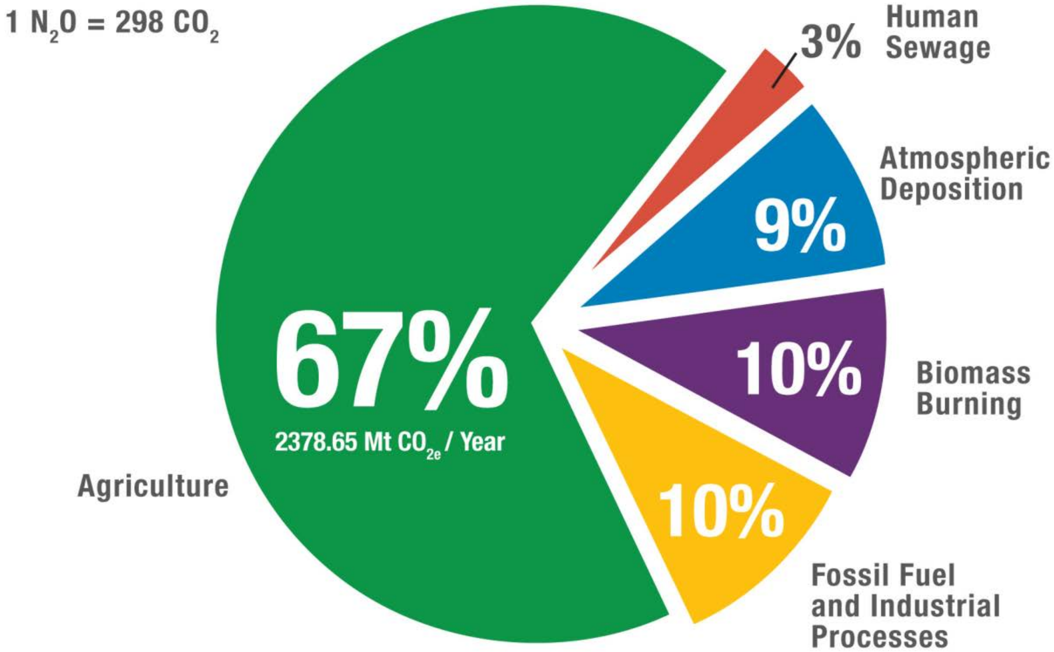

Figure 2. Anthropogenic sources of nitrous oxide in the atmosphere include agriculture, fossil fuel combustion, the burning of biomass, atmospheric deposition, and human sewage. Source: IPCC 2007

Table 1. Explanation of the criteria and treatments corresponding to the different management strategies mentioned in this report. Each nitrogen treatment was applied in each zone and NDVI was collected in each plot. The different N management strategies were simulated in a post-processing of the data.

MZ[1]	NDVI class[2]	N Rate[3]	Weighted average N rate[4]
Farmer's strategy			
-	-	168	168
Management zone strategy			
Low	-	112	168
Medium	-	168	
High	-	224	
Remote sensing within management zones strategy			
Low	High	0	112
Low	Medium	56	
Low	Low	112	
Medium	High	56	
Medium	Medium	112	
Medium	Low	168	
High	High	112	
High	Medium	168	
High	Low	224	

1. Productivity potential management zones based on bare soil imagery, topography and yield history.
2. NDVI classes as determined by K means clustering analysis of NDVI values
3. Nitrogen rate applied at the locations corresponding to the MZ and NDVI classes criteria
4. Average was weighted by the proportion of the area corresponding to each combination of criteria on the total area.

The daily N_2O budget was estimated using the ecosystem model DAYCENT (Parton et al., 1998; Del Grosso et al., 2001). This biogeochemical model estimates the fluxes of C and N in air, plants and soil for a given area (Del Grosso et al., 2008). The outputs of the model include daily N-gas flux (N_2O, NO_x, N_2), CO_2 flux from heterotrophic soil respiration, soil organic C and N, net primary production, H_2O and NO_3 leaching, and other ecosystem parameters (Parton et al., 1998). The required inputs for the DAYCENT model are the daily minimum and maximum temperature, precipitation, management timing and operations such as soil cultivation, planting, crop, fertilizer application and harvest, and soil texture. Climate data were acquired from a Colorado Agricultural

Meteorological Network (CoAgMet) meteorological station located 1.3 km south of the experimental site. The equilibrium for soil organic C was established on 4000 years of native vegetation followed by 46 years of cultivated land (i.e. 28 years of low productivity maize and 18 years of high productivity maize). Three different N management scenarios were tested for year 2010.

A Tukey's Honestly Significant Difference test was conducted to compare grain yield and NUE across the three N management approaches using a significance level of 0.05.

Results and Discussion

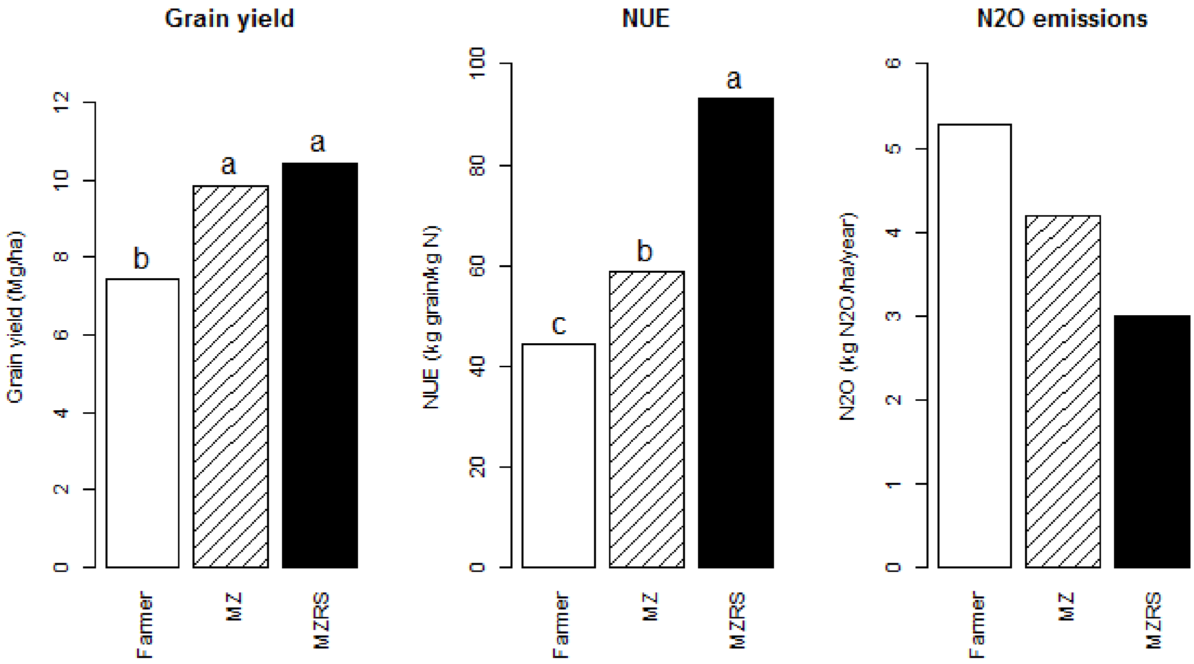

Figure 3. Bar graphs of the difference in grain yield, N use efficiency (NUE), and nitrous oxide emissions across three N management practices: farmer's uniform N management (Farmer), variable-rate N management based on management zones (MZ) and variable-rate N management based on remote sensing within management zones (MZRS). Different letters indicate significant (α = 0.05) differences among treatments.

Results from this case study showed that the MZRS precision N management approach could increase NUE by more than 100% and decrease N_2O emissions by almost 50% without impairing the grain yield as compared to the uniform farmer's approach (Figure 3). This study suggests that significant improvements in precision management of N fertilizer can be achieved by adjusting NDVI based N rate algorithms for each zone independently.

Assessment of the impacts on N_2O emissions modeled in this study shows that, if the benefits associated with precision N management practices were to be extrapolated to the entire corn production area of the US, such VRN practices could offset N_2O emissions by up to 10% overall. Mitigating greenhouse gas emissions using advanced VRN approaches is a "smart" way to practice agriculture. It may not be an exaggeration to couple the Precision Agricultural practices with Climate Smart concepts, which together may be referred to as "Climate Smart Precision Agriculture".

Farming has changed significantly in the recent decades and will continue to change in the years ahead. Farming in the future would mandate adopting climate smart practices to ensure continued increase in productivity, efficiency, profitability while achieving sustainability.

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