ABSTRACT

YIELD, BIOMASS AND NITRATE LEACHING POTENTIAL FOR CAULIFLOWER GROWN ON A SANDY LOAM WITH ORGANIC AND CONVENTIONAL FERTILIZERS

Nitrate contamination in drinking water continues to be a significant unresolved environmental issue worldwide, and in agricultural regions of California. Cauliflower is a shallow rooted crop with high demand for Nitrogen (N), thereby providing a challenge to optimizing yield while minimizing the potential for nitrate leaching. Hence, this study focused on comparing the effects of different fertilizer types and rates on biomass, yield and nitrate leaching potential for drip irrigated cauliflower grown on a sandy loam soil. The experimental layout was a two factor randomized complete block design, with organic soybean meal (ORG) and conventional UAN32 applied at rates of 0, 75, 150 and 225 lbs N/acre. In the study, UAN32 and the ORG fertilizers increased the biomass production by 61% and 30%, respectively, at the two highest application rates. Marketable yields were higher in response to 150 and 225lbs N/acre compared to the 0 and 75lbs N/acre, regardless of the fertilizer type. Post-harvest soil nitrate levels within the top 4 feet increased with application rates for both UAN32 and ORG. Overall, application rates of 225lbN/acre intensified the potential to leach nitrates below the root zone, with an insignificant economic return from adding extra nitrogen. Hence, for the sandy loam soil used in this study it is recommended that N application rates for cauliflower should not exceed 150lbs/N acre, regardless if it is being applied as an organic soybean meal or UAN32 synthetic fertilizer.

Josué Samaño Monroy
May 2016
YIELD, BIOMASS AND NITRATE LEACHING POTENTIAL FOR CAULIFLOWER GROWN ON A SANDY LOAM WITH ORGANIC AND CONVENTIONAL FERTILIZERS

by
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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Plant Science in the Jordan College of Animal Sciences and Agricultural Education California State University, Fresno May 2016
APPROVED

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INTRODUCTION

Agriculture is the base for modern civilization, with the first human settlements being established along rivers around the world in order to support agricultural production and ensure food supply for the society. In general, farming practices are based on models that modify the environment at a certain location to provide a chosen plant with the appropriate conditions to develop and produce food (Rigby & Cáceres, 2001). This basic food production concept seats on the principle of modifying and controlling the environment for agricultural purposes. At the same time, agriculture is controlled by environmental factors that at times cannot be manipulated (Howden et al., 2007).

Although agriculture has allowed human civilization to grow and expand, it continues to be faced with environmental, economic and social challenges in its quest to keep feeding the planet’s rapidly increasing population with diminishing resources. Environmental challenges include factors associated with climate change and global warming, drastic weather events, such as heavy rains in some areas and prolonged droughts in other areas, and the rise in carbon dioxide (CO₂) levels (Howden et al., 2007). In addition, arable land acreage has been decreasing due to depletion of water sources or salinity related problems as well as increased urbanization. Some of the economic factors affecting agriculture production worldwide include the rise of fuel and energy prices, market monopolies and globalization, and the takeover of local small farms by relatively bigger agriculture corporations. A social phenomenon of people migrating from rural farming areas to growing urban cities enhances the current socio-economical structure of agriculture (Tilman et al., 2002). The environmental and socioeconomic challenges for food production are aggravated by high population growth rates.
According to the U.S. Census Bureau (USCB, 2015), human population will grow from 6 billion in 1999 to 9 billion by 2044. This represents a 50% increase that will only take 45 years; as a result, there is a need to increase food production and distribution to supply the future demand. And, there is also a need to do it with limited resources and environmentally sound alternatives. It is also very important to generate more sustainable farming systems that would allow the present generation to get enough food supply without compromising the future generation’s ability to do so (Rigby & Cáceres, 2001).

In summary, the sustainable farming system principle is based on three pillars- it must be economically feasible, socially acceptable and environmentally sound (Rigby & Cáceres, 2001). For the purposes of this study the focus was on the agronomic production (economics) of a cropping system and its impact on the environment. More specifically, the research was conducted on a cauliflower crop grown on a sandy loam soil in Central San Joaquin Valley (SJV) in attempt to assess the potential of nitrate (NO$_3^-$) being leached beyond the root zone. Two Nitrogen (N) fertilizers sources were compared- an organic soybean meal based product (ORG) and the conventionally used Urea Ammonium nitrate (UAN).

Cauliflower (Brassica oleracea var. Botrytis cv Incline) was selected for this study because of its contribution to California’s vegetable industry, its relatively shallow root zone and the amount N commonly applied during the growing season. For example, in 2015 California cauliflower production accounted for 33,900 acres compared to 32,900 acres in 2010, representing a total production value of around 309 million dollars (CDFA, 2015; Geisseler & Horwath, 2015). It is produced along the state in the Central coast, South coast, San Joaquin Valley and southern deserts of Riverside and Imperial Counties (Koike et al., 2009). Cauliflower is practically transplanted and harvested year
round in California, and fields are subjected to high N fertilizer applications to ensure profitable yield. This factor added to the sandy texture of the soils can contribute to ground water nitrate (NO$_3$) loading. Nitrate- nitrogen (NO$_3$-N) is a byproduct of the N fertilizers, and excess amounts in water can be harmful to the environment and the human health. The California Department of Public Health has set the safety threshold value for the NO$_3$-N concentration in drinking water to be under 10 mg/l, and total NO$_3$ to be at a maximum of 45 mg/l (CDPH, 2014).

High nitrate concentrations in drinking water can cause what is commonly referred to as “blue baby syndrome”- methemoglobinemia conditions: a reduction the blood’s ability to deliver oxygen into the organs, resulting in a series of adverse health consequences, mainly affecting young child and pregnant women (Ongley, 1996). In the environment, excessive NO$_3$-N concentrations cause hypoxia and eutrophication of water bodies. Elevated NO$_3$ levels in ground water have been reported in recent studies along California’s agricultural Central Valley, with around 94% of the total NO$_3$-N pollution in groundwater being attributed to cropland (Harter & Lund, 2012).

There is obviously a need to evaluate and implement irrigation and fertilizer management practices that address the issue of nitrate leaching, for various vegetable cropping systems. Hence, the major objective of this study was to compare the effects of ORG and UAN fertilizers, applied at three rates, on the biomass, yield and soil NO$_3$ levels for cauliflower cultivar ‘incline’, grown on a sandy loam soil. The data generated from the study as part of a larger project aimed at optimizing water and N use efficiency in vegetable cropping systems in the SJV, will help in determining the NO$_3$ leaching potential of the cole crops with similar growth characteristics to cauliflower. Subsequently, the findings from this study will guide the implementation of best fertilizer management practices
(BFMPs) for vegetable cropping systems in the on-going efforts of CA growers to maximize agronomic yields and minimize adverse environmental effects.
LITERATURE REVIEW

Cauliflower Production in California

Cauliflower (Brassica oleracea var. Botrytis) belongs to the family of Brassicaceae, also called the Cruciferae family, and known colloquially in North America as cole crops includes broccoli, Brussels sprouts, kale, and collard greens (Murillo, & Mehta, 2001; Koike et al., 2009). It is an annual plant, reproduces by seeds, and is usually cultivated as a cool season crop. The edible part of the plant that is of most commercial interest is the head; a white curd that in physiological term is an immature flower. The crop is believed to have originated in Asia Minor and went through many transformations until it became popular in the Mediterranean region since the 600BC (Rubatzky & Yamaguchi, 2012).

Cauliflower production in California accounts for 86% of the total US production (Geisseler & Horwath, 2015). The harvested area in California for 2010 was 32,900 acres, and the production accounted for 210 million dollars (NASS, 2011). In 2014, the production was 313,6000 tons with an income of 309 million dollars (CDFA, 2015). The Central Coast, South Coast, South Eastern Desert and the San Joaquin Valley (SJV) are the most important producing regions. Around 85% of the total production in the state is located in the coastal regions. Arizona is the second largest producer state, with the regions of the Yuma Valley accounting for only 9% of the US cauliflower production (NASS, 2011).

Nitrogen

Nitrogen (N) is the fifth most abundant element on earth, its most common form is the di- nitrogen (N₂) molecule found in the atmosphere. Nitrogen availability on earth is limited by the fact that around 91.3% in Earth’s core and
mantle, and therefore out of circulation (Ussiri & Lal, 2013). The rest 8.7% is
distributed in the biosphere as follows: 26.04% is geologic N and can be found in
rocks, 73.93% is atmospheric N and is in N$_2$ form, non-reactive inert gas form. A
triple bound molecule that has to be transformed into Nr to be available for life.
The rest 0.03% is reactive nitrogen (Nr), found in the atmosphere, land and water
(Ussiri & Lal, 2013).

In living tissues, N is essential for life, as it contributes to the synthesis of
the two most important polymers in life; proteins and nucleic acids. Along with
phosphorus (P), N is a component of deoxyribonucleic acid (DNA), adenosine
triphosphate (ATP) and phospholipids molecules of cell membranes. While there
is abundant N$_2$ in the atmosphere, this form of N cannot be used directly by plants.
In general, N is used for biological functions in its reactive forms (Nr), and
therefore the N$_2$ has to be transformed either by industrial means or by
microorganism through biological nitrogen fixation (BNF) (Galloway et al, 2008).

Climatic and edaphic factors determine N availability for plants and
mobility in the ecosystem (Barker & Pilbeam, 2015). In general, limited N
availability ultimately determines the development of agricultural and natural
ecosystems. Nitrogen cycling in agricultural operations is determined primarily by
additions of N fertilizer and N outputs like crop removal. In natural ecosystems
there are additional factors that significantly affect N cycling, such as temperature,
soil, vegetation type and BNF. N cycling is also different in a relatively lower N-
level temperate forest compared to a rich in N rain forest. However, there has been
a reported increase of N deposition in North American and European temperate
forest due to N saturation in the global N cycle (De Vries et al., 2009).

Only less than 2% of the earth N is available to living organism, the rest is
in form of sedimentary rocks and in the atmosphere as the triple bounded inert gas
molecule N₂. Nitrogen is subjected to a variety of biochemical transformations due to its range of valence, and its ability to exist in at least eight oxidation states, as it can go from -3 as NH₃ to +5 as NO₃-N. Furthermore, all the transformations are mainly mediated by bacteria and microorganisms and through series or redox reactions (Ussiri & Lal, 2013).

Organisms are essential for maintaining the natural N cycle in balance (Vitousek et al., 2013). For example, N reactions such BNF converts N₂ into NH₄ by a reductive process, whereas Nitrification is a process that oxidizes NH₄ into NO₃. Denitrification, is the anaerobic oxidation of NO₃ and NO₂ releasing N₂. Those N transformations mediated by bacteria and microorganism are part of the N cycle, that is the flow and transfer of N between the atmosphere, oceans, lands and life.

Before human intervention, the N cycle was in equilibrium by the BNF and other reactions. But since the introduction of the Haber-Bosch process for industrial fixation of nitrogen, that equilibrium has been altered. Haber-Bosch process uses N₂ and H₂ to create NH₃, and currently dominates the transformations of N₂ into Nr, replacing BNF as main source of Nr to the environment (Galloway et al., 2008). This anthropogenic alteration of the N cycle has been causing a series of environmental consequences with N saturation.

**Nitrogen Cycle**

It is also important to understand the N cycle and how the N flows into the troposphere and pedosphere going through transformations that make life possible on Earth. There are N additions to the soil that make it available for plant use. There is also N fixation by microorganisms and bacteria that have the ability to take atmospheric N₂ and nitrify it into the soil. N fixation by lightning produces
conditions of excessive heat and energy that can break down the strong triple bound of the N\(_2\) molecule and separate the N making it react with O\(_2\) to form NO. This makes the N available to react with oxygen and produce NO\(_2\) continuing into the cycle by the so-called atmospheric deposition. N additions to the soil can also occur via the decomposition processes taking place primarily in the soil surface. Organic matter from plant and animal sources decomposes and releases N back into the soil to continue with the cycle. And, the most recent N addition is made by human activity when synthetic N fertilizers are incorporated in the soil.

The N transformations taking place in the nitrogen cycle are the atmospheric N\(_2\) going into NO\(_3\) by N fixation process. The mineralization of organic N to inorganic forms (NH\(_4\)) available for plant uptake or to nitrification; the process by which NH\(_4\) is transformed to NO\(_2\) and consequently into NO\(_3\) by certain soil microorganism that make it available for plant uptake at different physiological growth stages. The N immobilization into organic forms, is a process promoted by soil biota that take up nitrogen for their living functions and cycles, making it unavailable for plant uptake.

The N losses from the soil are accounted for by volatilization in the form of NH\(_3\), enhanced by relatively high pH (more than 7.4) on calcareous soils, which contain low H\(^+\) ions. These soils will favor volatilization by its low conversion rates from NH\(_3\) to NH\(_4\) that would remain in the soil for plant uptake. Also in moist soils, volatilization is favored. Denitrification is a process promoted by heterotrophic bacteria, which reduces oxidized forms of nitrogen (NO\(_3\)), making it unavailable for plant uptake (Barker & Pilbeam, 2015).

By applying the above concepts to a farm scale results in the consideration of N budgets or N balances. This approach involves all those nitrogen, additions, losses and transformations mentioned above. At the farm level, the N-budget
accounts for all the inputs, an outputs, sources, sinks, and transformations by which the nitrogen (N) passes through (Barry et al., 1993). Some components of the N-budgets, depending on the purpose of the study, include fertilizer, manure, crop residue as inputs and harvested crop, atmospheric losses, nitrates leaching as nitrogen outputs. Figure 1 is an example of the on-farm N-budgets.

**Figure 1: On farm nitrogen budget that accounts for inputs and outputs.**

**Green Revolution**

Nitrogen fertilization has been around since the agriculture started, but traditional N fertilization included manure and compost applications to increase soil fertility. Then, after the so called Green revolution from the 1930s-1960s, a period of technology transfer, research and development that was characterized by the technological spread around the globe, there was exponential increase in the use of synthetic N fertilizers (Evenson & Gollin, 2003). Since then, the technology which already existed in developed countries started being promoted in the rest of the world. This resulted in the distribution of high-yielding cereal grains varieties, hybridized seeds, synthetic fertilizers, pesticides, irrigation systems, and heavy
farming machinery to replace animal traction on the farm to a tractor. With this exposure to the technology, research centers were established during and after the green revolution, improved varieties for rice, wheat, and maize were developed, and subsequently there was an overall significant beneficial effect on food production as global crop yields increased (Evenson & Gollin, 2003). From the 1960s to date, the world population has almost doubled with overall food production per capita also being higher than it was in the 1960s (Hedden, 2003). The combination of the high yielding varieties, the intensive use of fertilizers and pesticides of the industrial agriculture has allowed this increase in the food production.

The fact is that as the production increased with the green revolution techniques, the amount of energy input to produce a crop increased faster than the yield. For example, the implementation of heavy farming machinery are completely reliant on oil for its field operations, and it now takes more energy input to produce a crop than it took before the green revolution. After the so called green revolution, the yields per unit of land increased, but the new food production system became more dependent on oil to run the agricultural production industry around the globe (Tilman, 1998). In addition to fossil fuel usage, these green revolution techniques rely on the extensive use of pesticides, herbicides and synthetic fertilizers- primarily N fertilizers- that in turn depend on oil for their production (Evenson et al., 2003).

**Nitrogen Fertilization**

After the second half of the XIX century the introduction of mineral fertilizers to add nutrients to agricultural lands became indispensable for increasing crop yields and boosting overall crop production (García-Garizábal, 2012). Fertilizers, and in particular N, are the second most important agricultural
input after water, since they supplement the essential nutrients for plant growth and yield increases. Nowadays, N fertilizers exist in a variety of chemical and physical forms. For example, it can be applied as a side dress or in the irrigation system. Furthermore, the fertilizers available in the market usually contain more than one nutrient in addition to N, such as the three most commonly applied macronutrients- nitrogen (N), phosphorous (P) and potassium (K).

Plants can take up N in two forms; as ammonium nitrogen (NH$_4^+$-N) nitrate nitrogen (NO$_3^-$-N). Some of the commercially available products containing these forms of N are anhydrous ammonia, urea, ammonium nitrate, urea-ammonium-nitrate (UAN), ammonium sulfate, diammonium phosphate (DAP), and, monoammonium phosphate (MAP) (Agronomy Guide, 1999/2000). The presence of N is essential for plant vegetative growth and biomass production. It is the fourth most important bio element after carbon, oxygen and hydrogen and is also the fifth most abundant element on Earth (Ussiri & Lal, 2013). In living tissues, N is essential, as it contributes to the synthesis of the two most important polymers in life: proteins and nucleic acids.

An adequate N supply in plants is indicated by dark green color in leaves and plant vigor. An N deficiency results in poor plant performance and yield losses, with the following symptoms (Barker & Pilbeam, 2015): stunted plants as the cells remain small and their cell walls become thicker; visual yellowing of leaves known as chlorosis; and, acceleration of the reproductive stage and senescence. Hence, a judicious N fertility management program and sound agronomic practices are needed to ensure efficient use of N fertilizers. Recent guidelines such as Best Fertilizer Management Practices (BFMPs) are important tools to achieve sustainable agricultural production (Roberts, 2007). Although synthetic fertilizer use has revolutionized the Ag industry with increased yields,
and more production per unit of land, there will always be a need to evaluate N fertilizer use efficiency in the cropping systems with the introduction of emerging irrigation technologies and improved cultivars. In addition, it is also worthwhile conducting similar evaluations in cropping systems that substitute the use of synthetic fertilizer with organic based fertilizers, approved for use in organic farming.

**Organic Fertilizers**

Organic agriculture is one of the fastest growing segments of U.S. agriculture (USDA-ERS, 2014). Consumer demand for organically produced goods has shown double-digit growth, providing market incentives for U.S. farmers. Organic sales account for over 4 percent of total U.S. food sales, though organic products account for a much larger share in some categories (USDA-ERS 2014). Producers are turning to certified organic farming systems as a potential way to lower input cost, decrease reliance on nonrenewable resources, capture high-value markets and premium prices, and increase farm income. Organic farming systems rely on ecologically based practices such as cultural and biological pest management, and virtually exclude the use of synthetic chemicals in crop production (USDA-ERS, 2014). Organic principles are based on the understanding the soil biology and the principle of work with the nature rather than try dominate it.

In long term studies with organic farming systems, the overall nutrient input has been found to be reduced by 34 to 51%, with pesticide use also reduced by 97% and only a 20% yield reduction was reported (Mäder et al., 2002). Yield reductions in organic farming as compared to conventional vary among the type of crops and region. For example, in Europe for organic grassland production, the
yield ranged from 70 to 100% of the conventional system yield (Mäder et al., 2002), but the profits of the organic farm were comparable with conventional farms. Organic farming systems provide greater soil stability and biodiversity, and in the long term enhance soil fertility and reduce synthetic fertilizer dependence (Rigby & Cáceres, 2001). Generally, organic farming practices are associated with overall soil fertility benefits and environmentally sound alternatives of produce agricultural goods (Mäder et al., 2002). Nonetheless, while the utilization of non-synthetic fertilizers which are approved for organic farming might be beneficial in the long term for the farmers, consumers and environment, there is still a need to evaluate the NO₃ leaching potential of these products. More importantly, regardless of whether the fertilizer source is synthetic or approved for organic farming, it is critical to assess the efficacy of any N fertilizer management program by calculating the overall N balance over the cropping season.

Nitrogen (N) Balance

An N balance is one method used to quantify different components that introduce and remove N from the farm, field, growth season, or over the duration of a crop rotation. In this approach, the unit of interest (e.g. farm, field, or cropping season) is seen as a box where there are inputs and outputs (Barry et al., 1993). The N balance considers all the inputs necessary to agricultural production in terms of N additions such as fertilizers, seeds, manure, N in irrigation water, atmospheric deposition, mineralization, nitrogen fixation, livestock purchases and other any other process or action that could add N to the farm. It also considers the outputs, in terms of crop removal, animal sales, volatilization, and leaching (Goss & Goorahoo, 1995).
Recent concerns about groundwater contamination have pointed farming practices as the main source of groundwater N loading. There is a need for a source of information that could help to account and mitigate N loading into groundwater. The N balance approach on farming systems is commonly used to estimate the potential for N leaching (Fried et al., 1976). This approach takes the assumption that with the continuous nitrogen flow through the soil profile, the soil reaches a steady-state of nitrogen content that will only leach and be replaced with the new input (Barry et al., 1993). Therefore, to estimate the N leaching potential of crop, an N balance can be used to obtain the difference between the N inputs such as fertilizer addition, irrigation water, precipitation, atmospheric deposition, manure, etc. and N outputs such as harvested crop, nitrous oxide emissions by denitrification process and any other data that could be available. Any “extra” or surplus N, is then assumed to potentially available for leaching beyond the root zone and into the groundwater.

**Nitrate Leaching**

To ensure high yields, over N fertilization can be a common farming practice based on the current costs of N fertilizers. Generally, any plant available N in the soil can be subjected to losses from within the root zone by the leaching process. The addition of N in excess of the plant needs, combined with indiscreet irrigation has been responsible for elevated nitrate levels in groundwater (Harter & Lund, 2012). This is because the movement of the N in the soil obeys to soil water dynamics since N is “carried out with water”.

The increase in nutrients additions into the farmland improved the yields significantly, but it also increased the pollution from farming practices. The fertilizer additions increased the available N for plant uptake, and therefore the
potential for nitrate (NO₃-N) leaching. This condition of abundant N in the soil combined with heavy irrigation practices led to the contamination of groundwater aquifers, rivers and lakes by nitrate leaching and runoff from farms (Min et al., 2012). Nitrogen movement along the soil profile is determined by hydraulic principles, the water dissolves the NO₃ ion and carries it. For example, even in the vadose zone, there may be condition when the soil becomes saturated, and gravitational flow, as opposed to capillary flow, predominates. Under these conditions the soil solution will transport any unused plant available N down the profile, until the ionic constituents reach the groundwater aquifers. N source, application rates, crop assimilation capacity and irrigation practices will determine the nitrate leaching below the root zone. The nitrate that runs below the plant root zone cannot be assimilated by the crop and therefore it becomes potential NO₃-N to be leached, which will pollute water bodies (Zotarelli et al., 2009). Proper irrigation management has proven to be important for decreasing almost 50% of the nitrates carried out to aquifers and rivers, especially when the fertilization rates were still high when compared to the crop needs (García-Garizábal et al., 2012).

**Nitrate Contamination in Water and Environment**

High concentration of nitrates in water represents adverse environmental consequences. It can cause eutrophication in water bodies; when a water body receives excessive concentration of nutrients, especially nitrates and phosphates (Edwards et al. 2008). This condition causes excessive growth of algae, which through the process of photosynthesis starts to consume the dissolve oxygen concentration in water. When the alga die and decomposes, high levels of organic matter and the decomposing organisms through reduction reactions deplete the water available oxygen, causing what is known as the “death” of a water body.
The low dissolved oxygen levels lead to a massive death in all present living organisms in the water that depend upon oxygen for vital processes.

Water bodies that are depleted of dissolve oxygen concentration are called anoxic waters by the US Geological Surveys, and this institute defines the anoxic waters as those in which total dissolve oxygen levels are less than 0.5 mg/l. The presence of excessive nutrients in water causes a misbalance in the natural ecosystems. Some visual signs of water bodies with elevated nutrients are those rivers and lakes that turn into greenish coloration due high algae populations, the lake can also start to host large populations of other aquatic plants such as water lilies. The NO₃-N pollution is very visible and can also be responsible for massive fish death. Environmental agencies have turn their attention into the issue because of the reduction in fish populations due to habitat destruction, the Colorado Department of Public Health, Water Quality Control Department, the optimal dissolved oxygen concentrations in water for fish life is 9-12mg/l.

The major environmental consequences for the presence of elevated nitrates in water can also have social and economic impacts. Such concerns have put researchers and government agencies to work together and focus efforts on measure and quantify nitrate concentration on aquifers, wells, rivers, lakes, and drinking water. The objective is to develop strategies to measure, monitor, manage and reduce the nitrate contents in water and its negative effects. Farm N budgets, BFMP’s, the implementation of irrigation and drainage systems, improved water use efficiency as well as nitrogen leaching studies are part of the efforts and actions that would help mitigate and control the high nitrate loading in the water sources (Ongley, 1996). The current study will contribute to these on-gong research efforts.
The Nitrates in California Drinking Water Report (Harter & Lund, 2012), used a mass balance approach to estimate nitrate loading into the groundwater basins in Tulare and Salinas areas in California. Some of the results point cropland and other farming activities are the principal sources of nitrate loading accounting for 96% of the total including municipal sewage systems and food processing plants. The sandy texture of many of the agricultural soils in California enhances the NO$_3$-N leaching. In the San Joaquin Valley, the vegetable cropping systems are subjected to high nitrogen rates to ensure high yields. Heavy irrigation practices and poor designed drainage systems combined with the sandy soils and high nitrogen rates in the cropland contribute to load the groundwater basins in the Valley with large amounts of NO$_3$-N (Zotarelli et al., 2007).

**Elevated Nitrate Contents in Drinking Water**

Nitrate contamination in water is a significant unresolved environmental issue worldwide, nitrate in ground water is a byproduct of nitrogen, the major input in the industrial agricultural production; however, excess nitrogen content in the water can harm the human health. The California Department of Public Health has set the max concentration of nitrate (NO$_3$) in drinking water as 45mg/l (CDPH, 2014).

Drinking water with high nitrates concentration can lead to a condition called methemoglobinemia (CDPH, 2014), which is an increase in the production of methemoglobin in the blood, decreasing the blood’s ability to release oxygen to tissue and organs, causing hypoxia conditions. The low oxygen concentration does not allow proper cell respiration. The greatest consequences for the high nitrates concentration in water is for infants, who are more susceptible to absorb nitrates into the bloodstream causing the “Blue Baby Syndrome”; a condition that can be
observed when there appears blueness in the infant’s feet, hands and around the mouth, it can cause diarrhea, vomiting, trouble breathing, and in some cases it can be fatal. High nitrates levels also affect pregnant women (CDPH, 2014).

Many small communities cannot afford safe drinking water; mainly areas located near farmland are the most affected. To provide safe drinking water to those communities represents a very high economical cost in terms of municipal water supply system installation or treatment plants. Remove nitrate from large groundwater basins is extremely costly and not technically feasible solution. The California’s Drinking Water technical report identifies that there is a high cost for NO₃ remediation in groundwater. The cost is associated with providing affected people with safe drinking water and also remediating environmental consequences. One of the proposed sources of income to assume part of the cost is to tax farmers a higher rate for the use of nitrogen fertilizer, which is the main source of NO₃-N in groundwater. In this fashion provide with an economic incentive for farmers to become more efficient in the fertilizer use and be able to reduce the NO₃-N loading in groundwater.

Irrigation management and drainage to reduce nitrate leaching and promote nitrogen use efficiency are by far the most feasible alternatives to reduce the nitrate contamination in water (Zotarelli et al., 2007). Nitrate leaching studies are needed to account for the nitrate leaching potential in the cropping systems.
STATEMENT OF PROBLEM

Prevailing farming practices of over fertilizing crops since the so-called “Green revolution” and the relatively cheap production of synthetic fertilizers have resulted in extensive groundwater pollution. The NO$_3$-N that is present in today’s drinking water dates back some 50-30 years; the time that takes to nitrate to travel down the soil profile into the groundwater. Recent concerns about high levels of NO$_3$-N in water are leading to new regulations regarding N management practices in important agricultural regions worldwide (Zotarelli et al., 2009). A better understanding of the factors affecting N contamination in water is essential in preventing adverse environmental, economic and public health N-related consequences. Nitrogen fertilization is the main source of nutrients added to the crops in order to increase yield and biomass production (Barker & Pilbeam, 2015). Current agricultural output would be hard to accomplish without the use of synthetic or organic N fertilizer additions to the soil to meet crop demands. Thus, it is important to understand the dynamics involving plant-soil-water relationships. Ultimately, there is a need for the implementation of BFMPs in an effort to achieve more efficient fertilizer use, increase crop nitrogen uptake, and reduce N leaching, thereby maintaining the sustainability of any cropping system. A primary step in achieving this goal is to quantify NO$_3$ levels in soil and plant tissue for a given crop, and then assess the NO$_3$ leaching index and its potential for groundwater contamination.

This study focused on analyzing yield and biomass production, as well as accounting the NO$_3$-N leaching potential, for a cauliflower cropping system on a sandy loam soil. This soil texture allows the water to percolate and carry NO$_3$-N down to the ground water. By comparing the impacts of an organic (ORG) and a
conventional (UAN) fertilizer applied at 75, 150 and 225 lbs/N per acre on a sandy loam soil, the study represented existing field conditions for a large portion of the SJV, where vegetable cropping systems and N fertilizations can have a major impact groundwater NO$_3$-N levels.
OBJECTIVES AND HYPOTHESES

Based on the identified priorities for BFMP and Nitrate Leaching Potential (NLP), this research focused on the comparison of the NLP for cauliflower treated with an organic soybean based (ORG) and conventional urea ammonium nitrate-32 (UAN) fertilizers.

Specific objectives were to:

1. Compare the effect of ORG and UAN fertilizers at three different rates on cauliflower above ground biomass production;
2. Compare the effect of ORG and UAN fertilizers at three different rates on cauliflower yield;
3. Quantify pre plant and post-harvest soil NO\textsubscript{3} levels within the top 4 feet of soil for the plots subjected to different rates of ORG and UAN;
4. Determine soil leaching index (LI) for the cauliflower subjected to ORG and the plots treated with UAN at three different rates;
5. Formulate a partial N budget for the cauliflower grown with the two fertilizers at three rates; and,
6. Characterize the spatial and temporal variability of NO\textsubscript{3}-N concentrations in solutions extracted with soil solution access tubes (SSAT) at depths of 12 and 24 inches.

By studying the dynamics involving N fertilization and NO\textsubscript{3}-N leaching; main effects and interactions of fertilizer type and rate can be found and attributed to current farming practices that result in ground water pollution. By testing fertilizer type by rate with harvested yield, data to nourish BFMP on cauliflower grown on a sandy loam soil was also assessed. Hence, the ultimate purpose of this study was to compare NLP for the cauliflower grown with ORG and UAN.
fertilizers at different rates. A better understanding of the production conditions that are driving \( \text{NO}_3^- \)-N leaching into the groundwater, along with the yield and biomass production data, would help to improve the implementation of BFMPs than can eventually reduce environmental and human health risks, associated with N fertilization without compromising crop production output.
MATERIALS AND METHODS

Location
The study was located at the California State University, Fresno Farm (36°48’55.42”N latitude and 119°43’56.52”W longitude). The soil type at the study site is classified as a well-drained Hanford fine sandy loam, with an average pH of 7.0.

Experimental Design
The study focused on the comparison of the potential for NO$_3$ leaching for two cauliflower crops with cultivar “incline,” planted in Fall 2014 and Fall 2015. The comparison of the NO$_3$-N leaching potential and plant response was for a soybean based organic fertilizer 7-1-2 and the conventional UAN-32 applied at three N fertilizer rates; 75, 150 and 225 lbs/N acre and a Control with no fertilizer addition. Hence, there were seven treatments as described in Table 1 with the following codes; Control, ORG1, ORG2, ORG3, UAN1, UAN2 and UAN3 replicated five times, resulting in a total of 35 plots.

Table 1: Fertilizer treatments. “None” means no fertilizer addition, “Organic” represents the organic fertilizer soybean meal 7-1-2, and “Conventional” represents the UAN-32.

<table>
<thead>
<tr>
<th>Code</th>
<th>Fertilizer Type</th>
<th>Fertilizer Rate (lbs/N acre)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>None</td>
<td>0</td>
</tr>
<tr>
<td>ORG1</td>
<td>Organic</td>
<td>75</td>
</tr>
<tr>
<td>ORG2</td>
<td>Organic</td>
<td>150</td>
</tr>
<tr>
<td>ORG3</td>
<td>Organic</td>
<td>225</td>
</tr>
<tr>
<td>UAN1</td>
<td>Conventional</td>
<td>75</td>
</tr>
<tr>
<td>UAN2</td>
<td>Conventional</td>
<td>150</td>
</tr>
<tr>
<td>UAN3</td>
<td>Conventional</td>
<td>225</td>
</tr>
</tbody>
</table>
The products used in this study for the Organic fertilizer (ORG) was a slow release soybean meal 7-1-2 commercially available as Phytagrow pellets, and the Conventional fertilizer (UAN) was UAN-32, urea-ammonium-nitrate, a liquid fertilizer commonly used in commercial operations.

The experimental layout was a two factor randomized complete block design (RCBD). The field layout was composed of 35 plots, 15ft wide by 12ft long arranged in five blocks. The beds were 5ft wide by 84ft long. Each block was composed of seven plots arranged in line and the final field dimensions were 75ft wide by 84ft long (Figure 2). Each plot was composed by three beds with the objective of conserving the middle bed for sampling and using the two outer border beds as buffers among the treatments. Wooden stakes were placed and labeled to separate and differentiate each plot. The field was fenced using chicken wire to prevent rabbits and other rodents from eating the plants. In addition, reflective tape was installed to deter birds from damaging the drip lines.

**Irrigation**

The field was irrigated with a surface drip irrigation system consisting of two lines per bed located in the inner part of the bed with 12 inches of separation. The drip tape was a Eurodrip 5/8 “seamless classic, 10 mil, 12” inches emitters spacing, 0.4 gph at 10psi or 0.58 gpm/100ft at 10psi. An Orbit 4 station Easy-Dial Electrical Timer was installed to control the irrigation. A manifold with two manual valves, one automatic valve, filter, pressure gauge and flow Metter was also installed as a part of the irrigation system.

**Fertilization**

The conventional plots were fertilized using a liquid urea-ammonium-nitrate 32, commonly known as UAN-32. The nitrogen from this fertilizer is
Figure 2: Experimental field layout for the randomized complete block design, seven treatments, 35 plots and five blocks.

Available is three forms; urea, ammonic and nitrate, from the solution ¼ is nitrate, ¼ ammonic and ½ is urea.

The organic plots were fertilized with a soybean meal based organic fertilizer and the nutrient composition is 7-1-2 for %N, %P₂O₅, and %K₂O, respectively. The information provided by the fertilizer manufactured is; commercial name: Phyta-Grow Leafy Green Special 7-1-2. Total nitrogen 7% (6%
water soluble organic nitrogen, 1% water insoluble organic nitrogen), available phosphoric acid 1%, soluble potash 2%. There were two fertilizer additions during the growing season and both UAN-32 and organic fertilizer additions were done by hand due to the nature of the experimental design on the field.

**Nitrate Leaching Measurements**

To quantify the nitrate leaching potential below the root zone of the crop, soil solution access tubes (SSATs) were installed to extract the soil solution at depths of 12 and 24 inches below the soil’s surface. The SSAT’s are manufactured by the Irrometer Company, and consisted of a ½-inch outside diameter polyethylene tube that extended to a desired length, with a porous ceramic tip, that allowed the soil solution to flow into the evacuated ceramic cup. The top of the SSAT was sealed with a rubber cap fitted with two capillary tubes to facilitate evacuation of the SSAT and collection of the soil solution from the porous cup.

The SSAT’s were placed vertically at 12 and 24 inches below the soil surface targeting the major volume of the root zone where the most significant nutrient absorption was expected to occur. On average the majority of a well-ramified root system for cauliflower can be found within the first 12 inches deep. Nitrate leached below 24 inches was therefore assumed to be potentially available for leaching (Weaver & Bruner, 1926). One 12 inches and one 24 inches SSAT were installed randomly in three out of five replications per treatment, with a total of 21 plots and 42 SSAT’s.

To supplement the soil solution information that could be useful in estimating the nitrate leaching, soil samples from the top 4ft were taken in 1 foot increments and analyzed to for soil NO₃-N concentrations. With the nitrate
concentration from the soil, the leaching index (L.I.) was calculated using the following formula adapted from Machet and Mary (1989):

\[
LI = \frac{\text{Amt.of NO}_3\text{-N (12–48 inches)}}{\text{Amt.of NO}_3\text{-N (0–48 inches)}}
\]

The LI from each plot was an estimate of the amount of NO$_3$-N below the top 12-in of soil in relation to the total NO$_3$-N content within the top 48-in of the soil depth.

**Sampling**

The Soil Solution Access Tubes (SSAT’s) were considered to be a suitable technique to monitor N leaching in non-structured soils (Webster et al., 1993). Solution samples were collected every week using a vacuum pump to apply 70 kPa of suction to the SSAT’s in order to generate a negative gradient and capture water. The solution samples are collected 24 h after the vacuum was applied (Zotarelli. et al., 2005). For this experiment the solution samples were also taken after any rain event.

To monitor soil moisture a Diviner 2000 was used and five access tubes were placed in the field. This is a portable device that consists on a display unit and a probe that measures soil water every 10cm when it is inserted in the access tube. (Sentek). Those readings were used to take decisions on irrigation practices, and for this study were only to monitor and record moisture trends along the season.

Soil was also sampled to determine the existing amount of NO$_3$-N and total nitrogen present at the moment of planting (Carter, 1993). Soil samples were taken pre-planting and post-harvest in the field at four depths; 12, 24, 36 and 48 inches in each of the 35 plots using soil auger to obtain a representative amount of soil.
A total of 140 soil samples were collected every sampling event to complete a total of 280 samples in each one of the two years of study.

To obtain yield and biomass production data, the cauliflower plants were harvested at maturity in each season. Each plot was composed by three beds wide by 12ft long. The plants were harvested from the middle bed, using the first and third bed as buffer from other treatments at the sides. To separate from subsequent treatments, the four plants were taken from the middle of the central bed, leaving 4ft in the head and 4ft in the tail of the bed.

Head and leaf were cut at the above ground level. Each head was weighted and diameter measure was taken, then chopped and placed in a labeled paper bag. Leaves were also weighted, chopped and placed in paper bags. After obtaining head fresh weigh and diameter, and leave fresh weight, the bags were send to dry in convection oven set at 65°C during 48 hours. After drying the samples were weighted again to obtain dry weight and calculate above ground biomass production.

**Samples Analysis**

For the soil solution and soil samples, nitrate concentrations were determined using a SEAL AQ2 Discrete Analyzer designed for environmental samples including water, soil and plant extracts. The AQ2 uses a 100% optical quality glass cuvette used for precise absorbance measurements, 10mm optimum path length, reagent wedges with on-board cooling, use only 20ul-400ul reagent per test, disposable reaction wells, cadmium coil for reduction of nitrate/nitrite determination, and a flexible software to manage the analyzer and indicate the desired test.
For determining the nitrate levels in the water extracts, the EPA-114-A Rev 9 method was used. In summary, a cadmium coil reduction process is followed by sulfanilamide reaction in the presence of N-(1-naphthylethylenediamine) dihydrochloride. The detection limit was 0.03 mg N/l with a range of 0.25 to 15 mg N/l.
RESULTS AND DISCUSSION

Aboveground Biomass Production

For this study two years of data were collected from field experiments in 2014 and 2015. First, the pooled data from both years was analyzed to test for any significant differences among years due to environmental factors that might differ from year to year and could potentially have an effect on the results. Analysis of variance (ANOVA) indicated that year had a significant effect on yield (Figure 3), and biomass (Figure 4) in 2014 and 2015 years of study (P=0.000). Hence, for consistency all other parameters measured throughout the experiment were analyzed separately on 2014 and 2015 data for the effects of fertilizer type and rate.

Figure 3: Mean cauliflower biomass production by year in 2014 and 2015.
Environmental Factors Affecting Plant Development

Plant development takes place in the phytosphere; here all the environmental factors form the plant habitat and include factors such as sunlight, water, temperature, moisture, energy flows (Larcher, 2003). The interactions between the plant and these environmental factors determine the overall plant growth. In this study the solar radiation, air temperature and relative humidity were measured and recorded from the on-farm CIMIS weather station to identify some of the factors that influence plant growth, biomass and yield production as well as the amount NO$_3$-N in the soil that is potentially available for leaching beyond the rootzone.

Figure 4: Mean cauliflower yield by year in 2014 and 2015 (kg).
Solar Radiation

Plant growth is affected by solar radiation, since sun is the source of energy that allows the photosynthesis process; a photochemical process driven by the absorption of photons by chlorophyll (Pearcy, 1991). For this study the solar radiation was measured in Langley (Ly) a unit used to measure solar radiation, also called “density of heat”. The solar radiation was recorded every day along the season from the on-farm CIMIS weather station (Figures 5 and 6), to observe variation how would the radiation would affect plant development.

Figure 5: Solar radiation (Ly/day) along the season in 2014.

Figure 6: Solar radiation (Ly/day) along the season in 2015.
Air Temperature

Figures 7 and 8 show the variations in average daily air temperatures during the growing season for cauliflower planted in 2014 and 2015, respectively. Air temperature is fundamental for plant development, because it affects the rates of metabolic activity in the plant (Pearcy, 1991). This parameter is of fundamental importance in crop production, plant physiology changes in function of the air temperature. It also affects evapotranspiration, the temperature influences the speed in which the water will evaporate from the leaf surface and helps to generate the negative potential in the roots to absorb water from the soil.

![Avg Air Temp (°F), 2014](image)

Figure 7: Average air temperature measure in Fahrenheit degrees along the season in 2014.

![Avg Air Temp (°F), 2015](image)

Figure 8: Average air temperature measure in Fahrenheit degrees along the season in 2015.
Relative Humidity

Figures 9 and 10 show the variations in average daily relative humidity (RH) during the growing season for cauliflower planted in 2014 and 2015, respectively. Relative humidity is an important factor in crop growth, as it directly influences evapotranspiration rates, and therefore plant water usage and irrigation scheduling. It can also allow for the development of fungal pathogens and cause an economic damage to the crop. Usually, when the relative humidity is high and the temperature ranges from 21°C to 30°C pathogens tend to thrive and damage the plant (El Hadrami et al., 2010). The combined effects of solar radiation, air temperature and RH can influence crop yield and overall biomass production.

Figure 9: Average relative humidity along the season in 2014.

Figure 10: Average relative humidity along the season in 2015.
The above climatic factors would also have an effect on plant development, biomass production and marketable yield. Climatic conditions would also influence NO$_3$-N leaching potential, since they affect evapotranspiration, water infiltration, and microbial activity in the soil that will influence mineralization rates.

However, the main objective of this study was not to compare results between years, but to acknowledge the climatic factors that influence plant development, biomass production and marketable yield for each year of crop growth. The main objective of this study was to compare the effect of different fertilizer types and rates on biomass and yield production, as well to account for NO$_3$-N leaching potential for each of the treatments.

Cauliflower Total Aboveground Biomass Production

Cauliflower total aboveground biomass was measured in grams (g) and obtained by drying leave and shoot at 65°C for 48 hours. The dry weight was used to compare the biomass production for the different treatments (Table 2 and Figure 11).

Table 2: Total aboveground biomass production (g) in response to the different treatments for 2014 and 2015 and also percentage increase in biomass production from 2014 to 2015.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Control</th>
<th>ORG1</th>
<th>ORG2</th>
<th>ORG3</th>
<th>UAN1</th>
<th>UAN2</th>
<th>UAN3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2014</strong></td>
<td>127.6</td>
<td>144.7</td>
<td>135.0</td>
<td>146.5</td>
<td>136.8</td>
<td>140.0</td>
<td>135.0</td>
</tr>
<tr>
<td><strong>2015</strong></td>
<td>288.0</td>
<td>292.2</td>
<td>395.0</td>
<td>435.0</td>
<td>357.5</td>
<td>492.5</td>
<td>540.5</td>
</tr>
<tr>
<td>% increase from <strong>2014-2015</strong></td>
<td>125%</td>
<td>102%</td>
<td>192%</td>
<td>197%</td>
<td>162%</td>
<td>251%</td>
<td>300%</td>
</tr>
</tbody>
</table>
Biomass in Response to Fertilizer Type

The average aboveground biomass production was 127.6 ± 6.67, 142.05 ± 3.85 and 137.0 ± 3.85 respectively for Control, Organic and Conventionally fertilized plots in 2014 (Table 3). Aboveground biomass production showed no significant difference among the fertilizer types (P> 0.05) (Figure 12). However, when comparing Control and Organic, there was a 12% increase with the use of Organic (P= 0.06) (Figure 12), which might justify organic fertilizer addition if greater biomass production is desired (Table 3).

Table 3: Average (± S.E.) aboveground biomass production in response to fertilizer type in 2014 and 2015.

<table>
<thead>
<tr>
<th>Fertilizer type</th>
<th>2014</th>
<th>% increase</th>
<th>2015</th>
<th>% increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>127.6 ± 7</td>
<td>287.9 ± 32</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Organic</td>
<td>142.0 ± 4</td>
<td>374.0 ± 19</td>
<td>30%</td>
<td></td>
</tr>
<tr>
<td>Conventional</td>
<td>137.0 ± 4</td>
<td>463.4 ± 19</td>
<td>61%</td>
<td></td>
</tr>
</tbody>
</table>

Figure 11: Aboveground biomass production in response to fertilizer treatments in 2014 and 2015.
For the 2015 field study, the average aboveground biomass production (g) 287.9 ± 32.4, 374.0 ± 18.7, 463.4 ± 18.7 respectively for Control, Organic and Conventional plots (Table 3). For this year, aboveground biomass production showed a significant difference among the fertilizer types (P= 0.001) (Figure 13). With the addition of Conventional fertilizer, there was an increase of 61% of total aboveground biomass production as compared to Control (Table 3). And a 30% increase with the use of Organic versus Control (Table 3). Cutcliffe & Munro
(1976) have reported a significant response of cauliflower to N fertilizer applications on yield and biomass production.

Figure 13: Above ground biomass production per fertilizer treatment in 2015.

**Biomass Production vs Rate**

Fertilizer rate was also tested on biomass production. For 2014, total aboveground biomass production did not show a significant difference between fertilizer rates (P> 0.05) (Figure 14). Average biomass production means in g/plant were: 127.6 ± 6.71, 140.9 ± 4.75, 137.2 ± 4.75 and 140.6 ± 4.75 grams for the 0, 75, 150 and 225 lbs/N acre fertilizer rates (Table 4). For 2015, total aboveground biomass production did show a significant effect between fertilizer
rates (P= 0.000) (Figure 15). Average biomass production means were; 287.9 ± 32.4, 324.8 ± 23, 443.7 ± 23, and 487.7 ± 23 grams for the 0, 75, 150 and 225 lbs/N acre fertilizer rates (Table 4).

Figure 14: Average above ground biomass production (g) ± S.E. in response to the different nitrogen fertilizer rates, 2014.
Figure 15: Average above ground biomass production (g) ± S.E. in response to the different nitrogen fertilizer rates, 2015.

Table 4: Average (± S.E.) aboveground biomass production in response to fertilizer rate in 2014 and 2015.

<table>
<thead>
<tr>
<th>Fertilizer Rate</th>
<th>2014</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 lbs/N acre</td>
<td>127.6 ± 6.5</td>
<td>287.9 ± 32</td>
</tr>
<tr>
<td>75 lbs/N acre</td>
<td>140.8 ± 4.6</td>
<td>324.8 ± 23</td>
</tr>
<tr>
<td>150 lbs/N acre</td>
<td>137.2 ± 4.6</td>
<td>433.7 ± 23</td>
</tr>
<tr>
<td>225 lbs/N acre</td>
<td>140.7 ± 4.6</td>
<td>487.7 ± 23</td>
</tr>
</tbody>
</table>
Generally, the higher N rates (R2, R3) produced more biomass than the lowest rate (Control, R1). Similar findings have been reported by Thompson et al. (2000) with a higher biomass production at N rates of 600 kg/ha. However, those high applications were due to the low residual N available in the soil. It also reported that N timing would have a greater effect on biomass production as compare to rate (Thompson et al., 2000). In this study the higher biomass production was achieved in response to the higher N rates as well (150 and 225 lbs/N acre), which are significantly lower than Thompson et al. (2000), but the residual N levels in the soil were higher and might have accounted for a part of the N uptake.

**Cauliflower Yield**

Cauliflower is an important vegetable crop in the California Central Valley and Salinas area. The cauliflower grown in California accounts for 86% of the total US production. In the state the most important producing regions are the Central Coast, South Coast, South Eastern Desert and the San Joaquin Valley. From those regions, 86% of cauliflower production is attributed to the coastal areas, since it is a cool season crop. The harvested area in California in 2012 was 32,900 acres, and the production accounts for 210 million dollars (NASS, 2011). Outside of the state of California, Arizona is the second largest cauliflower producer, in the Yuma Valley, the production accounts for nearly 9% of total US production (NASS, 2011).

For this field study, cauliflower yield was an important component since one of the objectives was to compare cauliflower yield in response to the different fertilizer treatments and rates; which include Organic and Conventional fertilizers and three nitrogen fertilization rates; 0, 75, 150 and 225 lbs/N acre. Cauliflower
yield data is the key part of the research to give it an agronomic approach to the
NO₃-N leaching environmental and health issues. In this fashion target a broader
audience from growers interested on yield and return to people concern on NO₃-N
leaching health implications.

Yield data was collected from the edible part of the plant that is of
marketable interest; commonly referred as head or curd, which in physiological
terms is an inflorescence, for this study purposes we will refer to it as “head”. The
head weight was taken on the field at the moment of harvest on kilograms and
subsequently the data was analyzed using ANOVA to look for main effects and
interaction within the treatments.

Head Weight vs. Fertilizer type

For the 2014 field study, the marketable yield from the fertilized plots were
significantly different (P=0.001) from the control plots which received no fertilizer
addition. However, there was no significant difference between fertilizer type
when comparing organic and conventional. Generally, there was a total yield
increase of 23% (Table 5) in response to fertilizer use compared to the control
(Figure 16). A similar trend was observed in 2015 with the fertilized plots being
significantly different (P= 0.008), but with a total yield increase of 59% in
response to fertilizer application (Figure 17, Table 5). Similar findings were
observed by Cutcliffe & Munro (1976) that reported an increase on yield from N
fertilizer addition and stated that N fertilization is very important in cauliflower
production.
Figure 16: Cauliflower average head yield per fertilizer treatment in 2014.

Figure 17: Cauliflower average head yield per fertilizer treatment in 2015.
Table 5: Average (± S.E.) cauliflower yield and percent increase in response to fertilizer type in 2014 and 2015.

<table>
<thead>
<tr>
<th>Fertilizer type</th>
<th>2014 Average Head Weight (kg)</th>
<th>2015 Average Head Weight (kg)</th>
<th>% increase*</th>
<th>2015 % increase*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>0.80 ± 0.16</td>
<td>0.98 ± 0.166</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Organic</td>
<td>0.98 ± 0.21</td>
<td>1.55 ± 0.096</td>
<td>23%</td>
<td></td>
</tr>
<tr>
<td>Conventional</td>
<td>0.85 ± 0.21</td>
<td>1.57 ± 0.096</td>
<td>59%</td>
<td></td>
</tr>
</tbody>
</table>

(*): The % increase for year 2014 and 2015 is the result of average head weight increase for rates 150 and 225 lbs/N acre as compared to 0 and 75 lbs/N acre.

**Head Weight vs. Rate**

Plant yield also showed a significant response when compared to fertilizer rate. For the 2014 study, cauliflower yield showed a significant difference (P= 0.000), similar results were obtained from the 2015’s field study data, (P= 0.000). However, for 2014 there was no significant difference between the Control and R1 (Figure 18). And there was also no difference between R2 and R3 (Figure 18). Generally, there was an increment of 24% in response to R2 and R3, as compared to Control and R1 in year 2014 (Table 6).

For the 2015 field study, the mean values of head weight in response to fertilizer rates were: 0.98 ± 0.13, 0.88 ± 0.09, 1.61 ± 0.09 and 2.18 ± 0.09 for Control, R1, R2 and R3 respectively (Table 6). However, there was no significant difference between Control and R1 (Figure 19). In contrast, R2 and R3 did show a significant difference (Figure 19). Generally, when comparing Control and R1 versus R2 and R3, there was an overall increase on yield of 103 % with the use of high N rates. This significant increase on yield validates nitrogen fertilizer applications on cauliflower crop to obtain higher economical crop return. Similar
findings have been reported by Cutcliffe & Munro (1976) for the yield increase in response to N fertilizer; they recommended the optimum N rate to increase cauliflower yield to be in the range of 112-224 kg/N ha. They reported no significant difference between high rates of nitrogen 224 and 336 kg/N ha. The 2015 results in the current study follow a similar trend and for the 2014 in which there was no significant difference in head weight among the two relatively higher N rates. This would imply that it is not advisable to choose the elevated N fertilization rates for cauliflower production on the sandy loam soil used in the current study.

Figure 18: Cauliflower yield in head weight (kg) compared to the different fertilizer rates in 2014.
Figure 19: Cauliflower yield in head weight (kg) compared to the different fertilizer rates in 2015.

Table 6: Average (± S.E.) cauliflower yield and percent increase in response to fertilizer rate in 2014 and 2015.

<table>
<thead>
<tr>
<th>Rate</th>
<th>Average Head Weight (kg)</th>
<th>% increase*</th>
<th>Average Head Weight (kg)</th>
<th>% increase*</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 lbs/N acre</td>
<td>0.80 ± 0.16</td>
<td></td>
<td>0.98 ± 0.13</td>
<td></td>
</tr>
<tr>
<td>75 lbs/N acre</td>
<td>0.86 ± 0.21</td>
<td></td>
<td>0.88 ± 0.09</td>
<td></td>
</tr>
<tr>
<td>150 lbs/N acre</td>
<td>1.00 ± 0.21</td>
<td>24%</td>
<td>1.61 ± 0.09</td>
<td>103%</td>
</tr>
<tr>
<td>225 lbs/N acre</td>
<td>1.03 ± 0.21</td>
<td></td>
<td>2.18 ± 0.09</td>
<td></td>
</tr>
</tbody>
</table>

(*): The % increase for year 2014 and 2015 is the result of average head weight increase for rates 150 and 225 lbs/N acre as compared to 0 and 75 lbs/N acre.
Head Size

Cauliflower head size was also analyzed to compare any differences among treatments for fertilizer type and rate. The head size represents a key component on the value of the crop, the marketable yield is based on curd size. Cultural practices during the harvest are based on curd size as cauliflower heads are placed into cartons in the field for shipping. Those cartons might fit 9-20 depending on the curd size, and the choice of size is associated with quality depending on the target market (IPM, 2000). For this study head size was reported in inches based on the circumference.

Head Size vs Fertilizer Type

Average head size in the 2014 field study in response to the different fertilizer types were: 23.88 ± 0.615, 23.42 ± 0.355 and 24.28 ± 0.355 inches (Table 7) for Control, Organic and Conventional plots. Which showed a response among the fertilizer types (P= 0.092), when comparing organic and conventional plots. However, there was no significant difference between Control plots and plots with fertilizer addition (Figure 20).

In 2015, average head sizes were: 20.4 ± 0.685, 23.7 ± 0.395 and 23.8 ± 0.395 inches (Table 7) respectively for Control, Organic and Conventional plots. Generally, there was a significant response to fertilizer type (P= 0.001), when comparing organic and conventional fertilizers. However, there was no significant difference between Control plots and those with fertilizer addition (Figure 21).
Figure 20: Cauliflower average head circumference by fertilizer type in 2014.

Figure 21: Cauliflower average head circumference by fertilizer type in 2015.
Table 7: Average (± S.E.) cauliflower head size in response to fertilizer type in 2014, measure in inches.

<table>
<thead>
<tr>
<th>Fertilizer type</th>
<th>Average Head Circumference (in) 2014</th>
<th>Average Head Circumference (in) 2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>23.88 ± 0.615</td>
<td>20.4 ± 0.685</td>
</tr>
<tr>
<td>Organic</td>
<td>23.42 ± 0.355</td>
<td>23.7 ± 0.395</td>
</tr>
<tr>
<td>Conventional</td>
<td>24.28 ± 0.355</td>
<td>23.8 ± 0.395</td>
</tr>
</tbody>
</table>

**Head size vs. Rate**

Average head size in the 2014 field study in response to the different fertilizer rates were: 23.88 ± 0.615, 19.61 ± 0.524, 24.21 ± 0.524 and 27.40 ± 0.524 inches (Table 8) for Control, Organic and Conventional plots. The response to rate was only significant at (P = 0.095) between R1 and R2. On the contrary, no significant difference was found between Control, R2 and R3 (Figure 22).

For the 2015 study, head size showed a significant difference (P = 0.000) within the different rates. However, there was no significant difference between Control and R1 (Figure 23). Unlike the high fertilizer rates R2 and R3, that did show a significant difference in between. Furthermore, when comparing the low N rates (Control, R1) versus the high N rates (R2, R3), there was an overall increase on head circumference of 28 % for the high N rates compared to the low N rates. Similarly, Toivonen et al. (1994), reported an increase on head size as the N rates increased. However, temperature and planting density had a greater effect on head size as compared to N rates (Toivonen et al., 1994). This fact could explain the variability of head size among treatments for 2014 were no significant difference was observed in response to fertilizer rates.
Table 8: Average cauliflower head size (± S.E.) in response to fertilizer rate. Circumference measure in inches for 2014 and 2015.

<table>
<thead>
<tr>
<th>Rate</th>
<th>Average Head Circumference (in)</th>
<th>2014</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 lbs/N acre</td>
<td></td>
<td>23.88 ± 0.615</td>
<td>20.4 ± 0.741</td>
</tr>
<tr>
<td>75 lbs/N acre</td>
<td></td>
<td>19.61 ± 0.524</td>
<td>23.16 ± 0.435</td>
</tr>
<tr>
<td>150 lbs/N acre</td>
<td></td>
<td>24.21 ± 0.524</td>
<td>24.51 ± 0.435</td>
</tr>
<tr>
<td>225 lbs/N acre</td>
<td></td>
<td>27.40 ± 0.524</td>
<td>23.88 ± 0.435</td>
</tr>
</tbody>
</table>

Figure 22: Cauliflower average head circumference by fertilizer rate in 2014.
Figure 23: Cauliflower average head circumference by fertilizer rate in 2015.

Soil Analysis

For this study soil samples were taken pre-planting and post-harvest at four depths to evaluate the soil NO$_3$-N content. In average, for the 2014 field study, the pre-planting soils showed a trend towards a higher NO$_3$-N content as compared to the Post-harvest. With an average per treatment Pre-planting of: 33.37, 36.11, 41.93, 42.15, 55.18, 32.99, and 33.74 NO$_3$-N mg/l respectively for Control, ORG1, ORG2, ORG3, UAN1, UAN2, and UAN3 (Table 9). Post-harvest NO$_3$-N levels were: 1.76, 9.55, 12.27, 13.94, 8.36, 7.66 and 19.13 NO$_3$-N mg/l respectively for Control, ORG1, ORG2, ORG3, UAN1, UAN2, and UAN3 (Table 9, Figure 24).
Table 9: Soil NO₃-N levels (mg/l) for Pre-planting and Post-harvest soil sampling for the different treatments in 2014.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Control</th>
<th>ORG1</th>
<th>ORG2</th>
<th>ORG3</th>
<th>UAN1</th>
<th>UAN2</th>
<th>UAN3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sampling</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-planting</td>
<td>33.37</td>
<td>36.11</td>
<td>41.93</td>
<td>42.15</td>
<td>55.18</td>
<td>32.99</td>
<td>33.74</td>
</tr>
<tr>
<td>NO₃-N mg/l</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% Decrease</td>
<td>94.7</td>
<td>73.5</td>
<td>70.7</td>
<td>66.9</td>
<td>84.8</td>
<td>76.8</td>
<td>43.3</td>
</tr>
</tbody>
</table>

Figure 24: Average soil NO₃-N levels within the top 4 feet at Pre-planting and Post-harvest for the different fertilizer treatments in 2014.
In the 2015 study the soil NO$_3$-N content for pre-planting and post-harvest was lower in average, with a mg/l concentration of: 9.60, 18.11, 19.38, 18.88, 14.00, 20.90 and 23.75 respectively for Control, ORG1, ORG2, ORG3, UAN1, UAN2, and UAN3 (Table 10). Post-harvest NO$_3$-N levels were: 0.27, 2.23, 5.47, 7.88, 2.80, 5.35 and 8.42 mg/l respectively for Control, ORG1, ORG2, ORG3, UAN1, UAN2, and UAN3 (Table 10, Figure 25). The NO$_3$-N concentrations for the 2015 followed a similar tendency as the 2014 soils, with a trend towards a higher concentration in Pre-planting soils as compared to Post-harvest.

Table 10: Soil NO$_3$-N levels (mg/l) for Pre-planting and Post-harvest soil sampling for the different treatments in 2015.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Control</th>
<th>ORG1</th>
<th>ORG2</th>
<th>ORG3</th>
<th>UAN1</th>
<th>UAN2</th>
<th>UAN3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sampling</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-planting</td>
<td>9.60</td>
<td>18.11</td>
<td>19.38</td>
<td>18.88</td>
<td>14.00</td>
<td>20.90</td>
<td>23.75</td>
</tr>
<tr>
<td>NO$_3$-N mg/l</td>
<td>Post-harvest</td>
<td>0.27</td>
<td>2.23</td>
<td>5.47</td>
<td>7.88</td>
<td>2.80</td>
<td>5.35</td>
</tr>
<tr>
<td>% Decrease</td>
<td>97.2</td>
<td>87.6</td>
<td>71.7</td>
<td>58.1</td>
<td>80.0</td>
<td>74.4</td>
<td>64.5</td>
</tr>
</tbody>
</table>

This trend shows how after harvest, the N in the soil could be taken up by the plant and removed from the field, denitrified, lost to the atmosphere by volatilization, immobilized by soil microbes in form of organic matter, stay in the soil ready for plant uptake available for next crop, lost by runoff or leach below the top 48-inches of the soil sampling in NO$_3$-N form (Hartz, 2007). To estimate the amount of nitrogen that could potentially be lost by leaching, the leaching indices (L.I.), were calculated for each treatment based on the soil NO$_3$-N content.
Figure 25: Soil NO$_3$-N levels for Pre-planting and Post-harvest for the different treatments in 2015.

**Soil NO$_3$-N in Response to Fertilizer Type**

For the 2014 field study soil NO$_3$-N concentration showed a significant effect ($P= 0.000$) in response to fertilizer type. With an average NO$_3$-N concentration of; $1.76 \pm 1.35$, $11.92 \pm 0.78$ and $11.71 \pm 0.78$ respectively for Control, Organic and Conventional (Table 11). However, Organic and Conventional plots were not significantly different from each other (Figure 26). For the 2015 study, the mean soil NO$_3$-N concentrations were: $0.27 \pm 0.75$, $5.20 \pm 0.43$ and $5.52 \pm 0.43$ respectively for Control, Organic and Conventional (Table 11). However, Organic and Conventional plots were not significantly different from each other (Figure 27), a similar trend comparable to 2014 results. Generally, plots with fertilizer addition showed significantly higher soil NO$_3$-N content as
compared to Control (Table 11). This difference in the NO$_3$-N concentrations is due to the fact that plant uptake consumes part of the nitrogen available in the soil; the other portion might be lost either by leaching, denitrification and volatilization (Hartz. 2007).

Table 11: Average (± S.E.) soil NO$_3$-N content in response to fertilizer type in 2014 and 2015.

<table>
<thead>
<tr>
<th>Fertilizer type</th>
<th>2014 (NO$_3$-N mg/l)</th>
<th>2015 (NO$_3$-N mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>1.76 ± 1.35</td>
<td>0.27 ± 0.75</td>
</tr>
<tr>
<td>Organic</td>
<td>11.92 ± 0.78</td>
<td>5.20 ± 0.43</td>
</tr>
<tr>
<td>Conventional</td>
<td>11.71 ± 0.78</td>
<td>5.52 ± 0.43</td>
</tr>
</tbody>
</table>

Figure 26: Soil NO$_3$-N concentrations (mg/l) in response to fertilizer type for 2014.
Figure 27: Soil NO₃-N concentrations (mg/l) in response to fertilizer type for 2015.

Soil NO₃-N in Response to Fertilizer Rate

Soil NO₃-N levels in response to fertilizer rate in 2014 showed a significant response (P= 0.000). With average NO₃-N concentrations of: 1.76 ± 1.16, 8.95 ± 0.82, 9.97 ± 0.82 and 16.54 ± 0.82 respectively for 0, 75, 150 and 225 lbs/N acre fertilizer rates (Table 12). The high rate; 225 lbs/N acre was significantly higher than the rest of the treatments; the 150 and 75 lbs/N acre rates were not significantly different from each other, whereas the lower rate, 0 lbs/N acre was significantly lower than the rest of the rates (Figure 28). In 2015, the average NO₃-N concentrations were: 0.27 ± 0.75, 2.51 ± 0.43, 5.42 ± 0.43 and 8.15 ± 0.43. The different fertilizer rates did show a significant difference (P= 0.000) among them (Figure 29). For this year, the soil nitrates content increased almost linearly as the
fertilizer rate, increasing with the higher rates. All soil samplings were done at Post-harvest, which suggest that all that residual nitrate is potentially to be leach and pollute groundwater. And higher N rates post a higher risk of environmental contamination.

Similar trends have been reported by others studying the soil nitrate content as a function of fertilizer rate. Jaynes et al. (2001) reported a constant increase on the NO$_3$-N concentration on soil and tile drainage at high N rates. They experimented with low, medium and high N rates, and found that the soil NO$_3$-N levels increased at post-harvest with any of the rates. In the study, it was also reported that tile drainage NO$_3$-N concentrations would exceed the allowed NO$_3$-N concentration of 10 mg/l established by the USEPA. Jaynes et al. (2001) concluded that if water quality and productivity are included in the concept of sustainable agriculture, dramatic changes will be required in farm management practices to consider them as sustainable practices (Jaynes et al., 2001).

Nitrogen fertilizer rates play and important role in agricultural production, to maintain the current yields and minimize the environmental pollution, best management practices have to be implemented.

Table 12: Average (± S.E.) soil NO$_3$-N content in response to fertilizer rate in 2014 and 2015.

<table>
<thead>
<tr>
<th>Fertilizer Rate</th>
<th>2014</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NO$_3$-N mg/l</td>
<td>NO$_3$-N mg/l</td>
</tr>
<tr>
<td>0 lbs/N acre</td>
<td>1.76 ± 1.16</td>
<td>0.27 ± 0.75</td>
</tr>
<tr>
<td>75 lbs/N acre</td>
<td>8.95 ± 0.82</td>
<td>2.51 ± 0.43</td>
</tr>
<tr>
<td>150 lbs/N acre</td>
<td>9.97 ± 0.82</td>
<td>5.42 ± 0.43</td>
</tr>
<tr>
<td>225 lbs/N acre</td>
<td>16.54 ± 0.82</td>
<td>8.15 ± 0.43</td>
</tr>
</tbody>
</table>
Figure 28: Soil NO$_3$-N concentrations (mg/l) in response to fertilizer rate for 2014.

Figure 29: Soil NO$_3$-N concentrations (mg/l) in response to fertilizer rate for 2015.
Soil NO$_3$-N Concentration as a Function of Depth

Soil samples were taken at four depths and for the higher N rates treatments- ORG2, ORG3, UAN2 and UAN3 there was a trend towards a higher NO$_3$-N concentration in the 36 and 48 inches as compared to the concentration in the top 12 and 24 inches (Tables 13 & 14). This gradient in the NO$_3$-N concentration is related to the leaching index (L.I.) that will be described in the next section. The high concentrations in some plots within the top 12-in of soil were probably the result of mineralization and the higher concentrations lower in the surface at 36-48-in are the result of NO$_3$-N leaching to depth in the horizon. Similar results for the NO$_3$-N concentrations at different depths were reported by Jaynes et al. (2001) on a rotation cropping system. Finding high NO$_3$-N concentrations at the top layers of the soil for some years, which were attributed to nitrogen mineralization. And in years with higher precipitation rates, soil NO$_3$-N concentrations were higher deeper in the soil horizon, attributed to NO$_3$-N leaching.

Table 13: Average NO$_3$-N (±S.E.) concentrations (mg/l) for each treatment at four depths; 12, 24, 36 and 48 inches in 2014.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Control</th>
<th>ORG1</th>
<th>ORG2</th>
<th>ORG3</th>
<th>UAN1</th>
<th>UAN2</th>
<th>UAN3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth (in)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>2.7</td>
<td>6.4</td>
<td>12.5</td>
<td>18.7</td>
<td>8.4</td>
<td>5.2</td>
<td>18.5</td>
</tr>
<tr>
<td></td>
<td>(±0.74)</td>
<td>(±3.13)</td>
<td>(±2.94)</td>
<td>(±0.92)</td>
<td>(±1.93)</td>
<td>(±2.67)</td>
<td>(±0.92)</td>
</tr>
<tr>
<td>24</td>
<td>1.4</td>
<td>10.6</td>
<td>11.1</td>
<td>10.3</td>
<td>6.7</td>
<td>8.5</td>
<td>17.1</td>
</tr>
<tr>
<td></td>
<td>(±0.63)</td>
<td>(±3.74)</td>
<td>(±2.60)</td>
<td>(±0.73)</td>
<td>(±1.78)</td>
<td>(±2.20)</td>
<td>(±0.83)</td>
</tr>
<tr>
<td>36</td>
<td>1.9</td>
<td>12.0</td>
<td>12.3</td>
<td>15.6</td>
<td>11.2</td>
<td>8.5</td>
<td>17.7</td>
</tr>
<tr>
<td></td>
<td>(±0.39)</td>
<td>(±3.00)</td>
<td>(±2.49)</td>
<td>(±2.72)</td>
<td>(±2.85)</td>
<td>(±2.54)</td>
<td>(±0.69)</td>
</tr>
<tr>
<td>48</td>
<td>1.0</td>
<td>7.3</td>
<td>7.6</td>
<td>11.2</td>
<td>7.3</td>
<td>8.6</td>
<td>23.2</td>
</tr>
<tr>
<td></td>
<td>(±0.28)</td>
<td>(±2.02)</td>
<td>(±3.51)</td>
<td>(±1.48)</td>
<td>(±1.67)</td>
<td>(±3.06)</td>
<td>(±0.79)</td>
</tr>
</tbody>
</table>
Table 14: Average NO$_3$-N (±S.E.) concentrations (mg/l) for each treatment at four depths; 12, 24, 36 and 48 inches in 2015.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Control</th>
<th>ORG1</th>
<th>ORG2</th>
<th>ORG3</th>
<th>UAN1</th>
<th>UAN2</th>
<th>UAN3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth (in)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>0.30 (±0.09)</td>
<td>3.4 (±1.72)</td>
<td>2.7 (±1.78)</td>
<td>7.7 (±0.87)</td>
<td>2.3 (±1.12)</td>
<td>7.7 (±1.53)</td>
<td>9.6 (±0.69)</td>
</tr>
<tr>
<td>24</td>
<td>0.32 (±0.05)</td>
<td>2.4 (±0.82)</td>
<td>5.9 (±1.21)</td>
<td>7.7 (±0.81)</td>
<td>2.5 (±1.13)</td>
<td>3.7 (±1.35)</td>
<td>6.2 (±0.42)</td>
</tr>
<tr>
<td>36</td>
<td>0.24 (±0.03)</td>
<td>1.35 (±0.54)</td>
<td>4.7 (±0.65)</td>
<td>8.2 (±0.84)</td>
<td>4.0 (±1.61)</td>
<td>5.0 (±0.59)</td>
<td>9.5 (±1.25)</td>
</tr>
<tr>
<td>48</td>
<td>0.22 (±0.05)</td>
<td>1.72 (±0.77)</td>
<td>9.25 (±2.35)</td>
<td>7.9 (±1.18)</td>
<td>2.3 (±0.65)</td>
<td>5.0 (±1.72)</td>
<td>8.3 (±1.08)</td>
</tr>
</tbody>
</table>

2014 Detailed Soil NO$_3$-N Content by Depth as a Function of Fertilizer Treatments

In the previous section the NO$_3$-N content in soil was shown in average within the top four feet of soil (Figures 30 & 31). However, in an effort to better evaluate the potential NO$_3$-N leaching it is worthwhile to quantify the amount of nitrate in each foot of soil. For example; nitrate in the top 12 inches could be more available for plant uptake than the nitrate in the 36-48 inches depth.

Soil NO$_3$-N Content Within 0 to 12 Inches as a Function of Fertilizer Type

Soil NO$_3$-N content at 12-inch depth for 2014, showed a significant effect (P= 0.032) in response to fertilizer type (Figure 32). With NO$_3$-N mean values of; 2.74 ± 3.05, 12.5 ± 1.76, and 10.6 ± 1.76 NO$_3$-N mg/l respectively for Control, Organic and Conventional fertilizers (Table 15). There was also a significant response to fertilizer type in 2015 (P= 0.007) (Figure 33). With NO$_3$-N mean values of; 0.31 ± 1.60, 4.62 ± 0.92 and 6.54 ± 0.92 NO$_3$-N mg/l respectively for Control, Organic and Conventional fertilizers (Table 15).
Figure 30: NO₃-N concentrations at four depths for all the treatments; Control, ORG1, ORG2, ORG3, UAN1, UAN2 and UAN3 for 2014.
Figure 31: NO$_3$-N concentrations at four depths for all the treatments; Control, ORG1, ORG2, ORG3, UAN1, UAN2 and UAN3 for 2015.
Figure 32: Soil NO$_3$-N concentrations (mg/l) at the top 12-inch in response to fertilizer type for 2014.

Table 15: Average (± S.E.) soil NO$_3$-N content at 12-inch depth in response to fertilizer type in 2014 and 2015.

<table>
<thead>
<tr>
<th>Fertilizer type</th>
<th>2014</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>2.74 ± 3.05</td>
<td>0.31 ± 1.60</td>
</tr>
<tr>
<td>Organic</td>
<td>12.5 ± 1.76</td>
<td>4.62 ± 0.92</td>
</tr>
<tr>
<td>Conventional</td>
<td>10.6 ± 1.76</td>
<td>6.54 ± 0.92</td>
</tr>
</tbody>
</table>
Figure 33: Soil NO$_3$-N concentrations (mg/l) at the top 12-inch in response to fertilizer type for 2015.

**Soil NO$_3$-N Content Within 0 to 12 Inches as a Function of Fertilizer Rate**

In 2014 at the top 12-inch of soil, there was a significant effect of fertilizer rate on the soil NO$_3$-N content (P= 0.000) (Figure 34). The mean values for the different rates were: 2.74 ± 2.24, 7.36 ± 1.58, 8.75 ± 1.58 and 18.58 ± 1.58 NO$_3$-N mg/l for the 0, 75, 150 and 225 lbs/N acre N fertilization rates (Table 16). In the 2015 study there was a significant effect of NO$_3$-N content in response to fertilizer rates (P= 0.000) (Figure 35), with NO$_3$-N values of; 0.31 ± 1.28, 2.86 ± 0.91, 5.20 ± 0.91 and 8.67 ± 0.91 NO$_3$-N mg/l for the 0, 75, 150 and 225 lbs/N acre N fertilization rates (Table 16).
Figure 34: Soil NO$_3$-N concentrations (mg/l) at the top 12-inch in response to fertilizer rate for 2014.

Table 16: Average (± S.E.) soil NO$_3$-N content in response to fertilizer rate in 2014 and 2015.

<table>
<thead>
<tr>
<th>Fertilizer Rate</th>
<th>2014</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 lbs/N acre</td>
<td>2.74 ± 2.24</td>
<td>0.31 ± 1.28</td>
</tr>
<tr>
<td>75 lbs/N acre</td>
<td>7.36 ± 1.58</td>
<td>2.86 ± 0.91</td>
</tr>
<tr>
<td>150 lbs/N acre</td>
<td>8.75 ± 1.58</td>
<td>5.20 ± 0.91</td>
</tr>
<tr>
<td>225 lbs/N acre</td>
<td>18.58 ± 1.58</td>
<td>8.67 ± 0.91</td>
</tr>
</tbody>
</table>
In the top 12-inch of soil for the field study in 2014, there was an interaction between Conventional fertilizer type by the 225 lbs/N acre N fertilization rate (Figure 36). There was an interaction for the Organic fertilizer by the 225 lbs/N acre N fertilization rate (Figure 36). For the 2015 field study there was also a significant interaction (P= 0.040) between Conventional fertilizer and 225 lbs/N acre and Organic with 225 lbs/N acre (Figure 37). Those interactions between fertilizer type and rate might be expected since it is the highest N fertilization rate used in the study, and in Figure 36 and 6.14 the mean differences can be appreciated.
Figure 36: Mean soil NO₃-N concentrations (mg/l) within the 0-12 inches as a function of fertilizer x rate interaction in 2014.
Figure 37: Mean soil NO$_3$-N concentrations (mg/l) within the 0-12 inches as a function of fertilizer x rate interaction in 2015.
Soil NO$_3$-N Content Within 12 to 24 Inches as a Function of Fertilizer Type

Soil NO$_3$-N content at 24-inch depth for 2014, showed a significant effect (P= 0.005) in response to fertilizer type (Figure 38). With NO$_3$-N mean values of; 1.42 ± 2.40, 10.67 ± 1.39 and 10.72 ± 1.39 NO$_3$-N mg/l respectively for Control, Organic and Conventional fertilizers (Table 17). There was also a significant response to fertilizer type in 2015 (P= 0.004) (Figure 39). With NO$_3$-N mean values of; 0.33 ± 1.20, 5.34 ± 0.69 and 4.12 ± 0.69 NO$_3$-N mg/l respectively for Control, Organic and Conventional fertilizers (Table 17).

Figure 38: Soil NO$_3$-N concentrations (mg/l) at the top 24-inch in response to fertilizer type for 2014.
Table 17: Average (± S.E.) soil NO$_3$-N content at 24-inch depth in response to fertilizer type in 2014 and 2015.

<table>
<thead>
<tr>
<th>Fertilizer type</th>
<th>2014 NO$_3$-N mg/l</th>
<th>2015 NO$_3$-N mg/l</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>1.42 ± 2.40</td>
<td>0.33 ± 1.20</td>
</tr>
<tr>
<td>Organic</td>
<td>10.67 ± 1.39</td>
<td>5.34 ± 0.69</td>
</tr>
<tr>
<td>Conventional</td>
<td>10.72 ± 1.39</td>
<td>4.12 ± 0.69</td>
</tr>
</tbody>
</table>

Figure 39: Soil NO$_3$-N concentrations (mg/l) at the top 24-inch in response to fertilizer type for 2015.
Soil NO$_3$-N Content Within 12 to 24 Inches as a Function of Fertilizer Rate

In 2014 at the top 24-inch of soil, there was a significant effect of fertilizer rate on the soil NO$_3$-N content (P= 0.001) (Figure 40). The mean values for the different rates were: 1.43 ± 2.25, 8.64 ± 1.59, 9.45 ± 1.59 and 13.70 ± 1.59 NO$_3$-N mg/l for the 0, 75, 150 and 225 lbs/N acre N fertilization rates (Table 18). In the 2015 study there was a significant effect of NO$_3$-N content in response to fertilizer rates (P= 0.000) (Figure 41), with NO$_3$-N values of; 0.328 ± 0.95, 2.50 ± 0.66, 4.83 ± 0.66 and 6.95 ± 0.66 NO$_3$-N mg/l for the 0, 75, 150 and 225 lbs/N acre N fertilization rates (Table 18).

Figure 40: Soil NO$_3$-N concentrations (mg/l) at the top 24-inch in response to fertilizer rate for 2014.
Table 18: Average (± S.E.) soil NO$_3$-N content in response to fertilizer rate in 2014 and 2015.

<table>
<thead>
<tr>
<th>Fertilizer Rate</th>
<th>NO$_3$-N mg/l 2014</th>
<th>NO$_3$-N mg/l 2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 lbs/N acre</td>
<td>1.43 ± 2.25</td>
<td>0.328 ± 0.95</td>
</tr>
<tr>
<td>75 lbs/N acre</td>
<td>8.64 ± 1.59</td>
<td>2.50 ± 0.66</td>
</tr>
<tr>
<td>150 lbs/N acre</td>
<td>9.45 ± 1.59</td>
<td>4.83 ± 0.66</td>
</tr>
<tr>
<td>225 lbs/N acre</td>
<td>13.70 ± 1.59</td>
<td>6.95 ± 0.66</td>
</tr>
</tbody>
</table>

Figure 41: Soil NO$_3$-N concentrations (mg/l) at the top 24-inch in response to fertilizer rate for 2015.
In the top 24-inch of soil for the field study in 2014, there was a significant interaction (P= 0.043) between Conventional fertilizer type by the 225 lbs/N acre N fertilization rate (Figure 42). For the 2015 field study there was no significant interaction (P> 0.05) among the fertilizer treatments (Figure 43) within the top 24 inch of soil.

Figure 42: Mean soil NO$_3$-N concentrations (mg/l) within the 12-24 inches as a function of fertilizer x rate interaction in 2014.
In 2014, there was an interaction effect for the Conventional fertilizer and the highest N rate, which might suggest for that treatment (UAN3) that at the top 24-inch of soil the soil the NO$_3$-N contents are higher than the rest. Therefore, there is a greater potential for those nitrates to continue to be leached below the crop root zone into the ground water.
Soil NO$_3$-N Content Within 24 to 36 Inches as a Function of Fertilizer Type

Soil NO$_3$-N content at 36-inch depth for 2014, showed a significant effect (P= 0.001) in response to fertilizer type (Figure 44). With NO$_3$-N mean values of; 1.87 ± 2.52, 13.33 ± 1.46 and 12.49 ± 1.45 NO$_3$-N mg/l respectively for Control, Organic and Conventional fertilizers (Table 19). There was also a significant response to fertilizer type in 2015 (P= 0.004) (Figure 45). With NO$_3$-N mean values of; 0.24 ± 1.43, 4.54 ± 0.83 and 6.18 ± 0.83 NO$_3$-N mg/l respectively for Control, Organic and Conventional fertilizers (Table 19).

Figure 44: Soil NO$_3$-N concentrations (mg/l) at the top 36-inch in response to fertilizer rate for 2014.
Table 19: Average (± S.E.) soil NO$_3$-N content at 36-inch depth in response to fertilizer type in 2014 and 2015.

<table>
<thead>
<tr>
<th>Fertilizer type</th>
<th>2014</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>1.87 ± 2.52</td>
<td>0.24 ± 1.43</td>
</tr>
<tr>
<td>Organic</td>
<td>13.33 ± 1.46</td>
<td>4.54 ± 0.83</td>
</tr>
<tr>
<td>Conventional</td>
<td>12.49 ± 1.45</td>
<td>6.18 ± 0.83</td>
</tr>
</tbody>
</table>

Figure 45: Soil NO$_3$-N concentrations (mg/l) at the top 36-inch in response to fertilizer rate for 2015.
Soil NO$_3$-N Content Within 24 to 36 Inches as a Function of Fertilizer Rate

In 2014 at the top 36-inch of soil, there was a significant effect of fertilizer rate on the soil NO$_3$-N content (P=0.000) (Figure 46). The mean values for the different rates were: 1.87 ± 2.27, 11.62 ± 1.62, 10.41± 1.62 and 16.68 ± 1.62 NO$_3$-N mg/l for the 0, 75, 150 and 225 lbs/N acre N fertilization rates (Table 20). In the 2015 study there was a significant effect of NO$_3$-N content in response to fertilizer rates (P= 0.000) (Figure 47), with NO$_3$-N values of; 0.24 ± 0.96, 2.70 ± 0.68, 4.52 ± 0.68 and 8.88 ± 0.68 NO$_3$-N mg/l for the 0, 75, 150 and 225 lbs/N acre N fertilization rates (Table 20).

Figure 46: Soil NO$_3$-N concentrations (mg/l) at the top 36-inch in response to fertilizer rate for 2014.
Table 20: Average (± S.E.) soil NO$_3$-N content in response to fertilizer rate in 2014 and 2015.

<table>
<thead>
<tr>
<th>Fertilizer Rate</th>
<th>2014 (NO$_3$-N mg/l)</th>
<th>2015 (NO$_3$-N mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 lbs/N acre</td>
<td>1.87 ± 2.27</td>
<td>0.24 ± 0.96</td>
</tr>
<tr>
<td>75 lbs/N acre</td>
<td>11.62 ± 1.62</td>
<td>2.70 ± 0.68</td>
</tr>
<tr>
<td>150 lbs/N acre</td>
<td>10.41 ± 1.62</td>
<td>4.52 ± 0.68</td>
</tr>
<tr>
<td>225 lbs/N acre</td>
<td>16.68 ± 1.62</td>
<td>8.88 ± 0.68</td>
</tr>
</tbody>
</table>

Figure 47: Soil NO$_3$-N concentrations (mg/l) at the top 36-inch in response to fertilizer rate for 2015.
In the top 36-inch of soil for the field study in 2014, there was no significant interaction (P> 0.05) among the fertilizer types and rates (Figure 48). For the 2015 field study there was also no significant interaction (P> 0.05) among the fertilizer treatments (Figure 49) within the top 36 inch of soil. Generally, in the 2015, a response was observed for the Organic and Conventional within the highest fertilizer rate of 225 lbs/N acre as compare to the lower rates.

Figure 48: Mean soil NO$_3$-N concentrations (mg/l) within the 24-36 inches as a function of fertilizer x rate interaction in 2014.
Figure 49: Mean soil NO$_3$-N concentrations (mg/l) within the 24-36 inches as a function of fertilizer x rate interaction in 2015.

Soil NO$_3$-N Content Within 36 to 48 Inches as a Function of Fertilizer Type

Soil NO$_3$-N content at 48-inch depth for 2014, showed a significant effect (P= 0.006) in response to fertilizer type (Figure 50). With NO$_3$-N mean values of; 1.00 ± 3.02, 11.21 ± 1.74 and 13.01 ± 1.74 NO$_3$-N mg/l respectively for Control, Organic and Conventional fertilizers (Table 21). There was also a significant response to fertilizer type in 2015 (P= 0.018) (Figure 51). With NO$_3$-N mean values of; 0.22 ± 1.75, 6.30 ± 1.01 and 5.21 ± 1.01 NO$_3$-N mg/l respectively for Control, Organic and Conventional fertilizers (Table 21).
Figure 50: Soil NO₃-N concentrations (mg/l) at the top 48-inch in response to fertilizer rate for 2014.

Table 21: Average (± S.E.) soil NO₃-N content at 48-inch depth in response to fertilizer type in 2014 and 2015.

<table>
<thead>
<tr>
<th>Fertilizer type</th>
<th>NO₃-N mg/l 2014</th>
<th>NO₃-N mg/l 2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>1.00 ± 3.02</td>
<td>0.22 ± 1.75</td>
</tr>
<tr>
<td>Organic</td>
<td>11.21 ± 1.74</td>
<td>6.30 ± 1.01</td>
</tr>
<tr>
<td>Conventional</td>
<td>13.01 ± 1.74</td>
<td>5.21 ± 1.01</td>
</tr>
</tbody>
</table>
Figure 51: Soil NO\textsubscript{3}-N concentrations (mg/l) at the top 48-inch in response to fertilizer rate for 2015.

Soil NO\textsubscript{3}-N Content Within 36 to 48 Inches as a Function of Fertilizer Rate

In 2014 at the top 48-inch of soil, there was a significant effect of fertilizer rate on the soil NO\textsubscript{3}-N content (P= 0.000) (Figure 52). The mean values for the different rates were: 1.00 ± 2.62, 8.20 ± 1.85, 10.95± 1.85 and 17.19 ± 1.85 NO\textsubscript{3}-N mg/l for the 0, 75, 150 and 225 lbs/N acre N fertilization rates (Table 22). In the 2015 study there was a significant effect of NO\textsubscript{3}-N content in response to fertilizer rates (P= 0.000) (Figure 53), with NO\textsubscript{3}-N values of; 0.22 ± 1.36, 2.02 ± 0.97, 7.10 ± 0.97 and 8.10 ± 0.97 NO\textsubscript{3}-N mg/l for the 0, 75, 150 and 225 lbs/N acre N fertilization rates (Table 22).
Figure 52: Soil NO₃-N concentrations (mg/l) at the top 48-inch in response to fertilizer rate for 2014.

Table 22: Average (± S.E.) soil NO₃-N content in response to fertilizer rate in 2014 and 2015.

<table>
<thead>
<tr>
<th>Fertilizer Rate</th>
<th>2014</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 lbs/N acre</td>
<td>1.00 ± 2.62</td>
<td>0.22 ± 1.36</td>
</tr>
<tr>
<td>75 lbs/N acre</td>
<td>8.20 ± 1.85</td>
<td>2.02 ± 0.97</td>
</tr>
<tr>
<td>150 lbs/N acre</td>
<td>10.95 ± 1.85</td>
<td>7.10 ± 0.97</td>
</tr>
<tr>
<td>225 lbs/N acre</td>
<td>17.19 ± 1.85</td>
<td>8.10 ± 0.97</td>
</tr>
</tbody>
</table>
Figure 53: Soil NO$_3$-N concentrations (mg/l) at the top 48-inch in response to fertilizer rate for 2015.

At a soil depth of 36-48 inch for the field study in 2014, there was a significant effect (P= 0.001) for the interaction between Conventional fertilizer and 225 lbs/N acre (Figure 54). For the 2015 field study there was no significant interaction (P> 0.05) between the fertilizer treatments and rates (Figure 55) within the top 48 inch of soil.

Figure 54: Mean soil NO$_3$-N concentrations (mg/l) within the 36-48 inches as a function of fertilizer x rate interaction in 2014.
Figure 55: Mean soil NO$_3$-N concentrations (mg/l) within the 36-48 inches as a function of fertilizer x rate interaction in 2015.

**Leaching Index (L.I.)**

Leaching index (L.I.) is an indicator of the potential of NO$_3$-N to leach down to ground water and pollute. NO$_3$-N is soluble and moves along with water in the soil profile. From the soil NO$_3$-N laboratory analyses performed in this research, the leaching indices were calculated and the data were analyzed using ANOVA to look for main effects and correlations with the different fertilizer treatments. The mean L.I. for the 2014 field study were: 1.41, 3.35, 3.86, 2.0, 3.25, 2.90 and 3.18 for Control, ORG1, ORG2, ORG3, UAN1, UAN2, and UAN3 respectively (Table 23, Figure 56) and for the 2015 the mean values for L.I. were: 0.60, 0.79, 0.59, 0.74, 0.67, 0.71 and 0.66 for Control, ORG1, ORG2, ORG3, UAN1, UAN2, and UAN3 respectively (Table 23, Figure 56).
Table 23: L.I. in response to the different treatments for year 2014 and 2015.

<table>
<thead>
<tr>
<th>Year</th>
<th>Control</th>
<th>ORG1</th>
<th>ORG2</th>
<th>ORG3</th>
<th>UAN1</th>
<th>UAN2</th>
<th>UAN3</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>0.60</td>
<td>0.79</td>
<td>0.59</td>
<td>0.74</td>
<td>0.67</td>
<td>0.71</td>
<td>0.66</td>
</tr>
<tr>
<td>2014</td>
<td>1.41</td>
<td>3.35</td>
<td>3.86</td>
<td>2.0</td>
<td>3.25</td>
<td>2.90</td>
<td>3.18</td>
</tr>
</tbody>
</table>

Figure 56: L.I. for each one of the seven treatments in 2014 and 2015.

The average leaching indices in response to fertilizer type in 2014 study were: $1.42 \pm 0.52$, $3.1 \pm 0.3$ and $3.1 \pm 0.3$ respectively for Control, Organic and Conventional fertilizer treatments (Table 24). There was a significant effect between fertilizer treatment ($P= 0.027$). However, there was no significant difference between organic and conventional fertilizers effect for L.I. (Figure 57). In contrast, plots with fertilizer addition showed a 118% increase on L.I. when compared to Control (Table 24). This suggests that the cauliflower fields with no fertilizer addition have 118% less potential to leach NO$_3$-N into the ground water.
Table 24: Average (± S.E.) leaching index (L.I.) in response to fertilizer type in 2014 and 2015.

<table>
<thead>
<tr>
<th>Fertilizer type</th>
<th>2014</th>
<th>% increase</th>
<th>2015</th>
<th>% increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>1.42 ± 0.51</td>
<td></td>
<td>0.60 ± 0.06</td>
<td></td>
</tr>
<tr>
<td>Organic</td>
<td>3.06 ± 0.30</td>
<td></td>
<td>0.71 ± 0.03</td>
<td></td>
</tr>
<tr>
<td>Conventional</td>
<td>3.10 ± 0.30</td>
<td>118 %</td>
<td>0.68 ± 0.03</td>
<td>15.8%</td>
</tr>
</tbody>
</table>

Figure 57: Fertilizer type and control effects on the Leaching Indices in 2014.

For the 2015 experiment, the average leaching indices in response to fertilizer type were: 0.60 ± 0.06, 0.71 ± 0.03 and 0.68 ± 0.03 respectively for Control, Organic and Conventional fertilizers (Table 24). There was no significant difference between fertilizer treatments with a P-value > 0.05. On the 2015 study
in average, there was a 15.8% greater potential to leach NO$_3$ with the use of organic fertilizer as compared to the conventional (Table 24, Figure 58).

In contrast for the 2014 field study, the average L.I. means were: 1.41 ± 0.513, 3.30 ± 0.363, 3.36 ± 0.363 and 2.57 ± 0.363 for the 0, 75, 150 and 225 lbs/N acre N rates respectively (Table 25). There was a significant difference between the treatments with a P-value of 0.020 (Figure 59). On the other hand, the rates fertilized with 75 and 150 lbs/N acre show no significant difference among them (P > 0.05). Overall the plots treated with 75 and 150 lbs/N acre showed 136% greater potential to leach NO$_3$ than the control plots with no fertilizer addition (Table 25).

Figure 58: Fertilizer type and control effects on the Leaching Indices in 2015.
Table 25: Average (± S.E.) leaching index (L.I.) in response to fertilizer rate in 2014 and 2015.

<table>
<thead>
<tr>
<th>Fertilizer Rate</th>
<th>2014</th>
<th>% increase</th>
<th>2015</th>
<th>% increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 lbs/N acre</td>
<td>1.42 ± 0.513</td>
<td></td>
<td>0.60 ± 0.06</td>
<td></td>
</tr>
<tr>
<td>75 lbs/N acre</td>
<td>3.30 ± 0.363</td>
<td></td>
<td>0.74 ± 0.04</td>
<td></td>
</tr>
<tr>
<td>150 lbs/N acre</td>
<td>3.36 ± 0.363</td>
<td></td>
<td>0.65 ± 0.04</td>
<td></td>
</tr>
<tr>
<td>225 lbs/N acre</td>
<td>2.57 ± 0.363</td>
<td>136%</td>
<td>0.70 ± 0.04</td>
<td>-</td>
</tr>
</tbody>
</table>

Figure 59: Different N fertilizer rates effect on Leaching Indices for the 2014 study.

When analyzing the effect of fertilizer rates on the L.I. for the different plots, there was no significant difference between the leaching indices in 2015 study for the different nitrogen fertilizer rates with mean values of: 0.60 ± 0.06, 0.74 ± 0.04, 0.65 ± 0.04 and 0.70 ± 0.04 for 0, 75, 150 and 225 lbs/N acre rates respectively (P > 0.05) (Table 25, Figures 60 & 61).
Figure 60: Different N fertilizer rates effect on Leaching Indices for the 2015 study.

Figure 61: Interaction Fertilizer x Rate on Leaching Indices for the 2015 study.
**Partial N Balance**

The nitrogen balance approach on farming systems is commonly used to estimate the potential for nitrogen leaching (Fried et al. 1976). This approach takes the assumption that with the continuous nitrogen flow through the soil profile, the soil reaches a steady-state of nitrogen content that will only leach and be replaced with the new input (Barry et al. 1993). Therefore, to estimate leaching potential a N balance can be used and is only a matter of obtaining a difference between the nitrogen inputs such as fertilizer addition, irrigation water, precipitation, atmospheric deposition, manure, etc. and nitrogen outputs such as harvested crop, nitrous oxide emissions by denitrification process and any other data that could be available. The remaining is nitrogen that is potentially to be leach into the groundwater.

For this nitrate leaching study a partial N balance approach was calculated for each of the seven treatments based on the average pounds of total nitrogen per acre that is potentially to be leach. The relative N balance was obtained from the total nitrogen detected on the soil within the top 4ft at pre-planting and post-harvest, fertilizer additions and total nitrogen that was removed at crop harvest. It was found that that average total nitrogen concentration ranged from 337 to 1481 lbs/N acre respectively for the Control and UAN3 treatments (Table 26), being the UAN3 the treatment with the highest N fertilizer application of UAN-32 at 225 lbs/N acre. According to other nitrogen leaching studies, a nitrogen excess in the N balance of 100 kg/N/ha a year is consider to be sufficient to cause nitrate contamination into groundwater (Ju et al. 2005).

Generally, the fertilized plots had an increase in terms of the amount of N that was available for potential leaching. Care must be taken in interpreting this results because, all this total N is not readily available for leaching, some might be lost through volatilization, denitrification, or remain in the soil.
Table 26: Relative potential for nitrogen leaching rate and pounds of total acre that are potentially to be leached for the seven treatments.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>lbs N/acre</th>
<th>Relative Potential for Leaching Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Control</td>
<td>336.89</td>
<td>1.00</td>
</tr>
<tr>
<td>2 ORG-R1</td>
<td>859.71</td>
<td>2.55</td>
</tr>
<tr>
<td>3 ORG-R2</td>
<td>898.59</td>
<td>2.67</td>
</tr>
<tr>
<td>4 ORG-R3</td>
<td>952.54</td>
<td>2.83</td>
</tr>
<tr>
<td>5 UAN-R1</td>
<td>647.59</td>
<td>1.92</td>
</tr>
<tr>
<td>6 UAN-R2</td>
<td>1084.23</td>
<td>3.22</td>
</tr>
<tr>
<td>7 UAN-R3</td>
<td>1481.39</td>
<td>4.40</td>
</tr>
</tbody>
</table>

The potential for leaching considering the Control as a value of 1, whereas the ORG ranged from about 2.55 to 2.83 the UAN from 1.92 to 4.40. In the graphical representation it appears to be significantly different (Figure 62). The ORG had an average of 903.6 lbs/N acre and the UAN showed a greater variability among the nitrogen rates. Unfortunately, the data for 2014 total N was not available and were not able to calculate the leaching potential. Early findings from this study suggest that generally, the UAN32 fertilizer applied at highest rates of 225 lbs/N acre had the greatest leaching potential.
Temporal and Spatial Variability in Soil Solution NO$_3$-N Content at 1ft and 2ft Depth

To identify the soil solution temporal and spatial variability in the NO$_3$-N concentrations in the study, soil solution access tubes (SSAT’s) were installed. The SSAT’s provide an “snap-shot” of the soil NO$_3$-N concentrations. This soil solution sampling method is an approach in estimating the potential for nitrogen leaching. Some studies have documented differences in the solute concentrations of the soil solution samples among different sampling methods, including soil solution access tubes, gravity samplers and soil core samples. Those differences are attributed to the fact that each method collects water from different pore sizes, therefore, different water fractions of the soil water that have different mobility in the soil and different solute concentrations (Landon et al., 1999).
Also the NO$_3$-N concentration in soil solution samples tends to be very high as compared to core soil samples. This is due to the fact that NO$_3$ molecule is soluble in water and therefore the highest concentrations will always be found in the soil solution as compared to soil bulk (Hartz, 2006).

For this study the soil solution samples were taken by sampling events; following a rainfall or irrigation event. The irrigation schedule was calculated based on ETc from the local CIMIS weather station. This schedule was designed to meet crop water demands and do not allow water to percolate down the ground. However, when rainfall events occurred mainly in 2014, the soil field capacity was exceeded and there was a greater potential to leach nitrogen. The samples were generally taken the day after the rainfall or irrigation event. In the graph below, (Figure 63) shows an average NO$_3$-N concentration of all sampling events along the season per treatment. And it can be appreciated how the NO$_3$-N concentration changed among the treatments and between the two sampling depths; 12-in and 24-in.

![Average NO3-N concentration in soil solution at 12 and 24-in depth by treatment. 2014](image)

Figure 63: Average soil solution NO$_3$-N concentration (mg/l) per treatment at 12-in and 24-in depth during the entire growing season in 2014.
Some of the soil solution NO$_3$-N concentration between the 12-in and 24-in depth can be explained from the fact that during the growing season, the N additions were done at soil surface level. However, it can be observed that in some treatments the 24-in depth soil solution shows and equally higher NO$_3$-N concentration as compared to the 12-in depth (Figure 63). Although it is not significantly different, the NO$_3$-N concentration goes toward the deeper part of the soil, which could be an indicator of the nitrate leaching.

To identify the temporal variability, the soil solution concentrations are also depicted in particular graphs of sampling events following days after transplant (D.A.T.) timeline (Figure 64, Figure 65). The soil solution nitrate concentrations from the collected samples will vary depending on the conditions of the sampling; for example, if it is close to a fertilization event or rainfall, the average NO$_3$-N concentration can range and to acknowledge the temporal variations the means are presented in the above mentioned graphs (Figure 64, Figure 65).

The coefficient of variation (CV) was calculated as a percent by dividing the Standard Deviation over the Mean for the NO$_3$-N concentration (Tables 27 & 28). And it is used to standardize the spatial variability of the nitrates around the field (Figure 2, p. 25) for the different treatments. For example; UAN-R2, in the Table 27, represents the average concentration for the samples that were taken at Plots 9, 26, 28, 30 and 32 at 12 and 24-in depth with a CV of 77%. This means that the NO$_3$-N concentrations for the plots treated with UAN-R2 had a 77% of variability among them as a function of the mean. CV allows to normalize the concentrations as a function of the mean in order to compare the variability for the different treatments (Table 27).
Figure 64: Soil solution NO₃-N concentration (mg/l) per treatment by sampling event in days after transplant (D.A.T.) at 12-in and 24-in depth for the 2014 growing season.
Figure 65: Soil solution NO$_3$-N concentration (mg/l) per treatment by sampling event in days after transplant (D.A.T.) at 12-in and 24-in depth for the 2014 growing season.
Table 27: Average NO$_3$-N concentration (mg/l) per treatment at 12-in and 24-in depth and Coefficient of Variation (CV) for 2014.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>12-in</th>
<th>CV</th>
<th>24-in</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>224.7</td>
<td>68%</td>
<td>141.7</td>
<td>49%</td>
</tr>
<tr>
<td>Org-R1</td>
<td>272.0</td>
<td>104%</td>
<td>66.8</td>
<td>43%</td>
</tr>
<tr>
<td>Org-R2</td>
<td>107.5</td>
<td>77%</td>
<td>109.8</td>
<td>58%</td>
</tr>
<tr>
<td>Org-R3</td>
<td>143.8</td>
<td>53%</td>
<td>174.2</td>
<td>42%</td>
</tr>
<tr>
<td>UAN-R1</td>
<td>119.8</td>
<td>110%</td>
<td>129.5</td>
<td>63%</td>
</tr>
<tr>
<td>UAN-R2</td>
<td>106.6</td>
<td>77%</td>
<td>44.1</td>
<td>146%</td>
</tr>
<tr>
<td>UAN-R3</td>
<td>299.6</td>
<td>105%</td>
<td>160.0</td>
<td>79%</td>
</tr>
</tbody>
</table>

Table 28: Average NO$_3$-N concentration (mg/l) per treatment at 12-in and 24-in depth and Coefficient of Variation (CV) for 2015.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>12-in</th>
<th>CV</th>
<th>24-in</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>163.7</td>
<td>98%</td>
<td>121.5</td>
<td>42%</td>
</tr>
<tr>
<td>Org-R1</td>
<td>214.3</td>
<td>30%</td>
<td>129.5</td>
<td>100%</td>
</tr>
<tr>
<td>Org-R2</td>
<td>211.5</td>
<td>132%</td>
<td>229.4</td>
<td>29%</td>
</tr>
<tr>
<td>Org-R3</td>
<td>158.2</td>
<td>71%</td>
<td>99.3</td>
<td>74%</td>
</tr>
<tr>
<td>UAN-R1</td>
<td>155.9</td>
<td>90%</td>
<td>163.1</td>
<td>100%</td>
</tr>
<tr>
<td>UAN-R2</td>
<td>42.4</td>
<td>68%</td>
<td>98.9</td>
<td>66%</td>
</tr>
<tr>
<td>UAN-R3</td>
<td>160.7</td>
<td>67%</td>
<td>141.7</td>
<td>31%</td>
</tr>
</tbody>
</table>

Generally, for the 2015 field study the soil solution NO$_3$-N concentration means were lower as compared to the 2014 (Figures 64-68). This trend might be explained due to the elevated Pre-planting soil nitrates levels in 2014. But also, it can be attributed to the fact that in 2015, the water application on the field was mainly irrigation water and in 2014 rainfall events were recorded during the growing period.
Figure 66: Average soil solution NO$_3$-N concentration (mg/l) per treatment at 12-in and 24-in depth during the entire growing season in 2015.

By looking at the SSAT’s solution sampling concentrations for the NO$_3$-N, some trends can be identified. However, there is great variability associated with the nitrates concentrations from the soil solution and no definitive conclusions can be outlined solely on the soil solution samples.

Further work to obtain a more detail NO$_3$-N estimations include taking soil samples every rain event that could potentially leach NO$_3$-N, but this type of sampling can disrupt the plant growth due to its destructive nature and the numerous samples that would have to be taken. Therefore, the best suitable option to obtain an estimate for the NO$_3$-N that is potentially to be leach is the use of SSAT’s. Landon et, al. (1999) concluded that suction lysimeters (SSAT’s) are more likely to have greater variation in the NO$_3$-N concentrations because it can obtain soil solution from different fractions of the soil water coming from different particle size that might have different mobility in the soil. Therefore, greater variability can be expected. Landon et, al. (1999) proposed that wick samples are a better method to obtain a more detail information of the soil solution that is recharging the groundwater.
Figure 67: Soil solution NO₃-N concentration (mg/l) per treatment by sampling event in days after transplant (D.A.T.) at 12-in and 24-in depth for the 2015 growing season.
Figure 68: Soil solution NO$_3$-N concentration (mg/l) per treatment by sampling event in days after transplant (D.A.T.) at 12-in and 24-in depth for the 2015 growing season.
For this study in addition to the SSAT’s, and to obtain a more detail information of the soil NO$_3$-N content, core soil samples were also taken at Pre-planting and Post-harvest to account for the NO$_3$-N concentration from the soil bulk at four depths in each of the plots.
CONCLUSIONS

Based on the literature review and objectives previously stated for this study, a summary of the main findings and conclusions are listed below:

**Biomass Production**

There was an overall aboveground biomass production increase with the use of fertilizers as compared to the control plots with no fertilizer addition. Generally, conventional fertilizer increased the biomass production by 61% and organic fertilizer by 30% as compared to the Control. Which justifies commercial farming practices of applying nitrogen fertilizer to increase biomass production.

For the fertilizer rate comparisons, in 2014 study there was no significant difference among the treatments, but on 2015, the highest N rates; R2 and R3 yielded significantly higher when compared to the lower rates; R1 and Control.

**Marketable Yield**

Marketable yield showed a significant increase with the use of fertilizers as compared to Control plots with no fertilizer addition. However, there was no significant difference between fertilizer types. Yield also showed a response to different fertilizer rates; higher rates R2 and R3 producing greater yield than R1 and Control. However, R3 yields did not show a significant difference from R2.

Generally, marketable yields were higher in response to R2 and R3 as compared to R1 and control regardless of the fertilizer type.

**Soil Solution NO$_3$-N Concentrations**

**Temporal and Spatial Variability**

The soil solution samples collected with SSAT’s in this study indicated that there is greater variability associated with the NO$_3$-N concentrations. Therefore, it
is not advisable to conclude on nitrate leaching potential solely from SSAT’s soil solution samples. However, it is an economical and relatively easy method to access soil solution and help estimate the soil solution nitrate concentrations. In addition, the NO$_3$-N concentrations spatial and temporal variability show trends that can be identified with the use of SSAT’s but need to be confirmed with the use of core soil samples.

**Soil NO$_3$-N Content as a Function of Fertilizer Type and Rate**

Soil nitrate contents in response to fertilizer type showed a higher NO$_3$-N content as compared to Control plots with no fertilizer addition. However, there was no significant difference between organic and conventional fertilizers, which suggest that the nitrate leaching might occur in either case with the use of nitrogen fertilizer into the soil.

When comparing nitrate leaching at different nitrogen fertilizer rates, there was an overall trend that suggest that soil NO$_3$-N content increased as the N addition increased. But, there was a significant difference between the highest rate of 225 lbs/N acre and the rest of the rates, resulting in the high rate to show a higher NO$_3$-N content in general.

Nitrate content in the soil as a function of depth did not show a significant different among the treatments. Generally, there was an interaction between UAN-32 fertilizer and the highest fertilizer rate of 225 lbs/N acre for the 0-12, 12-24, 24-36 and 36-48 inches of soil.

In conclusion, cauliflower growers whose fields are sandy loam soil should not exceed the 150lbs/N acre rate, regardless if it is being apply as a soybean meal or UAN-32 synthetic fertilizer, since the is no significant yield increase reported between 150 lbs/N acre and 225 lbs/N acre nitrogen fertilization rates. But there is
a greater potential to leach significant amounts of nitrogen when increasing the fertilizer rate. The economic return from adding extra nitrogen appears to be insignificant and there is a greater environmental risk of nitrate leaching into groundwater.
REFERENCES


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