

University of Nevada, Reno

**Effects of Soil Moisture, Texture, and Vegetation Type on C and N  
Transformations in Agricultural Fields of Northwestern Nevada**

Thesis submitted in partial fulfillment of the requirements for the degree of Master of  
Science in Hydrologic Sciences

By:

Zachary C. Johnson

Dr. Paul S. Verburg, Thesis Advisor

May 2010

Copyright by Zachary C. Johnson 2010  
All Rights Reserved



University of Nevada, Reno  
Statewide • Worldwide

THE GRADUATE SCHOOL

We recommend that the thesis  
prepared under our supervision by

**ZACHARY C. JOHNSON**

entitled

**Effects of Soil Moisture, Texture, and Vegetation Type on C and N  
Transformations in Agricultural Fields of Northwestern Nevada**

be accepted in partial fulfillment of the  
requirements for the degree of

**MASTER OF SCIENCE**

Paul S. Verburg, Ph. D., Advisor  
and Graduate School Representative

Robert R. Blank, Ph. D., Committee Member

Watkins W. Miller, Ph. D., Committee Member

Marsha H. Read, Ph. D., Associate Dean, Graduate School

May, 2010

## ABSTRACT

Irrigation is a common requirement for agriculture in semi-arid areas in the Western United States due to relative scarcity of water resources. In these areas, oftentimes competing demands for water are present including agriculture, municipal use and protection of natural ecosystems, resulting in conflict situations. One example of an area where these conflicting demands are intertwined is the Walker Basin, a semi-arid region in northwestern Nevada. Increased agricultural and municipal water use has reduced streamflows into Walker Lake, a terminal desert lake, causing lake levels to drop. As a result, lake salinity has increased to levels that are detrimental to native fish populations. The study presented in this thesis focused on the effects of alternative crops on soil quality in the Walker River Basin. Alternative crops are proposed to reduce water use while maintaining economic viability. This study was part of a large research project focusing on the potential for reducing water use in the Walker Basin and its effects on agriculture, natural ecosystems and the economy in this area.

A laboratory and field study were conducted to explore the effects of soil moisture, texture, temperature, and vegetation type on C and N transformations in soils from the Walker River Basin where alternative crops were planted. The primary objective of the laboratory study was to measure the effects of soil moisture, texture, and vegetation type on the C and N transformations in soils taken from two agricultural sites and a wildlife refuge site. The two agricultural field soils were planted with tef, amaranth, alfalfa, and switchgrass while the wildlife refuge area remained fallow. Carbon and N transformations in these soils were measured using constant temperature incubations with three moisture treatments. Carbon transformations in incubations of

pre- and post-planting soils and N transformations in pre-planting soils generally increased with increasing moisture while N transformations in post-planting soils were highest in the 0.15 ( $\text{g g}^{-1}$ ) moisture treatments. High clay contents most likely contributed to lower  $\text{CO}_2\text{-C}$  production rates and net changes in total extractable N for the wildlife refuge area soils in the pre-planting incubation. Clay appeared to have a negative effect on the  $\text{CO}_2\text{-C}$  production rates in the post-planting incubation for the two agricultural fields, which was somewhat surprising since textural differences between the two fields in this incubation were relatively small. Aboveground biomass generally did not significantly affect the C and N fluxes. However, tef soils showed the highest C mineralization rates and had the largest aboveground biomass production. Generally, the post-planting incubation had higher C fluxes and lower N fluxes than the pre-planting incubation indicating that the quality of available N or the availability of organic-N may have decreased over the growing season since total C and N generally did not differ between pre- and post-planting incubations.

The primary objective of the field study was to measure the effects of soil moisture, temperature, and vegetation type on C and N transformations in two agricultural fields of the Walker River Basin planted with tef, amaranth, alfalfa, and switchgrass. One field received three irrigation regimes (50%, 75% and 100% of estimated plant water use) while the other field only received the 50% irrigation treatment. Moisture was the primary driver for  $\text{CO}_2\text{-C}$  respiration with higher moisture levels resulting in higher  $\text{CO}_2\text{-C}$  respiration rates. The number of days since last irrigation application appeared to negatively affect the  $\text{CO}_2\text{-C}$  respiration rates in our soils. Total above-ground biomass appeared to affect the C respiration rates positively

and the net changes in inorganic-N negatively. The effects of vegetation type on the C and N transformations were not consistent over the establishment growing season. Field was the primary driver for changes in inorganic N with one field producing net positive changes and the other field producing net negative changes over the establishment growing season possibly due to differences in biomass production in combination with differences in mineralization rates. Soil temperature was not widely significant for this study but when it was significant it affected the C and N transformations negatively most likely because high temperatures often coincided with low soil moisture levels. Texture did not play a significant role in the C and N transformations because of relatively small differences in texture between the two fields.

In the short-term, none of the alternative crops grown appeared to have immediate detrimental effects on soil quality versus the traditionally grown alfalfa. In fact, the tef and amaranth crops grew quite well over the establishment season without detrimentally impacting soil C and N transformations as measured in this study. As a result, these two alternative crops have high potentials for the future in this area.

## DEDICATION

I would like dedicate this thesis first and foremost to my wife, Britt. Thank you for your countless hours of help, love and support. I would not have been able to complete this work without you. To my Mom and Dad, whose guidance and support brought me to the point I'm at today. To my brothers, Josh and Scott, who always looked out for me and continue to be a large part of my life. To my in-laws, Bob, Wendy, Mikel, and Diane, for accepting me into their family and supporting Britt and myself. To the rest of my family, for their support and love.

I would like to thank my advisor, Paul Verburg, for all of the time, effort, support, patience, and cat and tortoise sitting. I would have never completed this project without you. I would also like to thank my committee members, Bob and Wally for their constructive feedback and comments that helped make this thesis a better product.

Oliver, Kirby, and Penny, thanks for behaving...most of the time.

## ACKNOWLEDGEMENTS

These projects were funded by a grant under Public Law 109-103, Section 208(a), through the U.S. Bureau of Reclamation (Cooperative Agreement 06FC204044).

Special thanks to Britt Johnson for helping with laboratory and field work, Ryan Loux for helping with field work, Jeramie Memmott for help in using the Lachat Autoanalyzer, Todd Caldwell for help in using the Saturn DigiSizer, and Jay Arnone III, Richard Jasoni, and Jessica Larsen for providing air and soil temperature and relative humidity data. We also would like to thank Wally Miller and Robert Blank for reviewing drafts of this work.



**TABLE OF CONTENTS**

|  |     |
|--|-----|
| Chapter 1: General Introduction.....   | 1   |
| Outline of Thesis.....   | 4   |
| Chapter 2: Effects of Soil Moisture, Texture, and Vegetation Type on Rates of C and N Mineralization: A Laboratory Study ..... | 7   |
| Introduction.....  | 8   |
| Materials and Methods.....   | 11  |
| Results.....   | 21  |
| Discussion.....  | 56  |
| Conclusions.....   | 66  |
| Chapter 3: Short-Term Effects of Soil Moisture and Vegetation Type on Rates of Soil C Respiration: A Field Study.....          | 70  |
| Introduction.....  | 71  |
| Materials and Methods.....   | 76  |
| Results.....   | 83  |
| Discussion.....  | 104 |
| Conclusions.....   | 111 |
| Chapter 4: General Discussion and Summary.....   | 117 |
| Chapter 2 Summary.....   | 117 |
| Chapter 3 Summary.....   | 118 |
| Implications and Future Work.....  | 119 |

## LIST OF TABLES

|   |     |
|---|-----|
| 2.1 Vegetation species planted in revegetation fields.....            | 16  |
| 2.2 Vegetation species planted in alternative fields.....             | 17  |
| 2.3 Soil characteristics.....   | 22  |
| 2.4 MANOVA results for the pre-planting incubation.....               | 32  |
| 2.5 MANOVA results for the post-planting incubation .....             | 33  |
| 2.6 Extractable N concentrations in the pre-planting incubation.....  | 40  |
| 2.7 Extractable N concentrations in the post-planting incubation..... | 41  |
| 2.8 Multiple regression results for the pre-planting incubation.....  | 55  |
| 2.9 Multiple regression results for the post-planting incubation..... | 56  |
| 3.1 Vegetation species planted in alternative fields.....             | 80  |
| 3.2 Soil characteristics.....   | 84  |
| 3.3 MANOVA results.....   | 93  |
| 3.4 Biomass percent N contents.....                                   | 102 |
| 3.5 Multiple regression results.....                                  | 103 |

## LIST OF FIGURES

|  |    |
|--|----|
| 2.1 Map of the Walker River Basin.....                   | 13 |
| 2.2 Map of field sites.....                              | 14 |
| 2.3 Layout of the agricultural fields.....               | 16 |
| 2.4 Total C content in the pre-planting incubation.....  | 22 |
| 2.5 Total N content in the pre-planting incubation.....  | 23 |
| 2.6 Total C content in the post-planting incubation..... | 24 |

|      |  |    |
|------|--|----|
| 2.7  | Total N content in the post-planting incubation.....   | 24 |
| 2.8  | Pre-incubation C/N ratios in the pre-planting incubation.....                                  | 25 |
| 2.9  | Pre-incubation C/N ratios in the post-planting incubation.....                                 | 26 |
| 2.10 | Percent extractable N in the pre-planting incubation.....                                      | 27 |
| 2.11 | Percent extractable N in the post-planting incubation.....                                     | 28 |
| 2.12 | Cumulative CO <sub>2</sub> -C respiration per gram of soil in the pre-planting incubation..... | 29 |
| 2.13 | Cumulative CO <sub>2</sub> -C respiration per gram of soil in the post-Valley Vista field..... | 31 |
| 2.14 | Cumulative CO <sub>2</sub> -C respiration per gram of soil in the post-Cottonwood field.....   | 32 |
| 2.15 | Cumulative CO <sub>2</sub> -C respiration per gram of C in the pre-planting incubation.....    | 34 |
| 2.16 | Cumulative CO <sub>2</sub> -C respiration per gram of C in the post-Valley Vista field .....   | 36 |
| 2.17 | Cumulative CO <sub>2</sub> -C respiration per gram of C in the post-Cottonwood field .....     | 36 |
| 2.18 | Exponential CO <sub>2</sub> -C respiration rate constant in the pre-planting incubation.....   | 37 |
| 2.19 | Exponential CO <sub>2</sub> -C respiration rate constant in the post-Valley Vista field.....   | 38 |
| 2.20 | Exponential CO <sub>2</sub> -C respiration rate constant in the post-Cottonwood field.....     | 39 |
| 2.21 | Net total extractable N content in the pre-planting incubation.....                            | 42 |
| 2.22 | Net total extractable N content in the post-Valley Vista field.....                            | 45 |
| 2.23 | Net total extractable N content in the post-Cottonwood field.....                              | 46 |
| 2.24 | Net nitrate-N content in the pre-planting incubation.....                                      | 47 |
| 2.25 | Net nitrate-N content in the post-Valley Vista field.....                                      | 49 |
| 2.26 | Net nitrate-N content in the post-Cottonwood field.....  | 50 |
| 2.27 | Net ammonium-N content in the pre-planting incubation.....                                     | 51 |
| 2.28 | Net ammonium-N content in the post-Valley Vista field.....                                     | 53 |
| 2.29 | Net ammonium-N content in the post-Cottonwood field.....                                       | 54 |

|      |   |     |
|------|---|-----|
| 2.30 | Quadratic response of CO <sub>2</sub> -C respiration rate in the pre-planting incubation.....                           | 57  |
| 2.31 | Quadratic response of CO <sub>2</sub> -C respiration rate in the post-Valley Vista field.....                           | 58  |
| 2.32 | Quadratic response of CO <sub>2</sub> -C respiration rate in the post-Cottonwood field.....                             | 58  |
| 2.33 | Clay and silt effect on cumulative C respiration for the 0.05 moisture treatment in<br>the pre-planting incubation..... | 63  |
| 3.1  | Map of the Walker River Basin.....  | 77  |
| 3.2  | Map of field sites.....   | 78  |
| 3.3  | Layout of the alternative agricultural fields.....  | 79  |
| 3.4  | Moisture content by vegetation throughout the growing season.....   | 86  |
| 3.5  | Overall moisture content by irrigation treatment over the growing season.....   | 87  |
| 3.6  | Overall moisture content by vegetation type over the growing season.....  | 88  |
| 3.7  | Daily temperature and relative humidity values .....  | 89  |
| 3.8  | CO <sub>2</sub> efflux rates by irrigation treatment.....   | 90  |
| 3.9  | Overall CO <sub>2</sub> -C efflux rates by irrigation treatment.....  | 91  |
| 3.10 | CO <sub>2</sub> efflux rates by vegetation type.....  | 92  |
| 3.11 | Overall CO <sub>2</sub> -C efflux rates by vegetation type.....   | 93  |
| 3.12 | Net total extractable N content by irrigation treatment.....  | 94  |
| 3.13 | Net total extractable N content by vegetation type.....   | 95  |
| 3.14 | Net nitrate-N content by irrigation treatment.....  | 97  |
| 3.15 | Net nitrate-N content by vegetation type.....   | 98  |
| 3.16 | Net ammonium-N content by irrigation treatment.....   | 99  |
| 3.17 | Net ammonium-N content by vegetation type.....  | 99  |
| 3.18 | Above-ground biomass by irrigation treatment.....   | 100 |

|  |     |
|--|-----|
| 3.19 Above-ground biomass by vegetation type.....                                  | 101 |
| 3.20 Effect of days since last irrigation on CO <sub>2</sub> respiration rate..... | 106 |

## CHAPTER 1: GENERAL INTRODUCTION

In many areas in the Western United States, irrigated agriculture is common often causing a high demand for limited water supplies. The increased need for potable water in urban areas and decrease in water quantity and quality as a product of agriculture and municipal needs requires the development of agricultural practices that demand less water while maintaining economic viability. However, changes to more water-efficient agricultural practices should aim to prevent decreases in soil quality, which in the long term could negatively impact agricultural yields. In this thesis, soil quality is defined as “the capacity of a soil to be functional, within limits imposed by the ecosystem and land use, to preserve the biological productivity and environmental quality, and promote plant, animal and human health” (Doran and Parkin, 1994). Several indicators of soil quality have been identified in previous studies including nutrient availability (particularly carbon (C) and nitrogen (N)), soil structure, bulk density, and soil fauna (Knoepp et al., 2000).

Nutrient availability is dependent on organic matter decomposition. Assuming no water limitation, the availability of organic matter to microbes in the soil will mediate the microbial activity and therefore the amount of soil organic N converted into inorganic forms that are available for plants (Ford et al., 2007). Soil moisture affects aerobic microbial activity via substrate diffusion through the soil matrix. In addition, soil moisture affects O<sub>2</sub> availability for microbial metabolism with O<sub>2</sub> diffusivity decreasing with increasing soil moisture (Ford et al., 2007). As a result, in semi-arid systems, substrate availability determines nutrient mineralization rates when water availability is high, but as soils become drier, substrate diffusion becomes the major determinant (Ford

et al., 2007). In addition, many arid systems are characterized by repeated wetting and drying cycles (Ford et al., 2007; Fierer and Schimel, 2002; Lundquist et al., 1999). This process has a significant effect on soil C and N transformations. Drying-rewetting events could result in moderate short-term changes in respiration rates, substantial reductions in long-term respiration rates, an increase in nitrifier activity, and an increase in the size of the microbial biomass C pool (Fierer and Schimel, 2002).

Soil temperature greatly influences microbial activity, microbial community structure, and thus C and N fluxes especially when moisture is not limiting (Cookson et al., 2006; Cookson et al., 2002; Zogg et al., 1997). The soil temperature can also affect root respiration (Chen et al., 2000). Because both soil organic matter (SOM) decomposition and root respiration depend on temperature and moisture it is not surprising that soil respiration is highly dependent on these factors. Dilustro et al. (2005) reported the effects of soil temperature, moisture, and texture on soil CO<sub>2</sub> efflux. In their study, the overall pattern of soil CO<sub>2</sub> efflux was related primarily to soil temperature. However, they mention that soil moisture extremes can limit CO<sub>2</sub> efflux as well. Tang et al. (2006) reported that soil temperature and soil moisture are two of the most important environmental parameters controlling variations in soil CO<sub>2</sub> efflux, however, the relationships between soil respiration and these two parameters vary in different ecosystems.

Decomposition rates of SOM typically decrease with increasing clay content, where organic matter is protected from microbial decomposition by the clay fraction (Hassink, 1994). As a result, C mineralization and decomposition rates in soils increase with decreasing clay content (Franzluebbers, 1999). This protection by clay-sized

particles has been ascribed to adsorption of organics onto clay and sesquioxide surfaces, encapsulation between clay particles, and/or entrapment in small pores of aggregates inaccessible to microbes (Hassink, 1994). Soil texture can influence soil CO<sub>2</sub> efflux through its effects on soil moisture, temperature, nutrient availability, and soil C residence times as well (Dilustro et al., 2005).

Changes in plant productivity, particularly root biomass, can strongly influence the soil microbial community by altering root exudation patterns and the supply of root C to soil through root turnover (Bardgett et al., 1999). Individual plant species effects are important determinants of ecosystem processes including organic matter decomposition and nutrient cycling (Hooper and Vitousek, 1997; Wardle et al., 1997; Grime, 1998). Variations in root exudation patterns amongst plant species can alter the supply of nutrients for plant and microbial growth. In the short term, the soil microbial community structure is influenced by plant species traits and changes in soil N availability (Bardgett et al., 1999).

The study presented in this thesis was part of a larger project located within the Walker River Basin, a major river system in northwestern Nevada (Figure 2.1). The Walker River originates from the eastern side of the Sierra Nevada Mountains in California and ends in Walker Lake, a terminal desert lake in northwestern Nevada. The region stretching approximately from the junction of Nevada state highways 208 and 339 north to Wabuska, NV represents a major agricultural area in the Mason Valley. Upstream diversions for irrigation and municipal purposes have caused a dramatic drop in water level and an associated increase in salinization of Walker Lake during the last century. The Walker River Basin Project is a collaborative research project between the



University of Nevada-Reno and the Desert Research Institute of Reno to assess the impacts of reducing water extraction from the Walker River on Walker Lake and its surrounding area. The research described in this thesis was part of an effort to determine alternative crop options for agricultural purposes that use less water while maintaining economic feasibility. Understanding the role that the soil moisture, soil temperature, soil texture, and vegetation type play on the cycling of C and N in these agricultural fields is vital in judging which alternative crops show the most economic promise while limiting the depletion of soil resources. The purpose of our study was to understand the effects of soil moisture, temperature, texture, and vegetation (the alternative crops) on C and N availability (therefore soil quality).

#### OUTLINE OF THESIS

The main objectives of this study were to determine the effects of soil moisture, soil temperature and vegetation type on C and N mineralization under laboratory and field conditions. We specifically tested the following main hypotheses:

- H1: Higher moisture levels, up to saturation, will lead to higher C and N transformations because of higher associated microbial activity
- H2: The soil with the highest clay fraction will have lower mineralization rates but higher accumulation of C due to the protection of soil organic matter from decomposition.
- H3: Temperature will effect the C and N transformations depending on the soil moisture condition.

H4: Higher amounts of biomass will result in higher C and N fluxes because of increased inputs of organic matter.

In the second chapter, we describe a laboratory study examining the effects of soil moisture, soil texture and vegetation type on rates of C and N mineralization using soil incubations at constant temperature. We use the results from this chapter to develop hypotheses to be tested in field studies. In the third chapter, we describe the results of a field study exploring the effects of soil moisture, soil temperature and vegetation type on rates of C mineralization. The fourth chapter presents an overall summary as well as recommendations for future studies.

## REFERENCES

- Bardgett, R.D., Mawdsley, J.L., Edwards, S., Hobbs, P.J., Rodwell, J.S., Davies, W.J. (1999) Plant species and nitrogen effects on soil biological properties of temperate upland grasslands. *Functional Ecology* **13**, 650-660.
- Chen, H., Harmon, M.E., Griffiths, R.P., Hicks, W. (2000) Effects of temperature and moisture on carbon respired from decomposing woody roots. *Forest Ecology and Management* **138**, 51-64.
- Cookson, W.R., Cornforth, I.S., Rowarth, J.S. (2002) Winter soil temperature (2-15°C) effects on nitrogen transformations in clover green manure amended or unamended soils: a laboratory and field study. *Soil Biology & Biochemistry* **34**, 1401-1415.
- Cookson, W.R., Marschner, P., Clark, I.M., Milton, N., Smirk, M.N., Murphy, D.V., Osman, M., Stockdale, E.A., Hirsch, P.R. (2006) The influence of season, agricultural management, and soil properties on gross nitrogen transformations and bacterial community structure. *Australian Journal of Soil Research* **44**, 453-465.
- Dilustro, J.J., Collins, B., Dunca, L., Crawford, C. (2005) Moisture and soil texture effects on soil CO<sub>2</sub> efflux components in southeastern mixed pine forests. *Forest Ecology and Management* **204**, 85-95.
- Doran, J.W. and Parkin, T.B. (1994) Defining and assessing soil quality. In: Doran, J.W., Coleman, D.C., Bezdicek, D.F., Stewart, B.A. (Eds.), *Defining Soil Quality for a*

- Sustainable Environment. *Soil Science Society of America Special Publication*, vol. 35. Soil Science of America, Madison, WI, pp. 3-21.
- Fierer, N. and Schimel, J.P. (2002) Effects of drying-rewetting frequency on soil carbon and nitrogen transformations. *Soil Biology & Biochemistry* **34**, 777-787.
- Ford, D.J., Cookson, W.R., Adams, M.A., Grierson, P.F. (2007) Role of soil drying in nitrogen mineralization and microbial community function in semi-arid grasslands of north-west Australia. *Soil Biology & Biochemistry* **39**, 1557-1569.
- Franzluebbers A.J. (1999) Potential C and N mineralization and microbial biomass from intact and increasingly disturbed soils of varying texture. *Soil Biology & Biochemistry*, **31**, 1083-1090.
- Grime, J.P. (1998) Benefits of plant diversity to ecosystems: immediate, filter and founder effects. *Journal of Ecology* **86**, 902-910.
- Hassink, J. (1994) Effects of soil texture and grassland management on soil organic C and N and rates of C and N mineralization. *Soil Biology & Biochemistry* **26**, 1221-1231.
- Hooper, D. and Vitousek, P.M. (1997) The effects of plant composition and diversity on ecosystem processes. *Science* **277**, 1302-1305.
- Knoepp, J.D., Coleman, D.C., Crossley Jr., D.A., Clark, J.S. (2000) Biological indices of soil quality: an ecosystem case study of their use. *Forest Ecology & Management* **138**, 357-368.
- Lundquist, E.J., Jackson, L.E., Scow, K.M. (1999) Wet-dry cycles affect dissolved organic carbon in two California agricultural soils. *Soil Biology & Biochemistry* **31**, 1031-1038.
- Tang, X.L., Zhou, G.Y., Liu, S.G., Zhang, D.Q., Liu, S.Z., Li, J., Zhou, C.Y. (2006) Dependence of Soil Respiration on Soil Temperature and Soil Moisture in Successional Forests in Southern China. *Journal of Integrative Plant Biology* **48**, 654-663.
- Wardle, D.A., Zackrisson, O., Hornberg, G., Gallet, C. (1997) The influence of island size area on ecosystem properties. *Science* **277**, 1296-1299.
- Zogg, G.P., Zak, D.R., Ringleberg, D.B., MacDonald, N.W., Pregitzer, K.S., White, D.C. (1997) Compositional and functional shifts in microbial communities due to soil warming. *Soil Science Society of America Journal* **61**, 475-481.

## **CHAPTER 2: EFFECTS OF SOIL MOISTURE, TEXTURE, AND VEGETATION TYPE ON RATES OF C AND N MINERALIZATION: A LABORATORY STUDY**

### **ABSTRACT**

Alternative crops are being considered to reduce the need for irrigation in the Walker River Basin, a semi-arid region in northwestern Nevada. Limited information, however, exists on the effects of these changes in land use on C and N mineralization. The objective of this study was to use laboratory incubations to explore the effects of soil moisture, texture, and vegetation type on the C and N transformations in soils from the Walker Basin under constant temperature. Soils were sampled from two agricultural fields and one field in a wildlife refuge prior to planting. In the two agricultural fields, soils were planted with tef, amaranth, alfalfa, and switchgrass while the wildlife refuge area remained fallow. C transformations in incubations of pre- and post-planting soils and N transformations in pre-planting soils generally increased with increasing moisture while N transformations in post-planting soils were highest in the 0.15 ( $\text{g g}^{-1}$ ) moisture treatments. The optimal gravimetric moisture content for the C transformations was between 0.15 and 0.30 ( $\text{g/g}$ ) and the moisture response was described by a quadratic function for both pre- and post-planting incubations. High clay contents most likely contributed to lower  $\text{CO}_2\text{-C}$  production rates and net changes in total extractable N for the Wildlife Area revegetation soils in the pre-planting incubation. Clay appeared to have a negative effect on the  $\text{CO}_2\text{-C}$  production rates in the post-planting incubation for the two agricultural fields, which was somewhat surprising since the textural difference between the two fields in this incubation was relatively small. Aboveground biomass was not a

widely significant factor affecting the C and N fluxes. However, tef did produce the largest C production rates and had the largest aboveground biomass production. Generally, the post-planting incubation had higher C fluxes and lower N fluxes than the pre-planting incubation indicating that the quality of available N or the availability of organic-N may have decreased over the growing season since total C and N generally did not differ between pre- and post-planting incubations. Further study is required to assess whether or not the existing differences and other non-existing differences will become more apparent following more growing seasons.

## INTRODUCTION

Soil organic matter (SOM), which includes a variety of carbon (C) compounds originating from plants, microbes, and other organisms, helps to maintain soil fertility and plays a critical role in the nutrient, water, and biological cycles. As a result, SOM is one of the most important indicators of soil quality (Komatsuzaki and Ohta, 2007; Lemenih et al., 2005). The activity of the microbial community in a soil is an indication of the presence of sufficient quantities of organic matter. A soil with higher amounts of microbial activity is considered healthier and better quality for agricultural purposes (Barrios et al., 2006). Declines in soil organic C (SOC) caused by the cultivation of soils has been studied in many long-term experiments (Grace and Oades, 1994; Golchin et al., 1995). In cultivated land, decomposition rates of SOC are typically higher compared to forest resulting in a considerable carbon loss when forests are converted to agricultural lands (Komatsuzaki and Ohta, 2007). Decreasing SOC contributes to low soil fertility and reduced cation exchange capacity resulting in the need for additional fertilizer inputs

to maintain economical yield (Komatsuzaki and Ohta, 2007). Conversely, increasing SOC increases crop yield response and conserves water quality thus improving soil quality.

Several studies have shown the importance of moisture in regulating microbial activity. For instance, Orchard and Cook (1983) found that a log-linear function could be used to describe relationship between water potential and microbial activity with respiration rates being directly proportional to gravimetric water content in some soils. Decomposition rates usually increase with water potential, from about -5 to -0.05 MPa (Lomander et al., 1998a), and then decrease in wetter and/or drier conditions due to oxygen deficiency (Campbell, 1978; Dilustro et al., 2005) and limiting microbial respiration (Dilustro et al., 2005).

The results from past studies of the effects of texture on C mineralization vary. Some studies have found that C mineralization is more rapid in soils with low compared to high clay content despite greater organic matter contents in the high versus low clay content soils (Franzluebbers, 1999; Hassink, 1994). However, other laboratory studies found that the effect of clay on soil C mineralization was not pronounced (Giardina et al., 2001; Motavalli et al., 1994). Wang et al. (2003) reported that immediately after the rewetting of their soils, when labile SOC was being mineralized, respiration was not influenced by clay in an incubation. However, later in the incubation, clay content slowed the rate of mineralization. Effects of texture on nitrogen (N) mineralization are also not consistent. Clay has been hypothesized to alter N mineralization rates by binding with organic matter to form soil aggregates that protect soil N from heterotrophic soil organisms. Hence, N mineralization has been found to be more rapid in sand soils

than in loam or clay soils (Pare and Gregorich, 1999). However, clay has also been found to be a weak predictor of soil N mineralization rates in laboratory studies (Giardina et al., 2001).

Plant species composition can affect organic matter decomposition and nutrient cycling (Hooper and Vitousek, 1997; Wardle et al., 1997; Grime, 1998). The structure and functional diversity of microbial communities in the soil is tightly related to plant species composition above-ground, which provides an important link between above- and below-ground processes (Kourtev et al., 2003). Changes in plant productivity, particularly root biomass, strongly influence the soil microbial community by altering root exudation patterns and the supply of root C to soil through root turnover (Bardgett et al., 1999). In addition, in the short term, the soil microbial community structure is influenced by plant species traits and changes in soil N availability (Bardgett et al., 1999). Previous studies have shown clearly that structurally and functionally distinct microbial communities develop under different plant species in time periods as short as three months (Degens and Harris, 1997; Bossio et al., 1998; Marilley and Aragno, 1999; Kourtev et al., 2003). The study by Kourtev et al. (2003) showed that both community structure and function were affected which altered the N concentrations, pH, and N mineralization in the soil.

In many semi-arid regions, agricultural practices have been in place for long periods of time. However, competing demands on scarce water supplies can result in conflict situations. In northern Nevada, studies are ongoing to test for alternative crops that would require less water while maintaining economic viability. For this study, we looked at the effects of alternative crops on soil quality. We used two laboratory

incubations to explore the effects of soil moisture, texture, soil C and N, and vegetation type on the C and N transformations in five field soils from three sites in the Walker Basin of northwestern Nevada. We specifically tested three hypotheses relevant to the role of moisture, texture, and vegetation on the C and N transformations:

H1: Soils with higher moisture contents, but not saturated contents, will exhibit higher C and N transformation rates.

H2: Soils with higher clay contents will have lower C and N mineralization because of the physical protection from decomposition.

H3: Soils with the most biomass will exhibit higher rates of C and N transformations because of higher inputs of organic matter.

## METHODS AND MATERIALS

### *Field Sites*

Soil samples were taken from three field sites located near Yerington, NV (Figures 2.1 and 2.2). The Mason County Wildlife Management Area site (*Lat: 39° 03'09.30"N Long: 119° 08'02.30"W*) was located approximately 8 km northeast of Yerington, NV (Figure 2.2). This site was dominated by willows with intervening grasses prior to removal. The soil was 75-80% Dithod Loam (coarse-loamy, mixed, superactive, mesic oxyaquic haploxerolls), typical for flood plains and low stream terraces, and 15-20% Fallon fine sandy loam (coarse-loamy, mixed, superactive, nonacid, mesic oxyaquic torrifluvents), saline alkali soils (USDA, 1984). The Valley Vista site (*Lat: 38° 51'00.45"N Long: 119° 10'59.20"W*) was located approximately 15 km south



of Yerington, NV (Figure 2.2). The field had been used for alfalfa production when the vegetation was removed prior to ripping and disking of the fields. The majority of the soils belonged to the Malpais (loamy-skeletal, mixed, superactive, mesic typic haplocambids) complex soils (60%), which are found on alluvial fans and colluvial slopes bordering mountains, while other soils belonged to the Tocan sandy loam (fine-loamy, mixed, superactive, mesic durinodic haplargids) 2-4% slopes (20%), and Tocan sandy loam 0-2% slopes (20%) (USDA, 1984).

The 5C Cottonwood Ranch site (*Lat: 38° 50' 50.33" N Long: 119° 11' 00.57" W*) was located approximately 150 m south of the Valley Vista site (Figure 2.2). This site had not been in production for several years and was used primarily as grazing land for burros and llamas. This site consisted of 100% Malpais complex 2-15% slopes soils, having a sandy texture (USDA, 1984). Soils here were highly compacted and void of vegetation prior to ripping and disking. The pre-planting incubation soils samples from this site were taken in early July 2007 and the post-planting samples were taken in late August 2008. Only the Valley Vista and Cottonwood sites were utilized in the post-planting incubation. All three sites were equipped with sprinkler irrigation systems. Each field was separated into an area designated for alternative crops while another area was used for revegetation trials with native plant species.

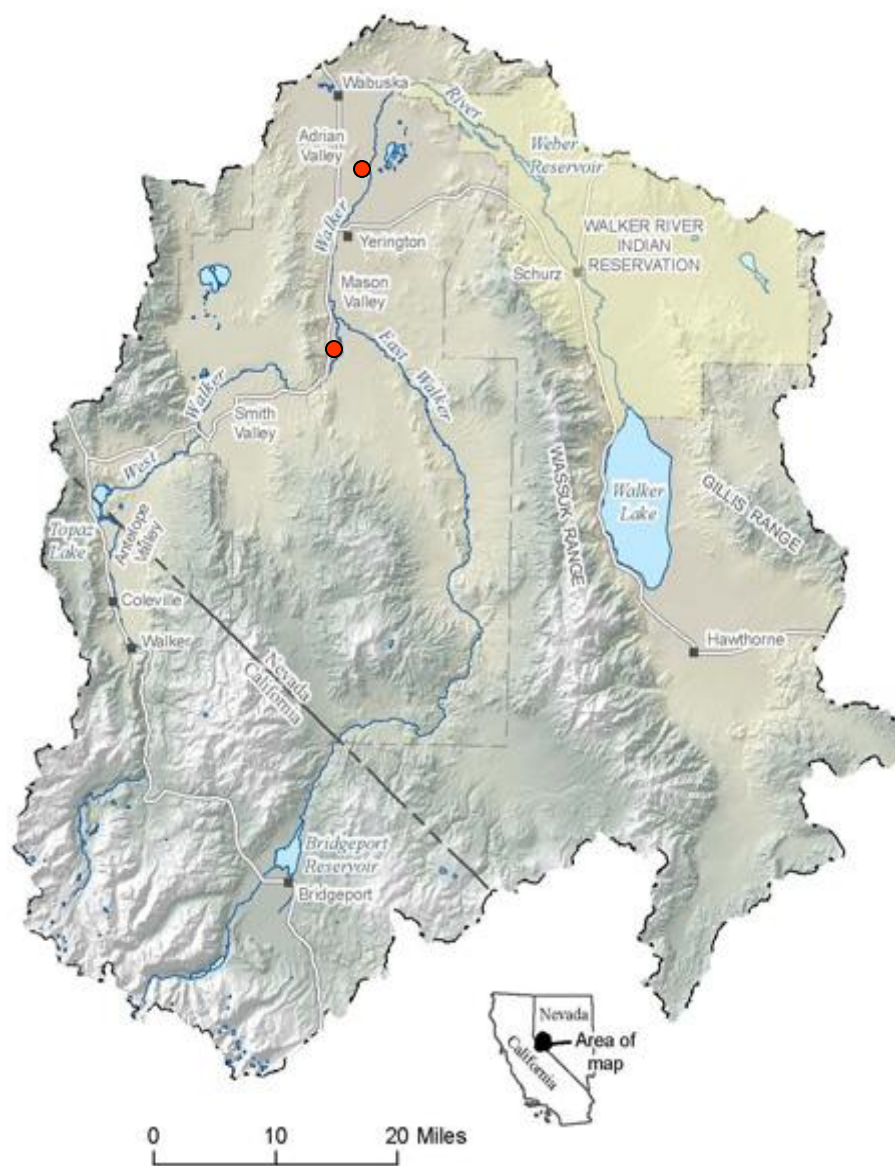


Figure 2.1: Map of the Walker River Basin. Red dots indicate approximate locations of field sites for this study. The lower dot represents the Valley Vista and Cottonwood sites. Courtesy of the USGS.

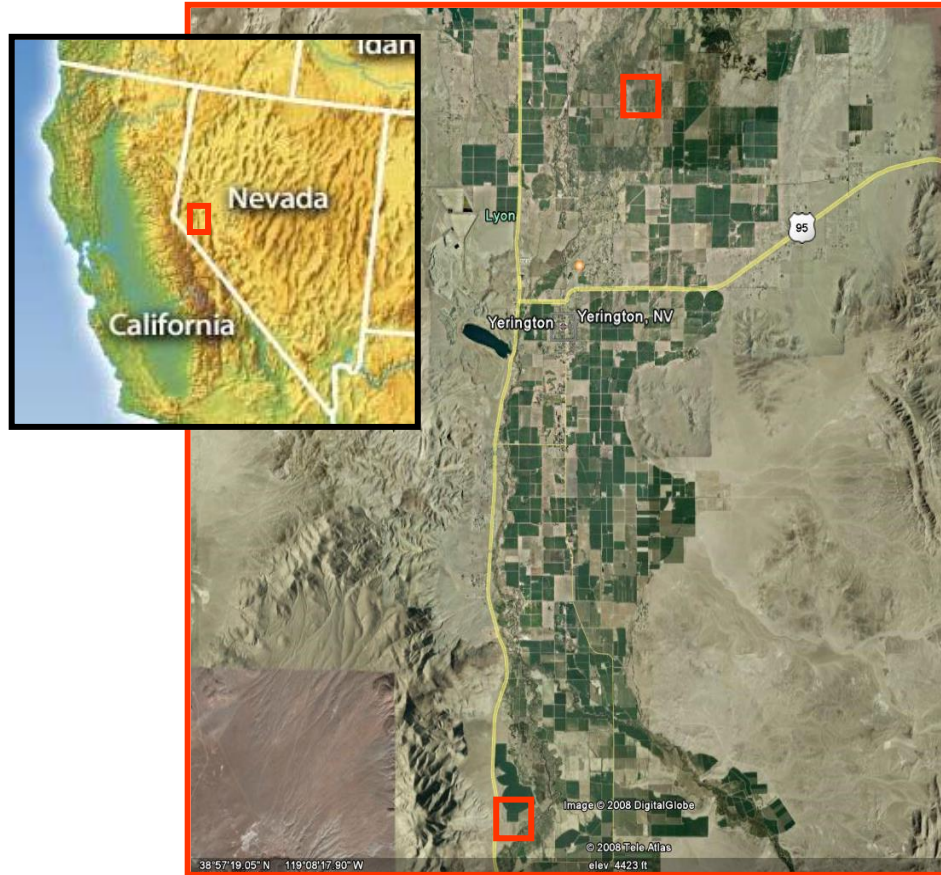


Figure 2.2: Map showing locations of field sites. Top red square indicates Wildlife Area, bottom red square indicates Valley Vista and Cottonwood Ranch locations. Inset map shows area location. Courtesy of Google Earth.

In the revegetation fields, six vegetation types were randomly distributed in 36 90' x 30' plots where each of the six columns included one of each vegetation type plot (Figure 2.3). The control in these fields was alfalfa. The alternative crop fields consisted of fifteen vegetation types in 135 24' x 30' plots where one of each vegetation type plot was randomly located in each of the nine columns (Figure 2.3). Alfalfa was also used as the control in these fields. Tables 2.1 and 2.2 show the vegetation planted in the revegetation and alternative crop fields respectively. For our study we focused on four crops: Tef (*Erograstis tef*), Amaranth (*Amaranth cruentus*), Alfalfa (*Medicago sativa*)

and Switchgrass (*Panicum virgatum*). Tef, amaranth, and switchgrass were chosen to represent the different types of crop planted (grass versus grain). Alfalfa was included in the fifteen vegetation types planted in the alternative fields to serve as a control since it is one of the most common forage crops grown in this area.

Tef is a summer cereal crop of great popularity in Ethiopia that does very well with limited irrigation (USDA, NRCS, 2008). Excess water and fertilizer have actually been seen to decrease grain quality and does not increase yield (Norberg et al., 2005). Tef is very nutritious and can be used for either human consumption or as cattle feed. Amaranth had been used as an American Indian food source and is well adapted to drought conditions as well as requiring little to no fertilizer (USDA, NRCS, 2008). Amaranth can also be used either for human consumption or as cattle feed. The major down side for Amaranth production today is the lack of approved herbicides for use (USDA, NRCS, 2008). Alfalfa is a N-fixer and a perennial forage crop typically produced in regions characterized by hot dry summers and cold winters. Switchgrass is a warm-season, perennial sod-forming grass native to the United States. It is tolerant of moderately saline or acidic soils and can be farmed similar to traditional forage (USDA, NRCS, 2008).

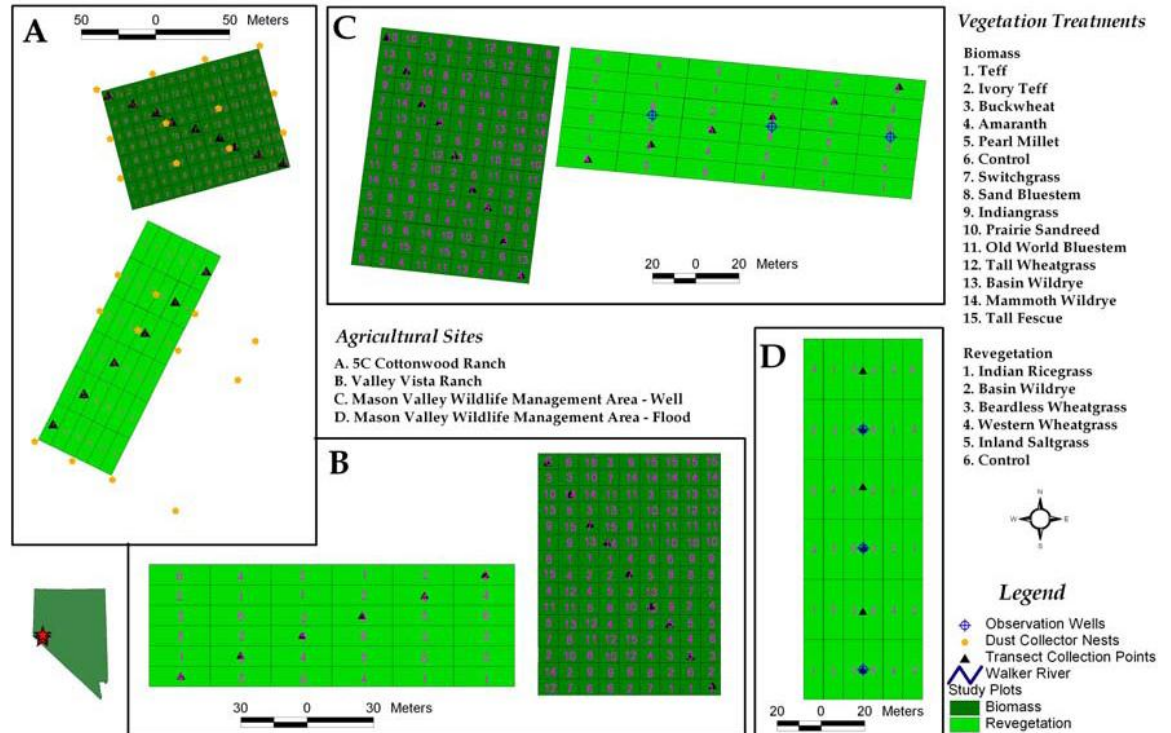


Figure 2.3: Layout and orientation of the agricultural fields (A-C). The revegetation fields are shown in light green, the alternative fields in dark green within each box. Courtesy of Erin Carroll-Moore

Table 2.1: Species of vegetation planted in revegetation fields. \* Indicates species used

|           |  |
|-----------|--|
| <b>1</b>  | <b>Indian ricegrass (<i>Achnatherum hymenoides</i>)</b>      |
| <b>2</b>  | <b>Basin Wildrye (<i>Leymus cinereus</i>)</b>                |
| <b>3</b>  | <b>Beardless wheatgrass (<i>Pseudoroegneria spicata</i>)</b> |
| <b>4</b>  | <b>Western wheatgrass (<i>Pascopyrum smithii</i>)</b>        |
| <b>5</b>  | <b>Inland saltgrass (<i>Distichlis spicata</i>)</b>          |
| <b>*6</b> | <b>Alfalfa (<i>Medicago sativa</i>)</b>                      |

Table 2.2: Species of vegetation planted in alternative fields. \* Indicates species used

|           |  |
|-----------|--|
| <b>*1</b> | <b>Dessie Tef (<i>Erograstis tef</i>)</b>                  |
| <b>2</b>  | <b>White seed Tef (<i>Erograstis tef</i>)</b>              |
| <b>3</b>  | <b>Buckwheat (<i>Fagopyrum esculentum</i> Moench)</b>      |
| <b>*4</b> | <b>Amaranth (<i>Amaranth cruentus</i>)</b>                 |
| <b>5</b>  | <b>Pearl millet (<i>Pennisetum glaucum</i> (L) R.BR.)</b>  |
| <b>*6</b> | <b>Alfalfa (<i>Medicago sativa</i>)</b>                    |
| <b>*7</b> | <b>Switchgrass (<i>Panicum virgatum</i>)</b>               |
| <b>8</b>  | <b>Sand bluestem (<i>Andropogon hallii</i>)</b>            |
| <b>9</b>  | <b>Indiangrass (<i>Sorghastrum nutans</i>)</b>             |
| <b>10</b> | <b>Prairie Sandreed (<i>Calamovilfa longifolia</i>)</b>    |
| <b>11</b> | <b>Bluestem (old world) (<i>Bothrichloa ischaemum</i>)</b> |
| <b>12</b> | <b>Tall wheatgrass (<i>Elytrigia elongate</i>)</b>         |
| <b>13</b> | <b>Basin wildrye (<i>Leymus cinereus</i>)</b>              |
| <b>14</b> | <b>Mammoth wildrye (<i>Leymus racemosus</i>)</b>           |
| <b>15</b> | <b>Tall Fescue (<i>Festuca arundinacea</i>)</b>            |

### *Laboratory Incubations*

We conducted two separate incubations. For the first incubation, we used soil samples taken prior to planting (pre-planting) while the second incubation involved soil samples taken at the end of one growing season (post-planting). Pre-planting soil samples from Wildlife Area site were taken in late October 2007. Since this field was not planted, no post-planting samples were taken from this site. Soil samples from the Valley Vista

and Cottonwood sites used in the pre-planting incubation were taken in late June 2007. For the post-planting incubation, only samples from the alternative agriculture fields were used. Samples for this incubation were taken in late August 2008 from each plot of interest within a 1.45 m<sup>2</sup> area around a PVC respiration ring after the aboveground vegetation within this area was cleared and sampled.

For each pre-incubation sampling, five vegetation plots for soil sampling were chosen randomly from each of the five fields, for a total of 25 plots. For the post-planting incubation, soil samples were pooled by vegetation type and homogenized resulting in a total of eight samples (2 fields x 4 vegetation types) from which sub-samples were taken. Soil samples used in both incubations were taken between zero and fifteen centimeters depth, air-dried, and sieved to two millimeters. Franzluebbers (1999) found that air-dried and coarsely sieved soil compared favorably to field-moist-intact soil cores for estimating soil microbial biomass and potential activity.

Based on preliminary tests, we determined that for the soil incubations fifteen grams of each soil would be used with three moisture levels of 0.05, 0.15, and 0.30 g H<sub>2</sub>O g soil<sup>-1</sup>. In the pre-planting incubation, for each soil, fifteen gram sub-samples of air-dried soil were placed into a 250 mL glass jar equipped with a septum in the lid. Next, DI water was added to each soil according to its designated moisture level by weight. Once the water was added the soils were stirred to ensure uniform moisture, then the lid was firmly screwed on to the jar and placed into a constant 25°C temperature refrigerator. Three replicates were used for each soil/moisture combination for a total of 75 samples in this incubation. Periodically, CO<sub>2</sub> production measurements were made by taking a 250 µL sample via syringe through the septum in the lids of the jars. These samples were

then injected into a LI-COR 6251 CO<sub>2</sub> analyzer for CO<sub>2</sub> measurements. The soils were allowed to sit for about six hours prior to the first CO<sub>2</sub> measurement in the pre-planting incubation. The pre-planting incubation lasted 34 days. Once, for this incubation (~12 days in), the jars were opened for about a minute to allow for reoxygenation when at least six of the samples were over 10 mgCO<sub>2</sub> L<sup>-1</sup> (5.4 mgCO<sub>2</sub>-C L<sup>-1</sup>).

In the post-planting incubation, nine sub-samples were taken from each of the pooled vegetation samples for each field (72 total). These nine sub-samples represented three replicates of the three gravimetric moisture levels used in these incubations (0.05, 0.15, 0.30 g H<sub>2</sub>O g soil<sup>-1</sup>). Fifteen grams of sub-sample were placed into a 250 mL glass jar and the appropriate amount of water was added. From this point, the post-planting incubation follows the same procedure as the pre-planting incubation. The samples in the post-planting incubation were allowed to sit for about two days prior to the first CO<sub>2</sub> sampling. Three times (~7, 15, and 25 days in) in this incubation, the jars were opened for about a minute to allow for replenishment of oxygen when at least six of the samples were above 10 mgCO<sub>2</sub> L<sup>-1</sup> (5.4 mgCO<sub>2</sub>-C L<sup>-1</sup>).

#### *Incubation Extractions*

Extractions were performed on the pre- and post-planting soil samples prior to and after the incubations (four sets of extractions) using 2M KCl. In each extraction, five grams of each soil were placed into a 50 mL plastic syringe equipped with a filter and 50mL of the KCl solution was then added and allowed to soak into the soil for 30 minutes. After these 30 minutes, the soils were extracted over a 30 minute time period using a SampleTek Vacuum Extractor. Blanks were collected by filtering the KCl solution without soil. Once the extractions were completed, the extract was injected into a



holding vial and frozen until analyzed (three weeks for the pre-planting incubation and two weeks for the post-planting incubation). The extracts were analyzed for ammonium (as  $\text{NH}_3$ ) and nitrate (as  $\text{NO}_3^- + \text{NO}_2$ ) using a Lachat autoanalyzer. The net change for the two N species ( $\text{mgN kg}^{-1}$ ) was calculated by subtracting the pre-incubation values from the post-incubation values. The summation of these two N species was considered the net change in “total” N. This net change is also referred to as the net “extractable” N.

#### *Statistical methods*

To estimate the  $\text{CO}_2$  production rate, we fitted an asymptotic function to our cumulative  $\text{CO}_2$ -C respired data and calculated a rate constant (k), with units of  $\text{day}^{-1}$ , using the approach of Stanford and Smith (1972). The function applied was:

$$C = C_a(1 - e^{-kt}) + C_0$$

where C is the cumulative  $\text{CO}_2$ -C respired ( $\mu\text{g}$ ),  $C_a$  is the maximum cumulative  $\text{CO}_2$ -C,  $C_0$  is the initial amount of  $\text{CO}_2$ -C respired which we assumed to be zero, and t is time in units of days.  $C_a$  and k were calculated by the regression of the function. Effects of field, moisture and vegetation type were explored using a 3-way Multivariate Analysis of Variance (MANOVA) with all interactions. The effects of moisture, texture, pre-incubation C/N, and pre-incubation percent (of total N) extractable N on cumulative  $\text{CO}_2$ -C production,  $\text{CO}_2$ -C respiration rate constant, net total extractable N concentration (nitrate + ammonium), net nitrate-N concentration, and net ammonium-N concentration were further examined using linear multiple regression analyses. All statistical analyses were carried out using DataDesk version 6.1. Effects were considered significant if  $p < 0.05$ . Two-sample t-tests assuming unequal variances were performed to determine differences among vegetation, field, and incubations. Results were considered different if

$p$  (two-tail)  $< 0.05$ . We analyzed the data for the pre- and post-planting incubations separately.

## RESULTS

### *Pre-incubation*

#### *Soil characteristics*

Table 2.3 shows the pre-incubation soil characteristics for the pre- and post-planting incubations. The Wildlife Area revegetation (sandy loam) field had a significantly higher percent clay and silt content and significantly lower percent sand content than the other four fields in the pre-planting incubation. The two Cottonwood fields (loamy sands) and the two Valley Vista fields (loamy sands) had similar particle distributions with minor differences. The post-planting Valley Vista and Cottonwood fields also had very similar particle distributions (loamy sands) with minor differences. Overall, the average percent clay, silt, and sand contents for the post-planting Valley Vista field were 3.85, 20.72, and 75.44 % respectively. The overall average percent clay, silt, and sand contents for the post-planting Cottonwood field were 3.26, 17.41, and 79.34 % respectively. Some significant differences were observed between the vegetation types but the differences were relatively small ( $< 0.50\%$ ) and most likely not ecologically relevant. The post-planting soil textures were similar to the pre-planting soil textures when comparing the same fields (e.g. pre-Cottonwood alternative versus post-Cottonwood).

Table 2.3: Soil characteristics

| Incubation    | Soil                      | Total C<br>g kg <sup>-1</sup> | Total N<br>g kg <sup>-1</sup> | C/N   | Clay<br>% | Silt<br>% | Sand<br>% |
|---------------|---------------------------|-------------------------------|-------------------------------|-------|-----------|-----------|-----------|
| PRE-PLANTING  | Wildlife Revegetation     | 16.42                         | 1.28                          | 12.87 | 14.70     | 54.68     | 30.61     |
|               | Cottonwood Revegetation   | 8.01                          | 0.74                          | 10.83 | 3.37      | 16.87     | 79.76     |
|               | Valley Vista Revegetation | 5.85                          | 0.61                          | 9.97  | 3.75      | 18.60     | 77.65     |
|               | Cottonwood Alternative    | 4.64                          | 0.50                          | 9.21  | 3.44      | 16.85     | 79.71     |
|               | Valley Vista Alternative  | 6.94                          | 0.70                          | 10.01 | 3.86      | 20.41     | 75.73     |
| POST-PLANTING | <b>Valley Vista</b>       |                               |                               |       |           |           |           |
|               | Tef                       | 5.60                          | 8.97                          | 8.58  | 3.76      | 20.01     | 76.23     |
|               | Amaranth                  | 5.14                          | 6.59                          | 8.44  | 3.86      | 20.41     | 75.73     |
|               | Alfalfa                   | 5.63                          | 12.01                         | 7.61  | 3.99      | 21.10     | 74.91     |
|               | Switchgrass               | 5.79                          | 9.10                          | 8.06  | 3.78      | 21.34     | 74.88     |
|               | <b>Cottonwood</b>         |                               |                               |       |           |           |           |
|               | Tef                       | 4.47                          | 2.78                          | 7.54  | 3.26      | 17.73     | 79.01     |
|               | Amaranth                  | 6.30                          | 7.29                          | 7.96  | 3.03      | 17.45     | 79.52     |
|               | Alfalfa                   | 4.60                          | 3.60                          | 7.23  | 3.51      | 17.59     | 78.90     |
|               | Switchgrass               | 5.64                          | 3.90                          | 7.30  | 3.22      | 16.86     | 79.92     |

The Wildlife Area revegetation field had a significantly higher total C and N content than the other four fields (Table 2.3; Figures 2.4 and 2.5).

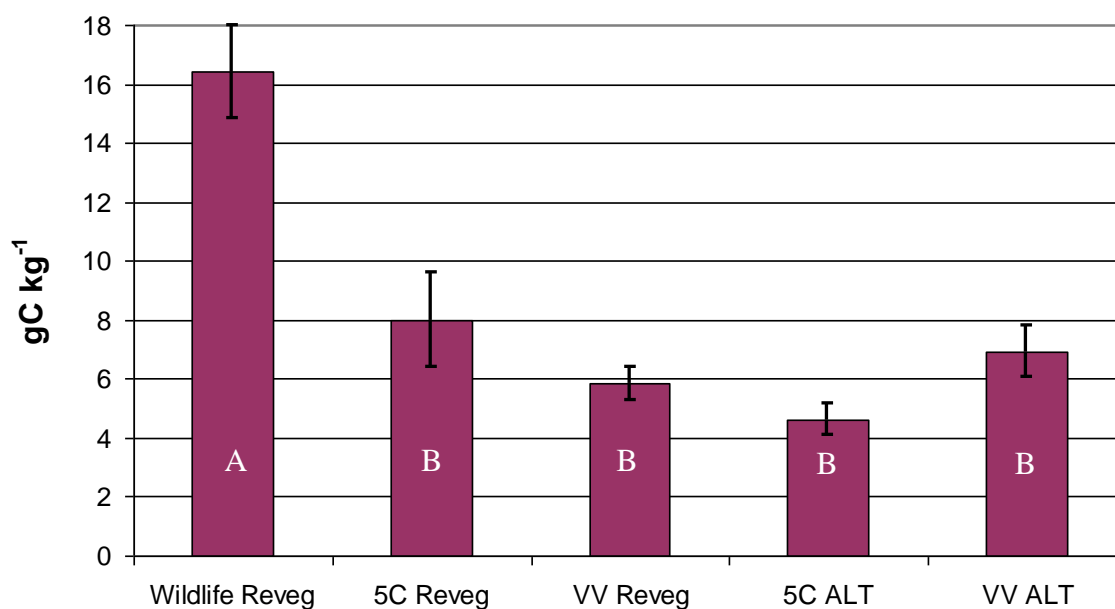


Figure 2.4: Average total C content for the pre-planting incubation soils (Wildlife revegetation, Cottonwood (5C) revegetation, Valley Vista (VV) revegetation, Cottonwood alternative, and Valley Vista alternative). Error bars represent standard error (n = 5). Letters represent significant differences between fields.

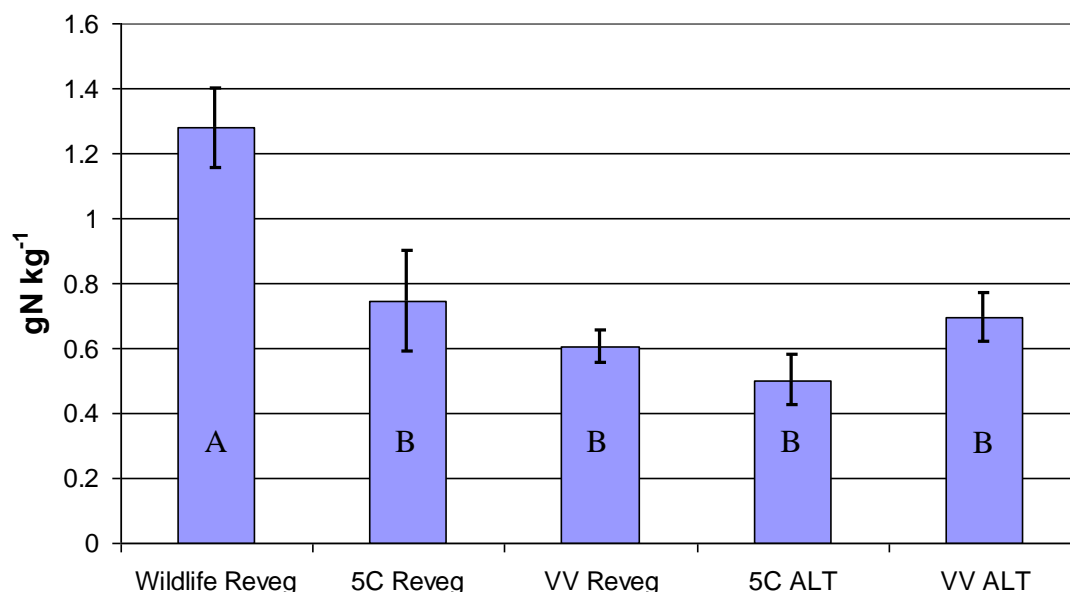


Figure 2.5: Average total N content for the pre-planting incubation soils (Wildlife revegetation, Cottonwood (5C) revegetation, Valley Vista (VV) revegetation, Cottonwood alternative, and Valley Vista alternative). Error bars represent standard error (n = 5). Letters represent significant differences between fields.

Overall, both post-planting fields had similar total C and N contents. All of the Valley Vista soils had a similar soil total C and N in the post-planting incubation (Fig. 2.6 and 2.7). Among the Cottonwood vegetation, tef ( $4.47 \text{ g kg}^{-1}$ ) and alfalfa ( $4.60 \text{ g kg}^{-1}$ ) had a significantly lower soil total C content than amaranth ( $6.30 \text{ g kg}^{-1}$ ). Tef also had a significantly lower soil total N content ( $0.59 \text{ g kg}^{-1}$ ) than amaranth ( $0.77 \text{ g kg}^{-1}$ ) and switchgrass ( $0.75 \text{ g kg}^{-1}$ ). The overall post-planting total C and N contents for the Valley Vista field were  $5.54 \pm 0.24$  and  $0.68 \pm 0.03 \text{ g kg}^{-1}$  respectively, which were similar to those of the pre-planting Valley Vista alternative field. The overall total C and N contents for the Cottonwood field were  $5.27 \pm 0.34$  and  $0.69 \pm 0.03 \text{ g kg}^{-1}$  respectively with the total N content being significantly higher than that of the pre-planting Cottonwood alternative field.

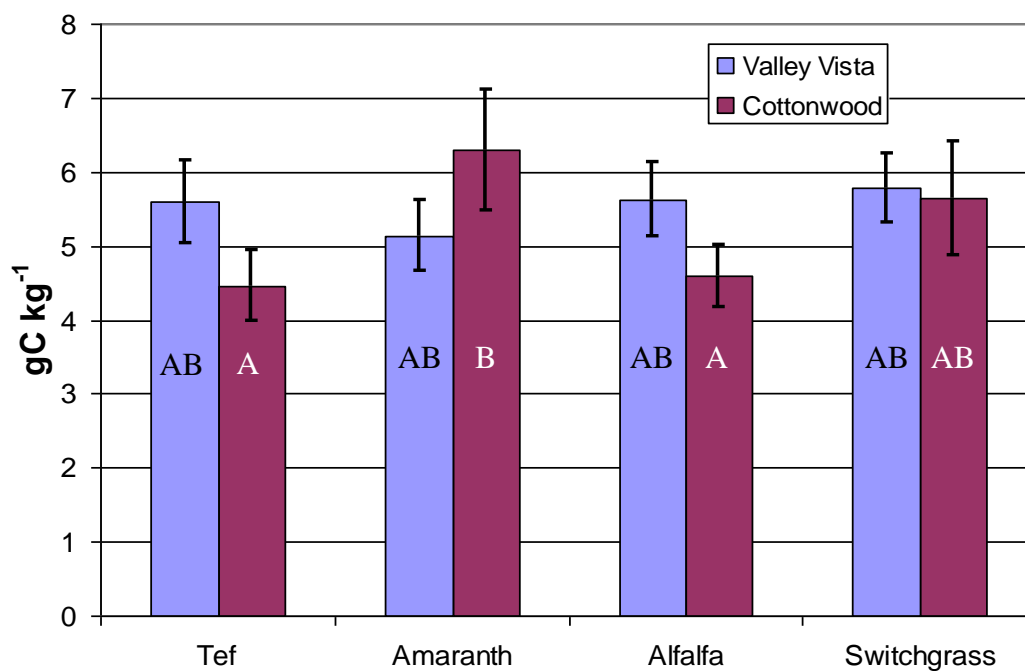


Figure 2.6: Average total C content for the post-planting soils. Error bars represent standard error (n = 9). Letters represent significant differences between fields and vegetation types.

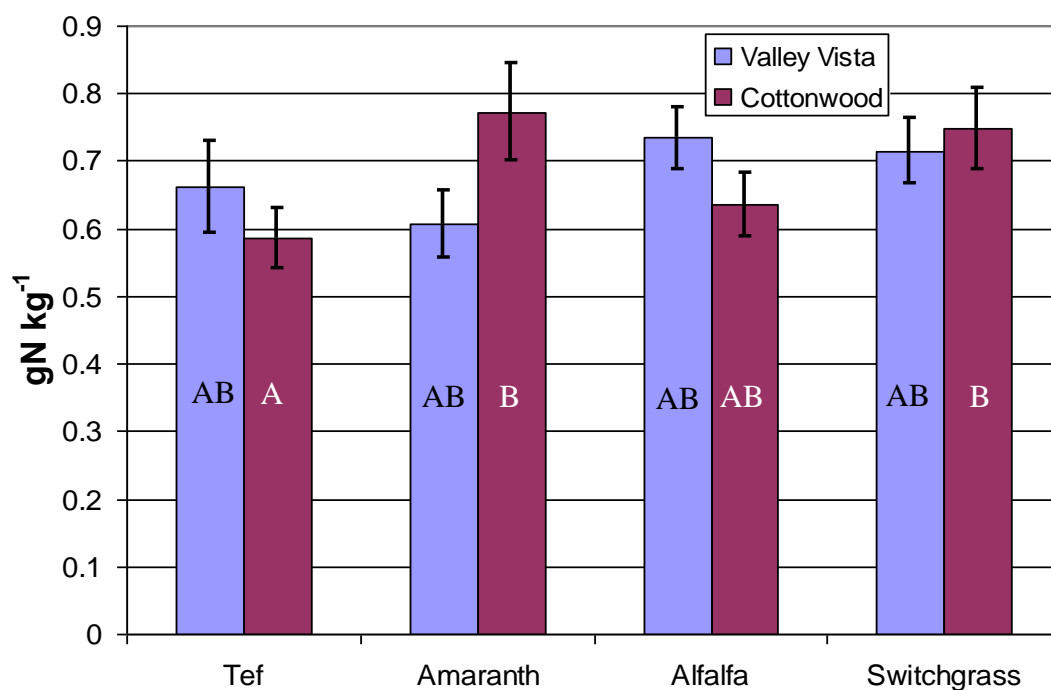


Figure 2.7: Average total N content for the post-planting soils. Error bars represent standard error (n = 9). Letters represent differences between fields and vegetation types.

The Wildlife Area revegetation field had a significantly higher C/N ratio (12.9) than the other four fields in the pre-planting incubation (Fig. 2.8). The Cottonwood revegetation field had a significantly higher average C/N ratio (10.8) than the Cottonwood alternative field (9.2).

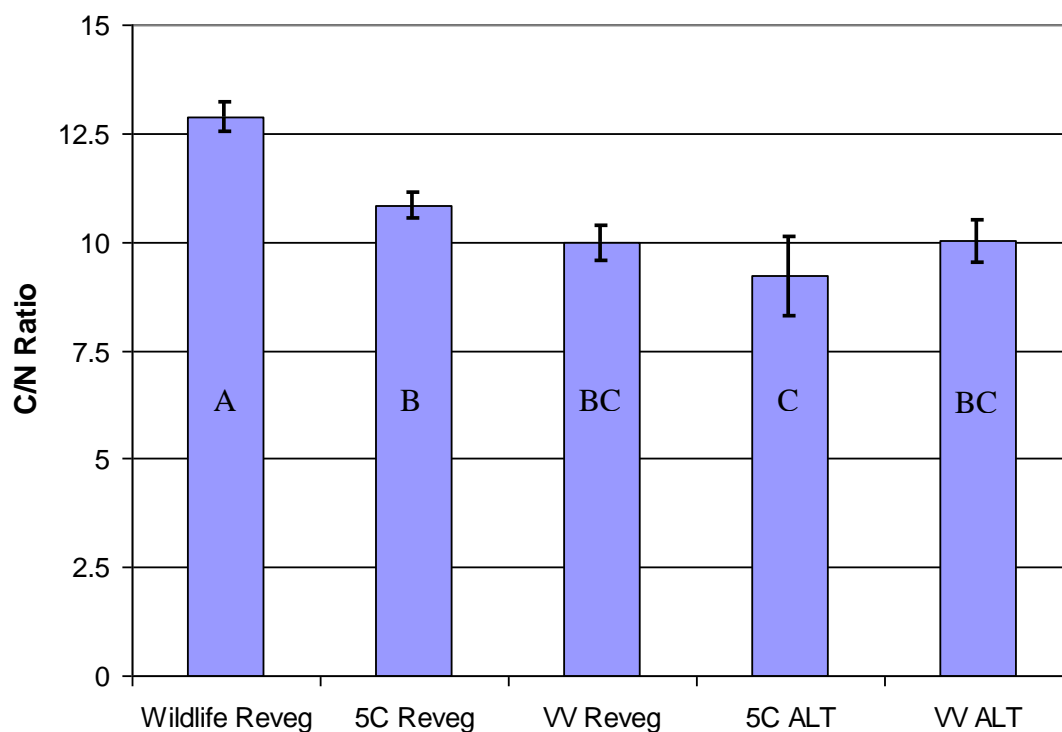


Figure 2.8: Average pre-incubation C/N ratios for the pre-planting incubation soils (Wildlife revegetation, Cottonwood (5C) revegetation, Valley Vista (VV) revegetation, Cottonwood alternative, and Valley Vista alternative). Error bars represent standard error (n = 5). Letters represent differences between fields.

Figure 2.9 shows the average C/N ratios for the post-planting incubation soils. The C/N ratios were similar for all vegetation types within both the Valley Vista and Cottonwood fields. Overall, the Valley Vista field had a significantly higher C/N ratio (8.17) than the Cottonwood field (7.51). Both of these were significantly lower than the pre-planting Valley Vista alternative and Cottonwood alternative C/N ratios.

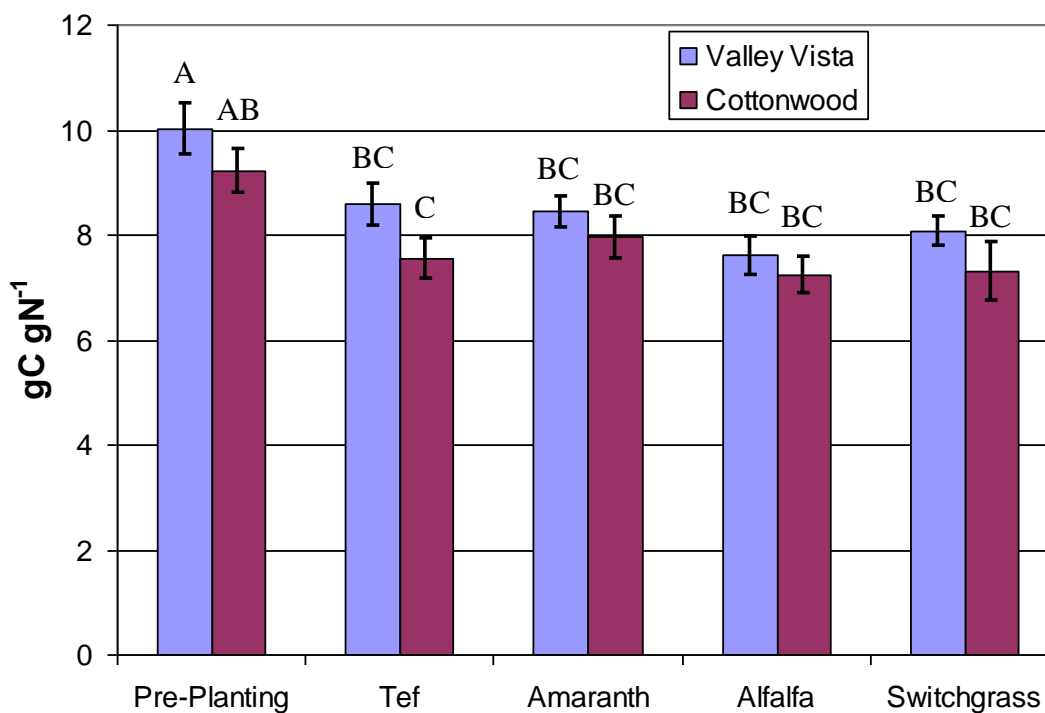


Figure 2.9: Average initial C/N ratios for the post-planting incubation soils. Error bars represent standard error ( $n = 9$ ). Letters represent significant differences between fields and vegetation types.

### *Extractable N*

Figure 2.10 shows the average extractable N contents in the pre-planting incubation soils as the percent of total N. The non-extractable N fraction (total N - extractable N) is not shown here since the patterns in non-extractable N were very similar to the patterns of total N content because the non-extractable fraction represented the majority (98.6%) of the total N content. The Wildlife Area revegetation extractable N content (0.45%) was significantly lower than the Cottonwood alternative (1.71%) and Valley Vista alternative (0.73%) contents.

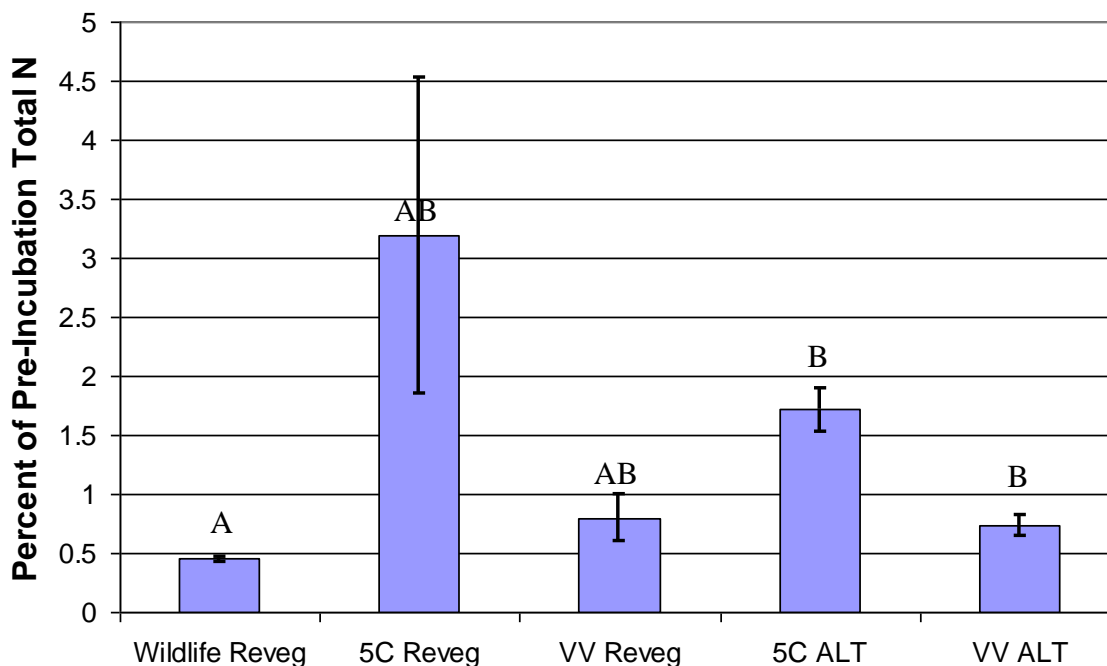


Figure 2.10: Average percent extractable N for the pre-planting incubation soils (Wildlife revegetation, Cottonwood (5C) revegetation, Valley Vista (VV) revegetation, Cottonwood alternative (ALT), Valley Vista alternative). Error bars represent standard error (n = 5). Letters represent significant differences between fields.

Figure 2.11 shows the average extractable N contents in the pooled post-planting incubation soils as the percent of total N. The non-extractable N fraction was not shown here since its patterns were very similar to the total N content patterns because the non-extractable N fraction represented the majority (98.2%) of the total N. Overall, the Valley Vista field had higher average percent extractable N content (1.34%) than the Cottonwood field (0.63%). The post-planting Valley Vista alternative field also had a significantly higher extractable N content than the pre-planting Valley Vista alternative field (0.73%). The post-planting Cottonwood alternative field, however, had a significantly lower extractable N content than the pre-planting Cottonwood alternative field (1.71%). Among the Valley Vista soils, alfalfa (1.64%) had a higher percent



extractable N than the other three vegetation types and amaranth (1.09%) had a lower percentage than the other three vegetation types in this field. The Cottonwood amaranth soils (0.94%) had significantly higher percent extractable N than the other three vegetation types in this field.

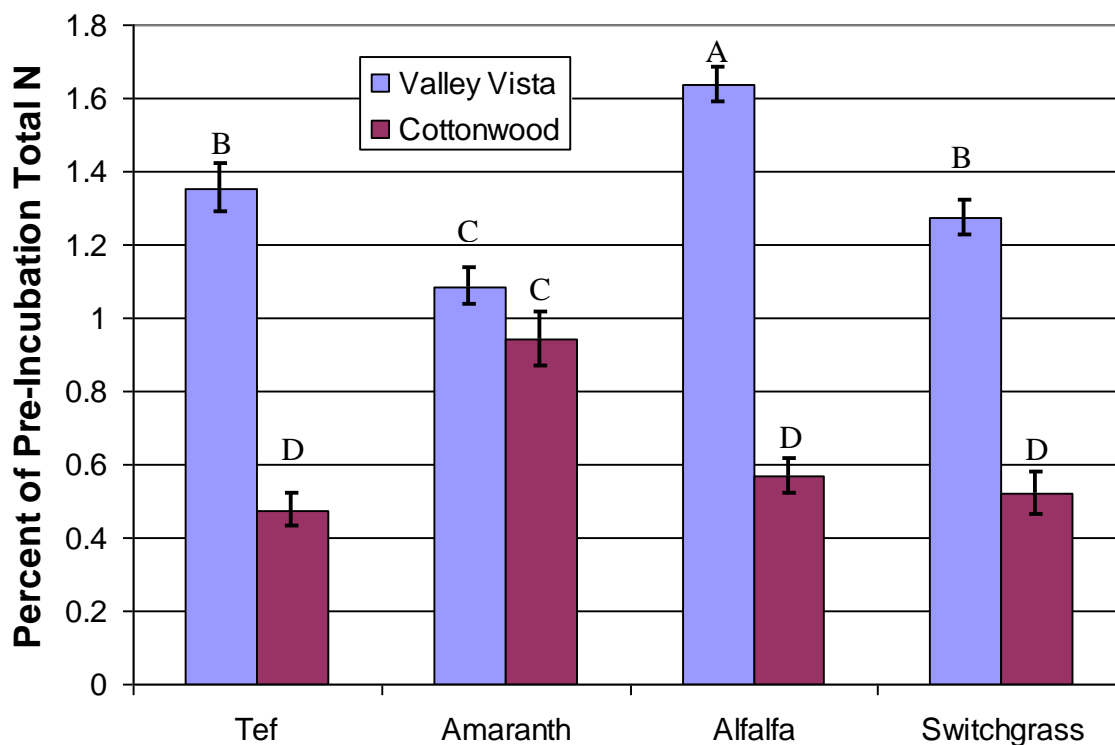


Figure 2.11: Average percent extractable N fraction for the post-planting Valley Vista and Cottonwood soils. Error bars represent standard error (n = 9). Letters represent significant differences between fields and vegetation types.

### *C Fluxes*

#### *Cumulative CO<sub>2</sub>-C mineralization per gram soil*

Figure 2.12 shows the average cumulative CO<sub>2</sub>-C production rates per gram of soil over the pre-planting incubation period. The MANOVA analysis revealed that moisture and field significantly affected the cumulative CO<sub>2</sub>-C production per gram of

soil in the pre-planting incubation (Table 2.4). For the pre-planting incubation, the overall CO<sub>2</sub>-C production for the 0.05, 0.15, and 0.30 moisture contents were  $1.42 \pm 0.32$ ,  $4.96 \pm 0.74$ , and  $6.65 \pm 0.71 \mu\text{gCO}_2\text{-C g}_s^{-1} \text{d}^{-1}$ . The 0.15 and 0.30 moisture treatments were not significantly different.

The cumulative CO<sub>2</sub>-C production varied by field, however, there were no significant differences in overall averages according to a t-test. Respiration rates were highest for the Cottonwood revegetation site ( $6.79 \pm 1.37 \mu\text{gCO}_2\text{-C g}_s^{-1} \text{d}^{-1}$ ) followed by the Valley Vista revegetation ( $4.67 \pm 0.89 \mu\text{gCO}_2\text{-C g}_s^{-1} \text{d}^{-1}$ ), Wildlife Area revegetation ( $4.02 \pm 0.90 \mu\text{gCO}_2\text{-C g}_s^{-1} \text{d}^{-1}$ ), Valley Vista alternative ( $3.88 \pm 0.67 \mu\text{gCO}_2\text{-C g}_s^{-1} \text{d}^{-1}$ ), and Cottonwood alternative ( $3.41 \pm 0.91 \mu\text{gCO}_2\text{-C g}_s^{-1} \text{d}^{-1}$ ) sites.

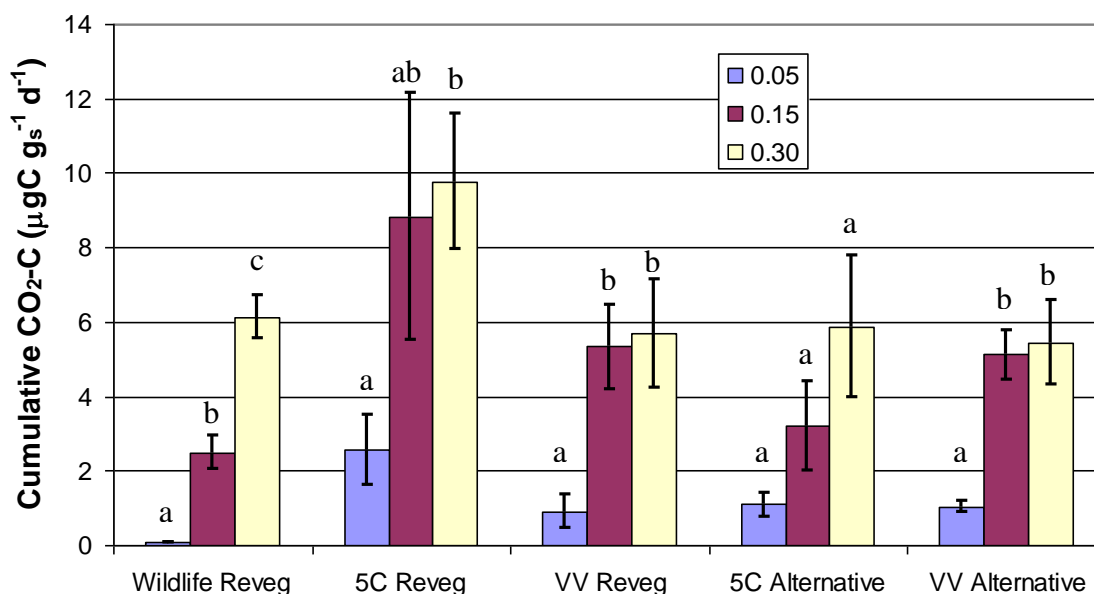


Figure 2.12: Average cumulative CO<sub>2</sub>-C respiration per gram soil rates in the pre-planting incubation for the three moisture treatments (0.05, 0.15, and 0.30 g g<sup>-1</sup>) (Wildlife revegetation, Cottonwood (5C) revegetation, Valley Vista (VV) revegetation, Cottonwood alternative, and Valley Vista alternative). Error bars represent standard error (n = 5). Lower case letters represent significant differences between moisture treatments within each field but not between fields.

Figures 2.13 and 2.14 show the average cumulative CO<sub>2</sub>-C respired rates over the post-planting incubation period in the Valley Vista and Cottonwood fields. The MANOVA analysis revealed that moisture, vegetation type, and the moisture\*field\*vegetation interaction significantly affected the cumulative CO<sub>2</sub>-C production per gram of soil in the post-planting incubation (Table 2.5). The average respiration rates in the post-planting incubation for the 0.05, 0.15, and 0.30 moisture treatments were  $5.08 \pm 0.47$ ,  $10.32 \pm 1.02$ , and  $9.81 \pm 1.01$   $\mu\text{gCO}_2\text{-C g}_s^{-1} \text{d}^{-1}$  with the rates in the 0.05 moisture treatment being significantly lower than the rates in the 0.15 and 0.30 moisture treatments.

Vegetation significantly affected respiration rates but only the tef soils had significantly higher rates than any of the other vegetation types in this incubation. Tef ( $11.64 \pm 1.29$   $\mu\text{gCO}_2\text{-C g}_s^{-1} \text{d}^{-1}$ ),) was followed by alfalfa ( $7.61 \pm 1.02$   $\mu\text{gCO}_2\text{-C g}_s^{-1} \text{d}^{-1}$ ), switchgrass ( $7.29 \pm 0.86$   $\mu\text{gCO}_2\text{-C g}_s^{-1} \text{d}^{-1}$ ), and amaranth ( $7.08 \pm 1.07$   $\mu\text{gCO}_2\text{-C g}_s^{-1} \text{d}^{-1}$ ).

Cumulative respiration rates also showed a significant moisture\*field\*vegetation interaction. Respiration rates were similar in all Valley Vista soils in the 0.05 moisture treatment. Similarly, respiration rates were the same in all Cottonwood soils at this moisture content. In the Valley Vista field soils, respiration rates were significantly higher in the tef soils than in the amaranth soils in the 0.15 moisture treatment. In contrast, at this moisture level cumulative respiration was the same for all the vegetation types in the Cottonwood field. For the Valley Vista field, respiration was higher in tef than in alfalfa soils in the 0.30 moisture treatment while for this moisture treatment, amaranth soils had higher respiration rates than alfalfa soils in the Cottonwood field. The

overall CO<sub>2</sub>-C production rates for the Valley Vista and Cottonwood alternative fields in the post-planting incubation were  $8.27 \pm 0.80$  and  $8.53 \pm 0.82 \mu\text{gCO}_2\text{-C g}_s^{-1} \text{d}^{-1}$  respectively. Both of these were significantly higher than the overall production rates for the pre-planting Valley Vista alternative ( $3.88 \pm 0.67 \mu\text{gCO}_2\text{-C g}_s^{-1} \text{d}^{-1}$ ) and Cottonwood alternative ( $3.41 \pm 0.91 \mu\text{gCO}_2\text{-C g}_s^{-1} \text{d}^{-1}$ ) fields.

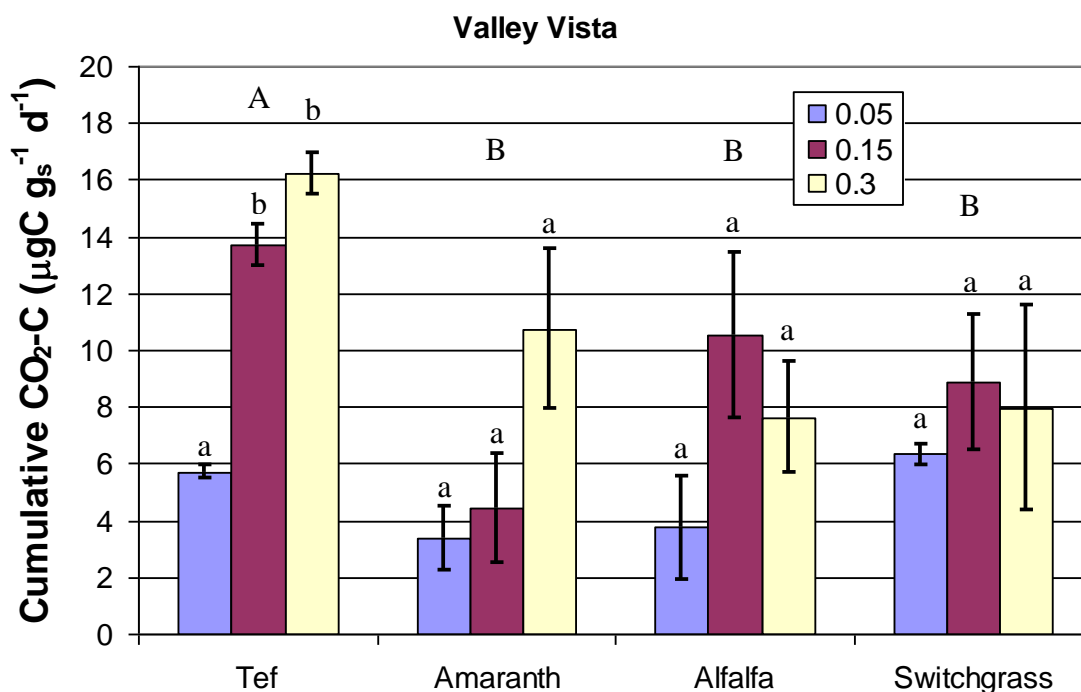


Figure 2.13: Average cumulative CO<sub>2</sub>-C respiration per gram soil rates in the post-planting Valley Vista field for the three moisture treatments (0.05, 0.15, and 0.30 g g<sup>-1</sup>). Error bars represent standard error (n = 3). Capital letters represent significant differences between vegetation types when combining the moisture treatments. Lower case letters represent significant differences between moisture treatments within each vegetation type but not between vegetation types.

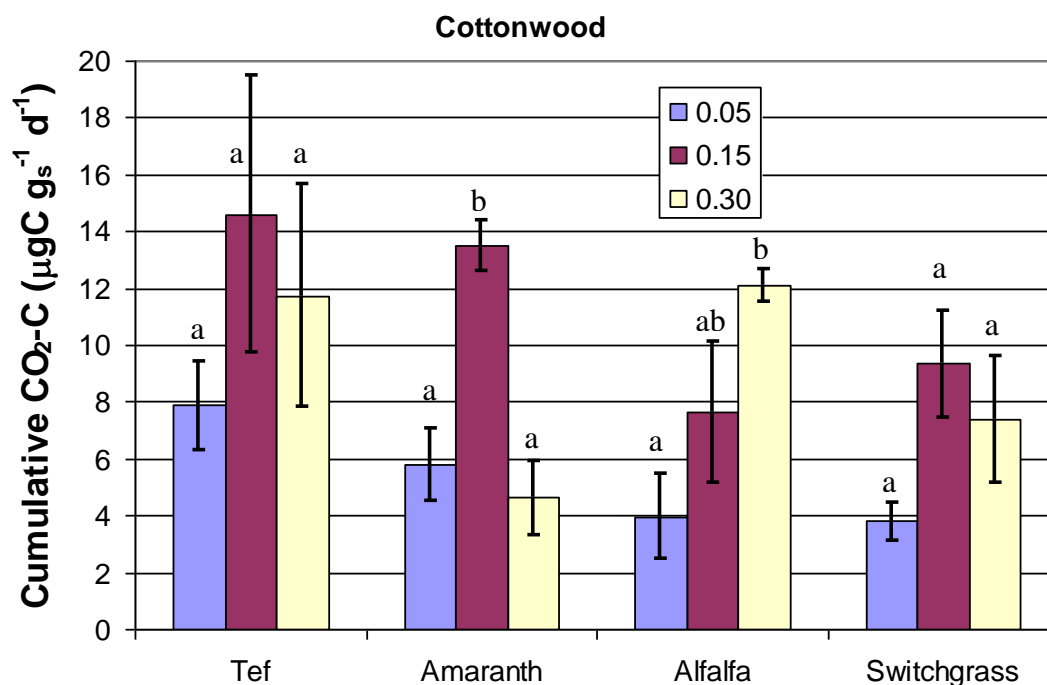


Figure 2.14: Average cumulative CO<sub>2</sub>-C respiration per gram soil rates in the post-planting Cottonwood field for the three moisture treatments (0.05, 0.15, and 0.30 g g<sup>-1</sup>). Error bars represent standard error (n = 3). Lower case letters represent significant differences between moisture treatments within each vegetation type but not between vegetation types.

Tables 2.4 and 2.5 show the MANOVA analysis results for the pre- and post-planting incubations respectively.

Table 2.4: MANOVA results for the pre-planting incubation.

| Factor  | Moisture | Field | Mst*Fld |
|---|----------|-------|---------|
| Cumulative C g <sub>s</sub> <sup>-1</sup> d <sup>-1</sup> | ****     | **    | ns      |
| Cumulative C g <sub>c</sub> <sup>-1</sup> d <sup>-1</sup> | ****     | **    | ns      |
| Rate Constant   | ns       | ns    | ns      |
| Net Total N   | ****     | ****  | ns      |
| Net Nitrate N   | ****     | ****  | ns      |
| Net Ammonium N  | ****     | ns    | *       |

ns = not significant (p > 0.05), \* = p < 0.05, \*\* = p < 0.01, \*\*\* = p < 0.001, \*\*\*\* = p < 0.0001

Table 2.5: MANOVA results for the post-planting incubation.

| Factor                  | Moisture | Field | Mst*Fld | Veg Type | Mst*VT | Fld*VT | Mst*Fld*VT |
|-------------------------|----------|-------|---------|----------|--------|--------|------------|
| Cumulative C $g_s^{-1}$ | ****     | ns    | ns      | **       | ns     | ns     | *          |
| Cumulative C $g_C^{-1}$ | ****     | ns    | ns      | ****     | ns     | ns     | *          |
| Rate Constant           | ****     | *     | ns      | ns       | ns     | ns     | ns         |
| Net Total N             | ****     | **    | *       | **       | ns     | *      | ns         |
| Net Nitrate N           | ****     | **    | *       | ***      | ns     | *      | ns         |
| Net Ammonium N          | *        | ****  | ns      | ****     | ns     | ****   | ns         |

ns = not significant ( $p > 0.05$ ), \* =  $p < 0.05$ , \*\* =  $p < 0.01$ , \*\*\* =  $p < 0.001$ , \*\*\*\* =  $p < 0.0001$

### *Cumulative CO<sub>2</sub>-C per gram C*

The MANOVA analysis showed that moisture and field affected the cumulative CO<sub>2</sub>-C production per gram C in the pre-planting incubation (Table 2.4; Fig. 2.15).

Overall, the average respiration rates for the 0.05, 0.15, and 0.30 moisture treatments were  $203.7 \pm 30.3$ ,  $772.1 \pm 99.3$ , and  $952.4 \pm 105.4$   $\mu gCO_2-C g_C^{-1} d^{-1}$  with the 0.15 and 0.30 moisture treatments being similar. The Valley Vista revegetation field showed the highest average respiration rate ( $1036.7 \pm 171.5$   $\mu gCO_2-C g_C^{-1} d^{-1}$ ) followed by the Cottonwood revegetation ( $852.3 \pm 130.5$   $\mu gCO_2-C g_C^{-1} d^{-1}$ ), Valley Vista alternative ( $582.4 \pm 104.2$   $\mu gCO_2-C g_C^{-1} d^{-1}$ ), Cottonwood alternative ( $562.2 \pm 141.5$   $\mu gCO_2-C g_C^{-1} d^{-1}$ ), and Wildlife Area revegetation ( $240.3 \pm 46.4$   $\mu gCO_2-C g_C^{-1} d^{-1}$ ) fields. The Valley Vista revegetation cumulative C respiration rate was only statistically similar to that of the Cottonwood revegetation field. Respiration rates in the Wildlife revegetation field were significantly lower than the other four fields. The Cottonwood revegetation cumulative C respiration was only significantly different from that of the Wildlife revegetation field.

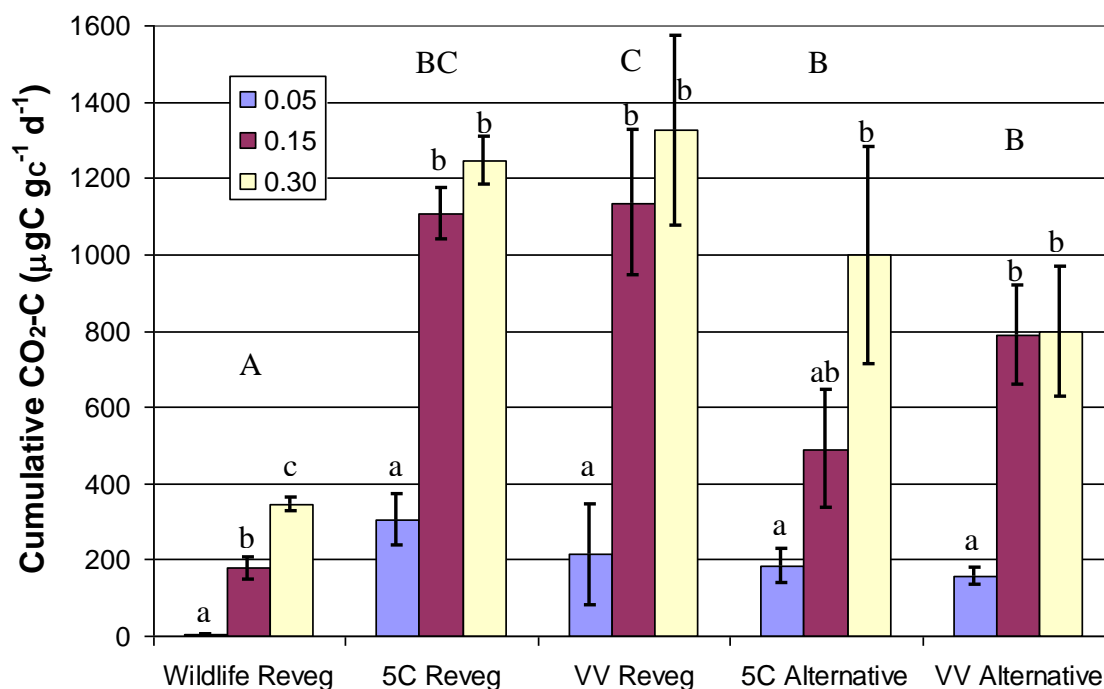


Figure 2.15: Average cumulative CO<sub>2</sub>-C respiration per gram of total C rates for the pre-planting incubation fields (Wildlife revegetation, Cottonwood (5C) revegetation, Valley Vista (VV) revegetation, Cottonwood alternative, and Valley Vista alternative). Error bars represent standard error (n = 5). Capital letters represent significant differences between fields when combining the moisture treatments. Lower case letters represent significant differences between moisture treatments within each field but not between fields.

In the post-planting incubation moisture, vegetation type, and the moisture\*field\*vegetation interaction significantly affected the cumulative respiration (Table 2.5; Figures 2.16 and 2.17). The patterns of cumulative CO<sub>2</sub>-C production per gram of C for each field in the post-planting incubation were very similar to the patterns of cumulative CO<sub>2</sub>-C per gram of soil in the post-planting incubation mentioned previously except for the moisture\*field\*vegetation interaction. Overall, the average values for the 0.05, 0.15, and 0.30 moisture treatments were  $957.8 \pm 99.6$ ,  $1929.9 \pm 208.4$ , and  $1879.5 \pm 208.5 \mu\text{gCO}_2\text{-C gC}^{-1} \text{d}^{-1}$ . Respiration rates were statistically equal in the 0.15 and 0.30 moisture treatments. Tef had significantly higher cumulative CO<sub>2</sub>-C

respiration than the other three vegetation types. Tef ( $2338.3 \pm 272.9 \mu\text{gCO}_2\text{-C g}_C^{-1} \text{d}^{-1}$ ) was followed by alfalfa ( $1508.7 \pm 207.6 \mu\text{gCO}_2\text{-C g}_C^{-1} \text{d}^{-1}$ ), switchgrass ( $1274.2 \pm 150.0 \mu\text{gCO}_2\text{-C g}_C^{-1} \text{d}^{-1}$ ), and amaranth ( $1235.2 \pm 187.1 \mu\text{gCO}_2\text{-C g}_C^{-1} \text{d}^{-1}$ ). Respiration rates were significantly higher in tef soils than the other three soils.

The MANOVA analysis showed a significant moisture\*field\*vegetation type interaction. In this incubation there were no significant differences in the 0.05 and 0.15 moisture treatments among the Valley Vista and Cottonwood soils. Across fields there were no significant differences when comparing the same vegetation in the 0.05 moisture treatment. However, in the 0.15 moisture treatment amaranth soils showed a higher respiration rate in the Cottonwood field ( $2141.3 \mu\text{gCO}_2\text{-C g}_C^{-1} \text{d}^{-1}$ ) than the Valley Vista amaranths ( $859.0 \mu\text{gCO}_2\text{-C g}_C^{-1} \text{d}^{-1}$ ). Among the Valley Vista soils, respiration rates were higher in tef ( $2895.5 \mu\text{gCO}_2\text{-C g}_C^{-1} \text{d}^{-1}$ ) than alfalfa ( $1358.1 \mu\text{gCO}_2\text{-C g}_C^{-1} \text{d}^{-1}$ ) soils in the 0.30 moisture treatment. In the Cottonwood soils, respiration rates were lower in amaranth ( $734.2 \mu\text{gCO}_2\text{-C g}_C^{-1} \text{d}^{-1}$ ) than alfalfa ( $2634.3 \mu\text{gCO}_2\text{-C g}_C^{-1} \text{d}^{-1}$ ) soils in the 0.30 moisture treatment. Only the alfalfa soils showed a significant difference between fields with the Valley Vista soils having the lower respiration rate in the 0.30 moisture treatment. Overall, the cumulative  $\text{CO}_2\text{-C}$  production per gram of C rate for the post-planting Valley Vista and Cottonwood alternative fields were  $1489.7 \pm 144.2$  and  $1688.5 \pm 180.2 \mu\text{gCO}_2\text{-C g}_C^{-1} \text{d}^{-1}$ , which were statistically similar. Both values were significantly higher than the pre-planting values ( $582.4 \pm 104.2$  for Valley Vista alternative and  $562.2 \pm 141.5 \mu\text{gCO}_2\text{-C g}_C^{-1} \text{d}^{-1}$  for Cottonwood alternative).



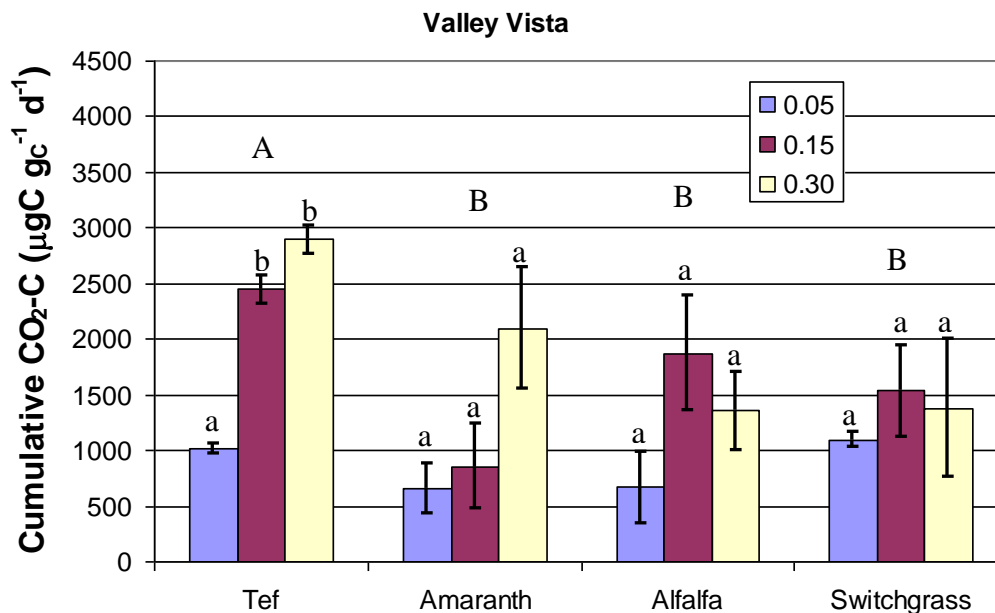


Figure 2.16: Average cumulative CO<sub>2</sub>-C respiration per gram of total C rates for the post-planting Valley Vista field. Error bars represent standard error (n = 3). Capital letters represent significant differences between vegetation types when combining the moisture treatments. Lower case letters represent significant differences between moisture treatments within each vegetation type but not between vegetation types.

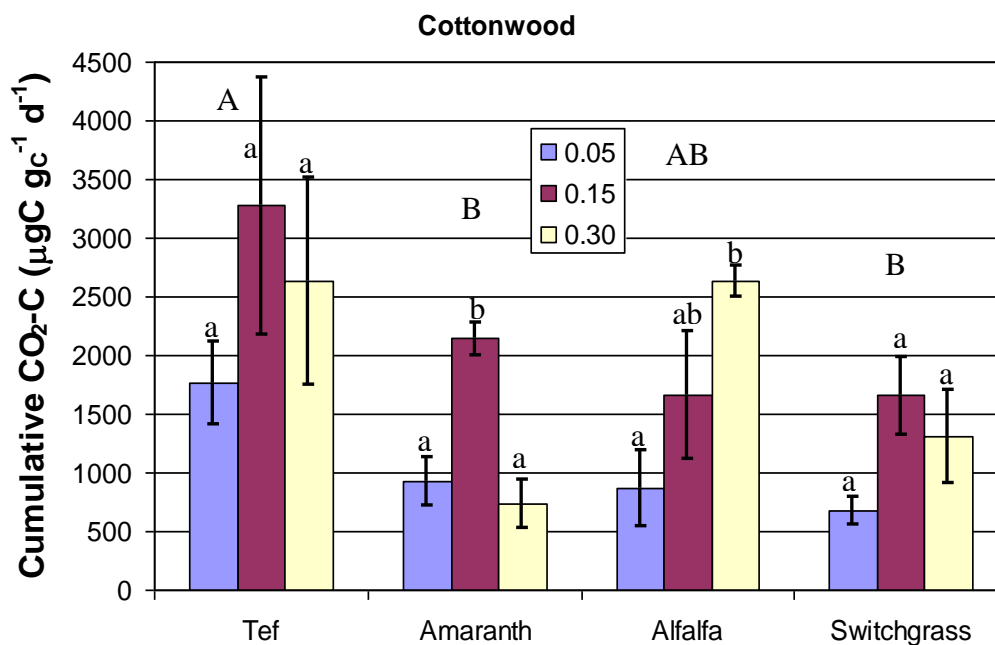


Figure 2.17: Average cumulative CO<sub>2</sub>-C respiration per gram of total C rates for the post-planting Cottonwood field. Error bars represent standard error (n = 3). Capital letters represent significant differences between vegetation types when combining the moisture treatments. Lower case letters represent significant differences between moisture treatments within each vegetation type but not between vegetation types.

### Exponential rate constant

In the pre-planting incubation, the MANOVA results (Table 2.4) showed that none of the factors significantly affected the respiration rate constants. Average respiration rate constants for this incubation, were  $0.242 \pm 0.066$ ,  $0.253 \pm 0.066$ , and  $0.183 \text{ d}^{-1} \pm 0.062$  for the 0.05, 0.15, and 0.30 moisture treatment values respectively (Fig. 2.18). On average the modeled cumulative  $\text{CO}_2\text{-C}$  respiration ( $C = C_a(1-e^{-kt})$ ) accounted for 97.9% of the variability in this incubation.

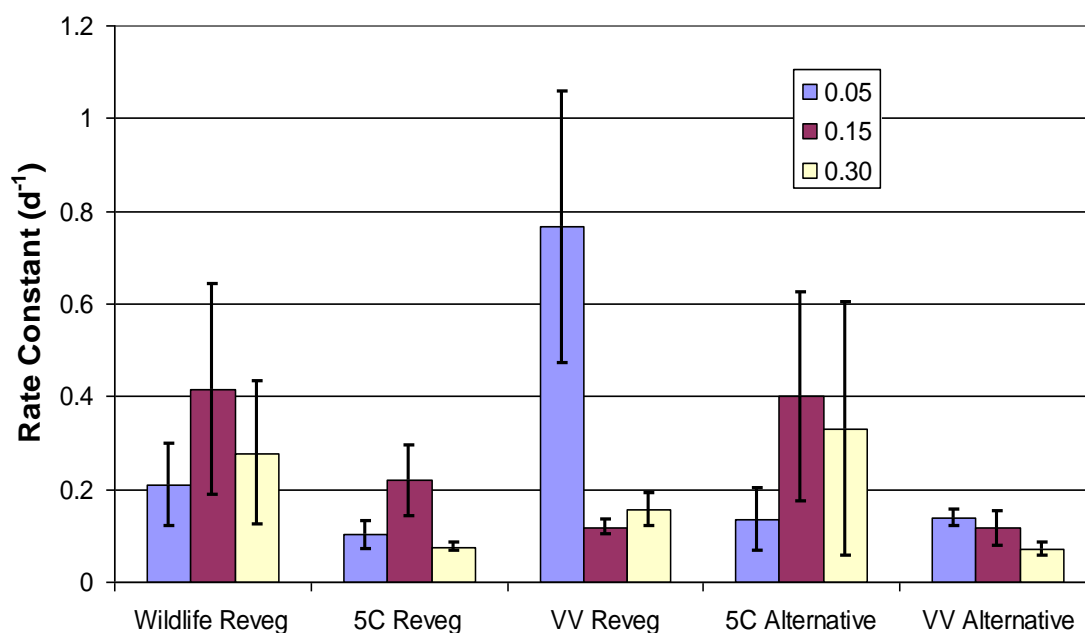


Figure 2.18: Average exponential  $\text{CO}_2\text{-C}$  respiration rate constant for the pre-planting incubation (Wildlife Area revegetation, Cottonwood (5C) revegetation, Valley Vista (VV) revegetation, Cottonwood alternative, and Valley Vista alternative). Error bars represent standard error ( $n = 5$ ).

Moisture and field significantly affected the rate constant in the post-planting incubation soil (Table 2.5). Generally, the rate constant decreased with increasing moisture in this incubation (Fig. 2.19 and 2.20). Overall, for the post-planting

incubation, the average 0.05, 0.15, and 0.30 moisture treatment rate constants were  $0.145 \pm 0.014$ ,  $0.083 \pm 0.007$ , and  $0.059 \text{ d}^{-1} \pm 0.003$ . Rate constants for the 0.05 moisture treatment were significantly higher than those for the 0.15 and 0.30 moisture treatments. The average rates for the Valley Vista and Cottonwood alternative fields were  $0.105 \pm 0.012$  and  $0.086 \pm 0.007 \text{ d}^{-1}$ . According to a t-test these two values were not significantly different. Neither of these two values were significantly different from their pre-planting counterparts. On average the modeled  $\text{CO}_2\text{-C}$  respiration ( $C = C_a(1 - e^{-kt})$ ) accounted for 97.3% of the variability in this incubation.

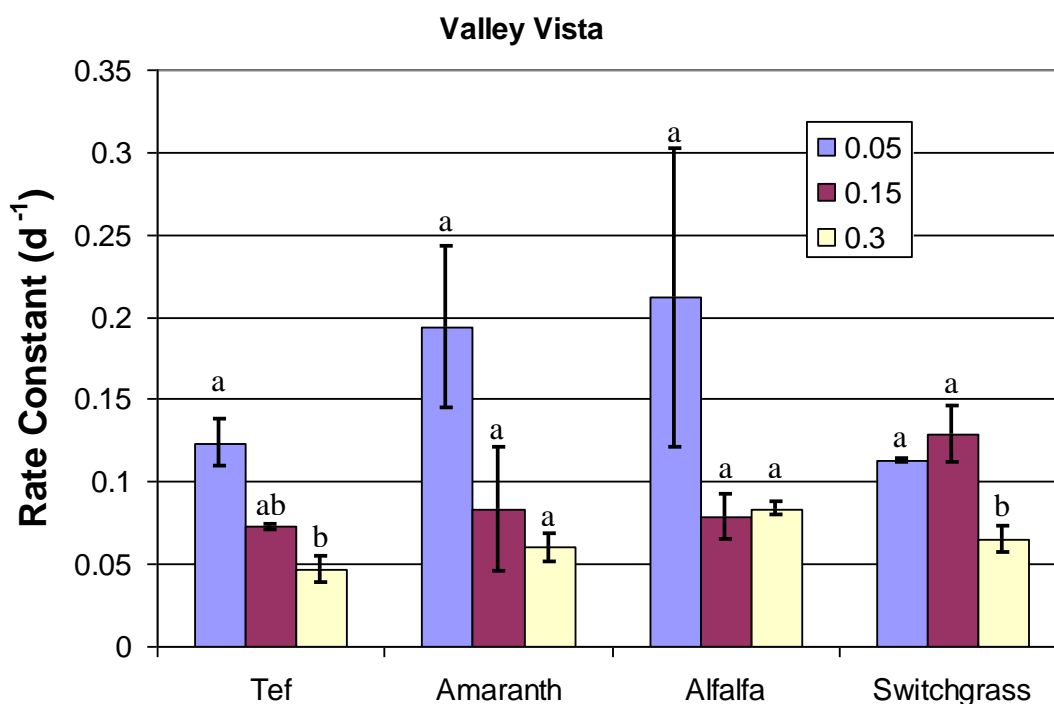


Figure 2.19: Average exponential  $\text{CO}_2\text{-C}$  respiration rate constant values in the post-planting Valley Vista field. Error bars represent standard error ( $n = 3$ ). Letters represent significant differences between moisture treatments within each vegetation type but not between vegetation types.

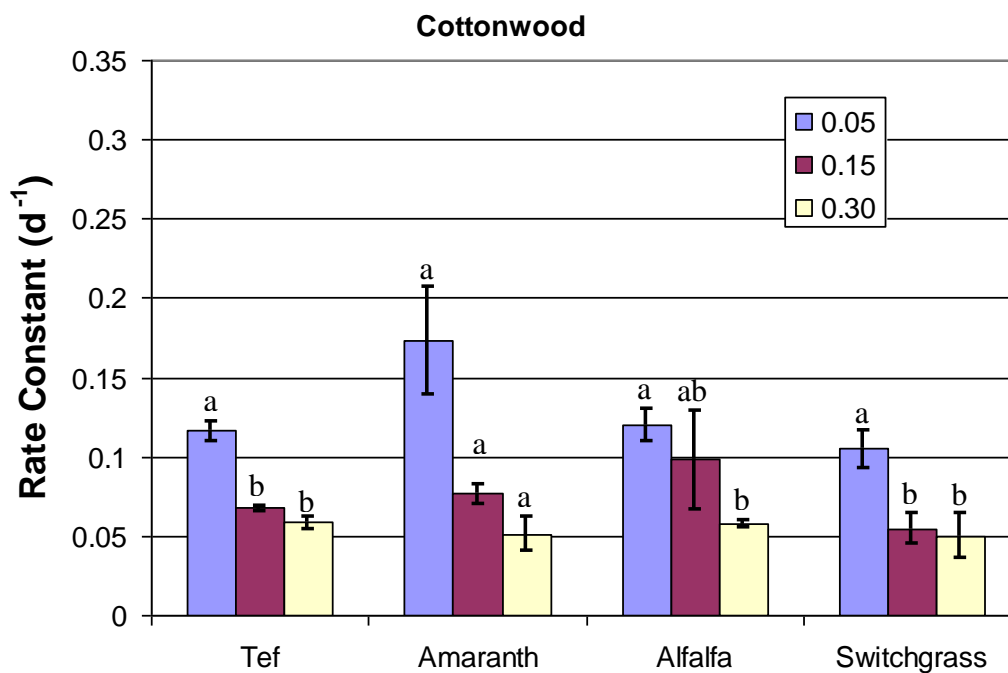


Figure 2.20: Average exponential  $\text{CO}_2\text{-C}$  respiration rate constant values in the post-planting Cottonwood field. Error bars represent standard error ( $n = 3$ ). Letters represent significant differences between moisture treatments within each vegetation type but not between vegetation types.

### *Net N Fluxes*

Table 2.6 shows the pre-incubation, post-incubation, and change in extractable N concentrations over the incubation period for the pre-planting incubation soils.

Table 2.6: Average extractable N concentrations before and after the pre-planting incubation

|                           | Moisture Treatment | Initial Extractable N (mgN kg <sup>-1</sup> ) |                              |       | Final Extractable N (mgN kg <sup>-1</sup> ) |                              |        | Extractable N Change (mgN kg <sup>-1</sup> ) |                              |        |
|---------------------------|--------------------|---|------------------------------|-------|---|------------------------------|--------|--|------------------------------|--------|
|                           |                    | NO <sub>3</sub> <sup>-</sup>                  | NH <sub>4</sub> <sup>+</sup> | Sum   | NO <sub>3</sub> <sup>-</sup>                | NH <sub>4</sub> <sup>+</sup> | Sum    | NO <sub>3</sub> <sup>-</sup>                 | NH <sub>4</sub> <sup>+</sup> | Sum    |
| Wildlife Revegetation     | 0.05               |   |                              |       | 5.64  | 3.42                         | 9.06   | 3.01   | 0.25                         | 3.26   |
|                           | 0.15               | 2.63  | 3.18                         | 5.80  | 16.85                                       | 0.20                         | 17.05  | 14.23  | -2.98                        | 11.25  |
|                           | 0.3                |   |                              |       | 43.67                                       | 0.18                         | 43.85  | 41.04  | -3.00                        | 38.05  |
| Cottonwood Revegetation   | 0.05               |   |                              |       | 32.78                                       | 10.37                        | 43.14  | 17.37  | 5.96                         | 23.33  |
|                           | 0.15               | 15.41   | 4.41                         | 19.81 | 100.23                                      | 0.17                         | 100.40 | 84.83  | -4.24                        | 80.59  |
|                           | 0.3                |   |                              |       | 141.03                                      | 0.60                         | 141.63 | 125.63                                       | -3.81                        | 121.82 |
| Valley Vista Revegetation | 0.05               |   |                              |       | 8.15  | 2.91                         | 11.06  | 5.89   | 0.61                         | 6.50   |
|                           | 0.15               | 2.26  | 2.30                         | 4.56  | 53.71                                       | 0.15                         | 53.86  | 51.45  | -2.15                        | 49.30  |
|                           | 0.3                |   |                              |       | 78.80                                       | 0.32                         | 79.12  | 76.54  | -1.98                        | 74.56  |
| Cottonwood Alternative    | 0.05               |   |                              |       | 13.51                                       | 3.12                         | 16.63  | 7.83   | 0.37                         | 8.19   |
|                           | 0.15               | 5.68  | 2.76                         | 8.44  | 40.59                                       | 0.11                         | 40.70  | 34.91  | -2.65                        | 32.26  |
|                           | 0.3                |   |                              |       | 69.34                                       | 0.41                         | 69.75  | 63.66  | -2.35                        | 61.31  |
| Valley Vista Alternative  | 0.05               |   |                              |       | 5.75  | 4.58                         | 10.33  | 3.66   | 1.72                         | 5.38   |
|                           | 0.15               | 2.09  | 2.86                         | 4.95  | 55.38                                       | 0.08                         | 55.46  | 53.29  | -2.79                        | 50.50  |
|                           | 0.3                |   |                              |       | 83.15                                       | 0.31                         | 83.46  | 81.06  | -2.55                        | 78.51  |

Table 2.7 shows the pre-incubation, final, and change in extractable N concentrations over the incubation period for the post-planting incubation soils.

Table 2.7: Average extractable N concentrations before and after the post-planting incubation

|                     | Moisture Treatment | Initial Extractable N (mgN kg <sup>-1</sup> ) |                              |       | Final Extractable N (mgN kg <sup>-1</sup> ) |                              |       | Extractable N Change (mgN kg <sup>-1</sup> ) |                              |       |
|---------------------|--------------------|---|------------------------------|-------|---|------------------------------|-------|--|------------------------------|-------|
|                     |                    | NO <sub>3</sub> <sup>-</sup>                  | NH <sub>4</sub> <sup>+</sup> | Sum   | NO <sub>3</sub> <sup>-</sup>                | NH <sub>4</sub> <sup>+</sup> | Sum   | NO <sub>3</sub> <sup>-</sup>                 | NH <sub>4</sub> <sup>+</sup> | Sum   |
| <b>Valley Vista</b> |                    |   |                              |       |   |                              |       |  |                              |       |
|                     | 0.05               |   |                              |       | 16.45                                       | 0.16                         | 16.61 | 9.69   | -2.05                        | 7.64  |
| Tef                 | 0.15               | 6.76  | 2.21                         | 8.97  | 40.87                                       | 0.18                         | 41.05 | 34.11  | -2.03                        | 32.09 |
|                     | 0.30               |   |                              |       | 13.40                                       | 0.32                         | 13.72 | 6.64   | -1.89                        | 4.75  |
|                     | 0.05               |   |                              |       | 14.63                                       | 0.10                         | 14.73 | 11.02  | -2.87                        | 8.15  |
| Amaranth            | 0.15               | 3.61  | 2.97                         | 6.59  | 37.36                                       | 0.11                         | 37.47 | 33.75  | -2.86                        | 30.88 |
|                     | 0.30               |   |                              |       | 16.69                                       | 0.23                         | 16.92 | 13.07  | -2.74                        | 10.33 |
|                     | 0.05               |   |                              |       | 22.90                                       | 0.12                         | 23.02 | 14.73  | -3.72                        | 11.01 |
| Alfalfa             | 0.15               | 8.17  | 3.85                         | 12.01 | 43.51                                       | 0.12                         | 43.64 | 35.35  | -3.72                        | 31.63 |
|                     | 0.30               |   |                              |       | 7.05  | 0.28                         | 7.33  | -1.11  | -3.57                        | -4.68 |
|                     | 0.05               |   |                              |       | 18.55                                       | 0.11                         | 18.66 | 12.64  | -3.07                        | 9.56  |
| Switchgrass         | 0.15               | 5.92  | 3.18                         | 9.10  | 41.04                                       | 0.27                         | 41.32 | 35.13  | -2.91                        | 32.22 |
|                     | 0.30               |   |                              |       | 11.32                                       | 0.42                         | 11.74 | 5.41   | -2.77                        | 2.64  |
| <b>Cottonwood</b>   |                    |   |                              |       |   |                              |       |  |                              |       |
|                     | 0.05               |   |                              |       | 7.87  | 0.19                         | 8.06  | 7.51   | -2.23                        | 5.28  |
| Tef                 | 0.15               | 0.36  | 2.42                         | 2.78  | 36.64                                       | 0.28                         | 36.92 | 36.28  | -2.14                        | 34.14 |
|                     | 0.30               |   |                              |       | 2.03  | 0.96                         | 2.99  | 1.67   | -1.46                        | 0.21  |
|                     | 0.05               |   |                              |       | 19.79                                       | 0.14                         | 19.93 | 17.16  | -4.52                        | 12.64 |
| Amaranth            | 0.15               | 2.63  | 4.66                         | 7.29  | 52.93                                       | 0.24                         | 53.17 | 50.30  | -4.42                        | 45.88 |
|                     | 0.30               |   |                              |       | 34.05                                       | 0.32                         | 34.37 | 31.42  | -4.34                        | 27.08 |
|                     | 0.05               |   |                              |       | 11.56                                       | 0.14                         | 11.70 | 10.30  | -2.19                        | 8.10  |
| Alfalfa             | 0.15               | 1.27  | 2.33                         | 3.60  | 36.29                                       | 0.31                         | 36.60 | 35.03  | -2.02                        | 33.00 |
|                     | 0.30               |   |                              |       | 20.89                                       | 0.35                         | 21.24 | 19.62  | -1.98                        | 17.65 |
|                     | 0.05               |   |                              |       | 10.73                                       | 0.18                         | 10.91 | 8.81   | -1.79                        | 7.02  |
| Switchgrass         | 0.15               | 1.93  | 1.97                         | 3.90  | 38.52                                       | 0.22                         | 38.73 | 36.59  | -1.75                        | 34.84 |
|                     | 0.30               |   |                              |       | 13.64                                       | 0.44                         | 14.08 | 11.72  | -1.53                        | 10.18 |

### *Net total extractable N*

Figure 2.21 shows the net change in total extractable N concentrations for the pre-planting incubation as the sum of the change in nitrate-N and ammonium-N concentrations. The MANOVA results showed that moisture and field were significant factors affecting the net change in total extractable N concentrations in the pre-planting incubation (Table 2.4). The average net total extractable N change for the 0.05, 0.15, and 0.30 moisture treatments were  $9.33 \pm 1.95$ ,  $44.78 \pm 6.56$ , and  $74.85 \pm 7.64$  mgN kg<sup>-1</sup>. All three moisture treatments were significantly different from each other. The Cottonwood

revegetation field showed the highest net change in total extractable N concentration ( $75.24 \pm 14.81$ ) followed by the Valley Vista alternative ( $44.80 \pm 8.41$  mgN kg<sup>-1</sup>), Valley Vista revegetation ( $43.45 \pm 8.11$  mgN kg<sup>-1</sup>), Cottonwood alternative ( $33.92 \pm 7.39$  mgN kg<sup>-1</sup>), and Wildlife Area revegetation ( $17.52 \pm 4.44$  mgN kg<sup>-1</sup>) fields. The net change in total extractable N in the Wildlife Area revegetation field was similar to that of the Cottonwood alternative field. The net total extractable N was higher in the Cottonwood revegetation field than in the Wildlife Area revegetation and Cottonwood alternative fields. Net total extractable N was higher in the Valley Vista revegetation and alternative fields than in the Wildlife Area revegetation field.

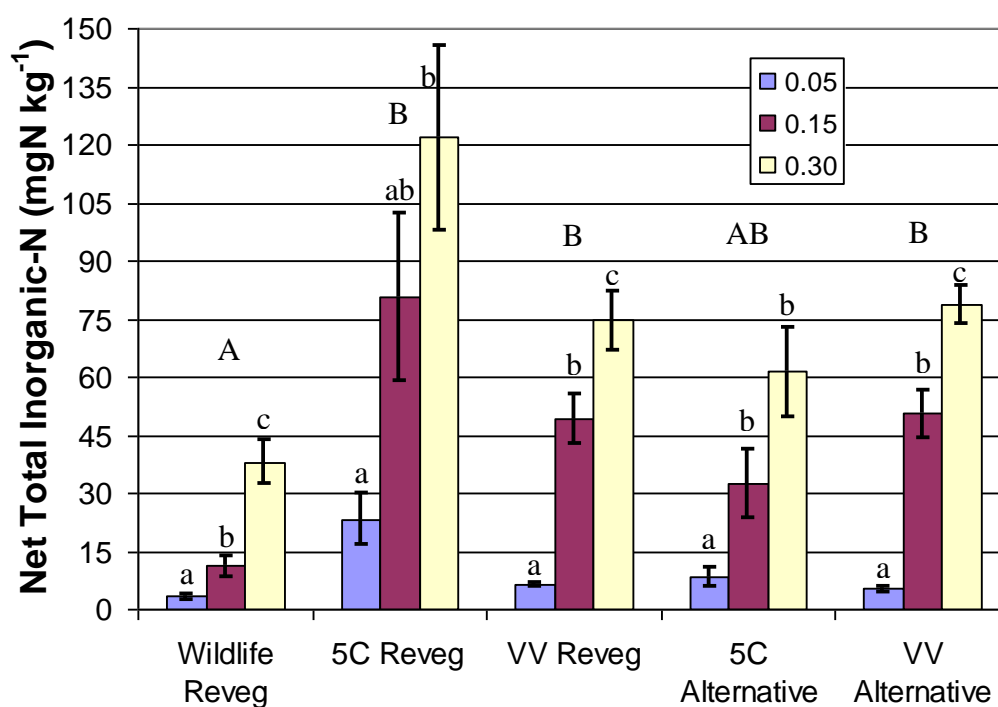


Figure 2.21: Average net total extractable N as the addition of net nitrate-N and net ammonium-N in the pre-planting incubation (Wildlife revegetation, Cottonwood (5C) revegetation, Valley Vista (VV) revegetation, Cottonwood alternative, Valley Vista alternative). Error bars represent standard error (n = 5). Capital letters represent significant differences between fields when combining moisture treatments. Lower case letters represent significant differences between moisture treatments within each field but not between fields.

Figures 2.22 and 2.23 show the net inorganic-N values in the post-planting incubation for the Valley Vista and Cottonwood fields. The MANOVA results showed that moisture, field, the moisture\*field interaction, vegetation type, and the field\*vegetation type interaction significantly affected the net total extractable N concentration in the post-planting incubation (Table 2.5). In contrast to the pre-planting incubation, the net total extractable N concentrations did not increase with moisture in this incubation. Instead, net total extractable N was highest in the 0.15 moisture treatment. Overall, the net total extractable N for the 0.05, 0.15, and 0.30 moisture treatments were  $8.68 \pm 0.52$ ,  $34.33 \pm 1.12$ , and  $8.52 \pm 2.69$  mgN kg<sup>-1</sup> respectively. Net total extractable N concentrations were similar for the Valley Vista ( $14.68 \pm 2.31$  mgN kg<sup>-1</sup>) and Cottonwood fields ( $19.67 \pm 2.56$  mgN kg<sup>-1</sup>). According to the t-test, however, there was no significant difference between these two values. The post-planting Valley Vista net total extractable N value was significantly lower than that of the pre-planting Valley Vista alternative field and the post-planting Cottonwood net total extractable N value was not significantly different than that of the pre-planting Cottonwood alternative field.

Some consistency in the difference between the two fields in the three moisture treatments was observed in this incubation where generally the Cottonwood net N concentrations were higher than the Valley Vista net N concentrations. In the 0.05 moisture treatment the average net total extractable N concentrations were similar for the Valley Vista ( $9.09 \pm 0.55$  mgN kg<sup>-1</sup>) and Cottonwood ( $8.26 \pm 0.90$  mgN kg<sup>-1</sup>) fields. For the 0.15 moisture treatment, net concentration was significantly lower in the Valley Vista field ( $31.70 \pm 0.92$  mgN kg<sup>-1</sup>) compared to the Cottonwood field ( $36.97 \pm 1.78$  mgN kg<sup>-1</sup>).



<sup>1</sup>). For the 0.30 moisture treatment, net total extractable N concentrations were lower in Valley Vista ( $3.26 \pm 2.95 \text{ mgN kg}^{-1}$ ) than in Cottonwood ( $13.78 \pm 4.07 \text{ mgN kg}^{-1}$ ).

Amaranth showed the largest net change in N ( $22.49 \pm 3.62 \text{ mgN kg}^{-1}$ ) of the vegetation followed by alfalfa ( $16.12 \pm 3.48 \text{ mgN kg}^{-1}$ ), switchgrass ( $16.08 \pm 3.24 \text{ mgN kg}^{-1}$ ), and tef ( $14.02 \pm 3.52 \text{ mgN kg}^{-1}$ ) but all these concentrations were statistically similar. Amaranth showed the largest net change in N concentration in the Valley Vista field ( $16.45 \pm 3.89 \text{ mgN kg}^{-1}$ ) followed by tef ( $14.83 \pm 4.93 \text{ mgN kg}^{-1}$ ), switchgrass ( $14.81 \pm 4.72 \text{ mgN kg}^{-1}$ ), and alfalfa ( $12.65 \pm 5.54 \text{ mgN kg}^{-1}$ ) but there were no significant differences. Amaranth also showed the largest net change in N for the Cottonwood field ( $28.54 \pm 5.59 \text{ mgN kg}^{-1}$ ) followed by alfalfa ( $19.58 \pm 4.23 \text{ mgN kg}^{-1}$ ), switchgrass ( $17.34 \pm 4.69 \text{ mgN kg}^{-1}$ ), and tef ( $13.21 \pm 5.31 \text{ mgN kg}^{-1}$ ) where all these concentrations were similar.

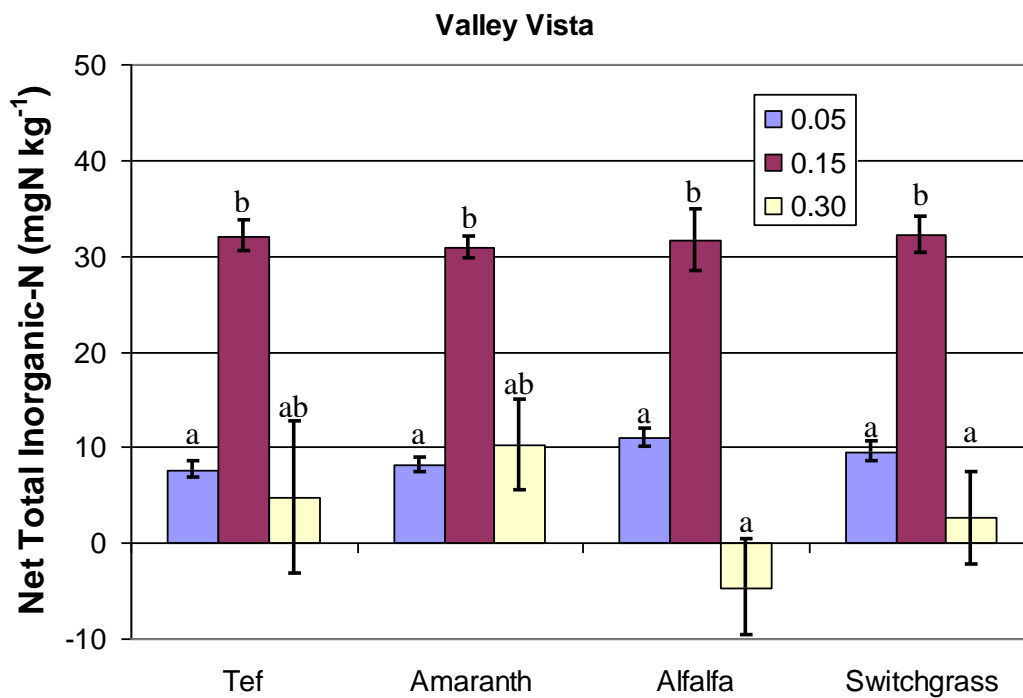


Figure 2.22: Average net total extractable N as the addition of net nitrate-N and net ammonium-N in the post-planting Valley Vista field. Error bars represent standard error ( $n = 3$ ). Letters represent significant differences between moisture treatments within each vegetation type but not between vegetation types.

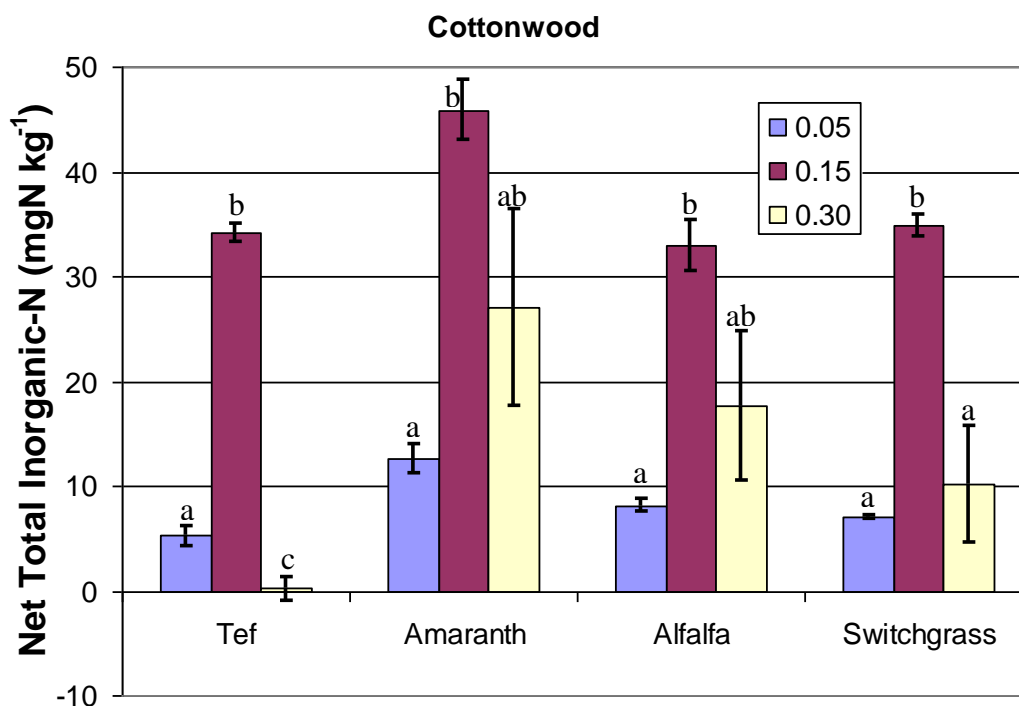


Figure 2.23: Average net total extractable N as the addition of net nitrate-N and net ammonium-N in the post-planting Cottonwood field. Error bars represent standard error ( $n = 3$ ). Letters represent significant differences between moisture treatments within each vegetation type but not between vegetation types.

#### *Net nitrate-N*

Figure 2.24 shows the average net change in nitrate-N concentrations for the pre-planting incubation. The MANOVA analysis showed that moisture and field affected the net nitrate-N concentrations in the pre-planting incubation (Table 2.4). The net changes in nitrate-N patterns in this incubation were very similar to the patterns of net total extractable N because nitrate-N made up 97.1% of the total extractable N change (absolute value of net nitrate-N + the absolute value of net ammonium-N). In general, the net nitrate-N concentrations increased with increasing moisture. Overall, the net nitrate-N concentrations for the 0.05, 0.15, and 0.30 moisture treatments were  $7.55 \pm 1.53$ ,  $47.74 \pm 6.74$ , and  $77.59 \pm 7.81$   $\text{mgN kg}^{-1}$  respectively and all values were

significantly different. The Cottonwood revegetation field showed the largest net change in nitrate-N concentration ( $75.94 \pm 15.90 \text{ mgN kg}^{-1}$ ) followed by the Valley Vista alternative ( $46.00 \pm 8.89 \text{ mgN kg}^{-1}$ ), Valley Vista revegetation ( $44.63 \pm 8.44 \text{ mgN kg}^{-1}$ ), Cottonwood alternative ( $35.46 \pm 7.64 \text{ mgN kg}^{-1}$ ), and Wildlife Area revegetation ( $19.43 \pm 4.70 \text{ mgN kg}^{-1}$ ) fields. The relationships between these concentrations were the same as those for net total extractable N in the pre-planting incubation.

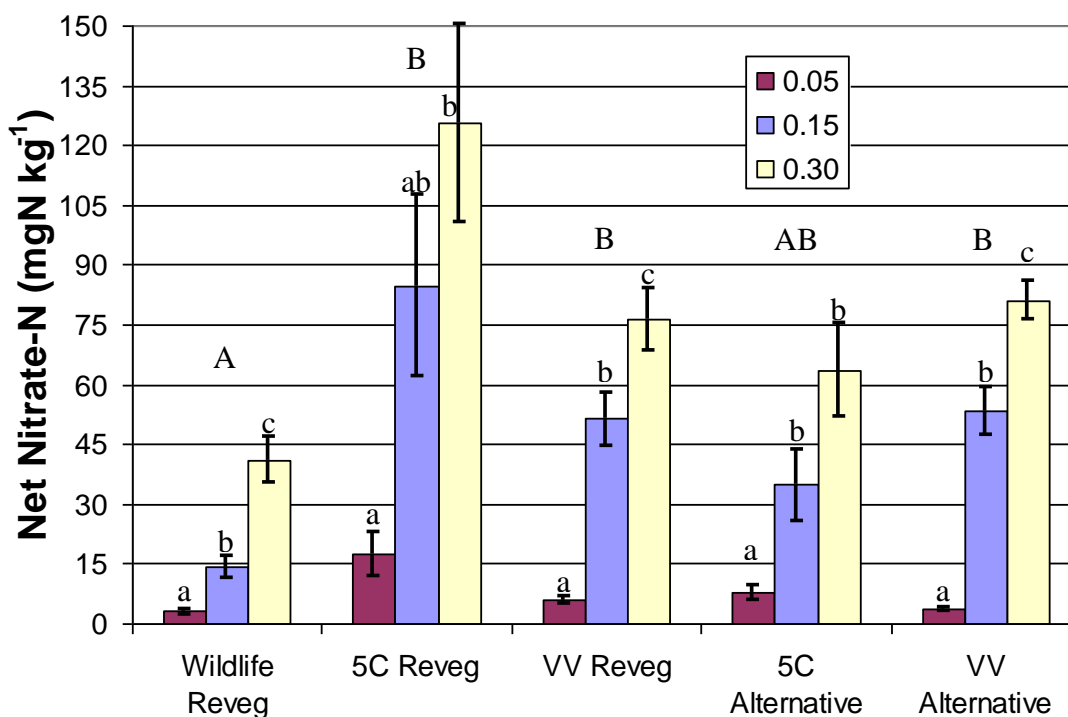


Figure 2.24: Average net nitrate-N in the pre-planting incubation (Wildlife revegetation, Cottonwood (5C) revegetation, Valley Vista (VV) revegetation, Cottonwood alternative, Valley Vista alternative). Error bars represent standard error (n = 5). Capital letters represent significant differences between fields when combining the moisture treatments. Lower case letters represent significant differences between moisture treatments within each field but not between fields.

Figures 2.25 and 2.26 show the average net nitrate-N values in the post-planting incubation for the Valley Vista and Cottonwood fields. The MANOVA analysis showed that moisture, field, the moisture\*field interaction, vegetation type, and the field\*vegetation type interaction affected net nitrate-N in the post-planting incubation

(Table 2.5). Nitrate-N made up 88.1% of the overall total extractable N change. The 0.05 moisture treatment consistently showed the lowest net nitrate-N concentration of the three moisture treatments. Generally, the 0.15 moisture treatment showed the highest net nitrate-N concentration of the three moisture treatments, which is similar to the net total extractable N concentrations in this incubation. Overall, the net nitrate-N concentration for the 0.05, 0.15, and 0.30 moisture treatments was  $11.48 \pm 0.68$ ,  $37.07 \pm 1.22$ , and  $11.05 \pm 2.75$  mgN kg<sup>-1</sup> where the 0.15 moisture treatment was significantly higher than the 0.05 and 0.30 moisture treatment. The net nitrate-N concentration was the same for the Valley Vista ( $17.53 \pm 2.31$  mgN kg<sup>-1</sup>) and Cottonwood ( $22.20 \pm 2.64$  mgN kg<sup>-1</sup>) fields. The patterns in net nitrate-N between the fields in the two incubations were the same as the patterns in the net total extractable N section mentioned previously.

The moisture\*field interaction only produced a significant difference in one of the moisture treatments in this incubation. In the 0.05 moisture treatment the net nitrate-N concentrations were similar for the Valley Vista ( $12.02 \pm 0.68$  mgN kg<sup>-1</sup>) and Cottonwood ( $10.94 \pm 1.18$  mgN kg<sup>-1</sup>) fields. For the 0.15 moisture treatment net nitrate-N concentrations were significantly higher in the Cottonwood ( $39.55 \pm 2.06$  mgN kg<sup>-1</sup>) than in the Valley Vista field ( $34.58 \pm 0.93$  mgN kg<sup>-1</sup>). For the 0.30 moisture treatment the net nitrate-N concentrations were the same for Valley Vista ( $6.00 \pm 2.91$  mgN kg<sup>-1</sup>) and Cottonwood ( $16.11 \pm 4.31$  mgN kg<sup>-1</sup>) fields.

Overall, amaranth showed the largest net change in nitrate-N ( $26.12 \pm 3.70$  mgN kg<sup>-1</sup>) followed by alfalfa ( $18.98 \pm 3.45$  mgN kg<sup>-1</sup>), switchgrass ( $18.38 \pm 3.24$  mgN kg<sup>-1</sup>), and tef ( $15.98 \pm 3.55$  mgN kg<sup>-1</sup>). However, there were statistically no differences. In the Valley Vista field, amaranth showed the largest net change in nitrate-N ( $19.28 \pm 3.90$

mgN kg<sup>-1</sup>) followed by switchgrass (17.72 ± 4.74 mgN kg<sup>-1</sup>), tef (16.81 ± 4.94 mgN kg<sup>-1</sup>), and alfalfa (16.32 ± 5.56 mgN kg<sup>-1</sup>) which were not significantly different. In the Cottonwood field, amaranth showed the largest net nitrate-N concentration (32.96 ± 5.58 mgN kg<sup>-1</sup>) followed by alfalfa (21.65 ± 4.21 mgN kg<sup>-1</sup>), switchgrass (19.04 ± 4.71 mgN kg<sup>-1</sup>), and tef (15.15 ± 5.37 mgN kg<sup>-1</sup>). The only significant difference here was a significantly higher amaranth net nitrate-N concentration than tef. There were no significant differences when comparing the same vegetation between the two fields.

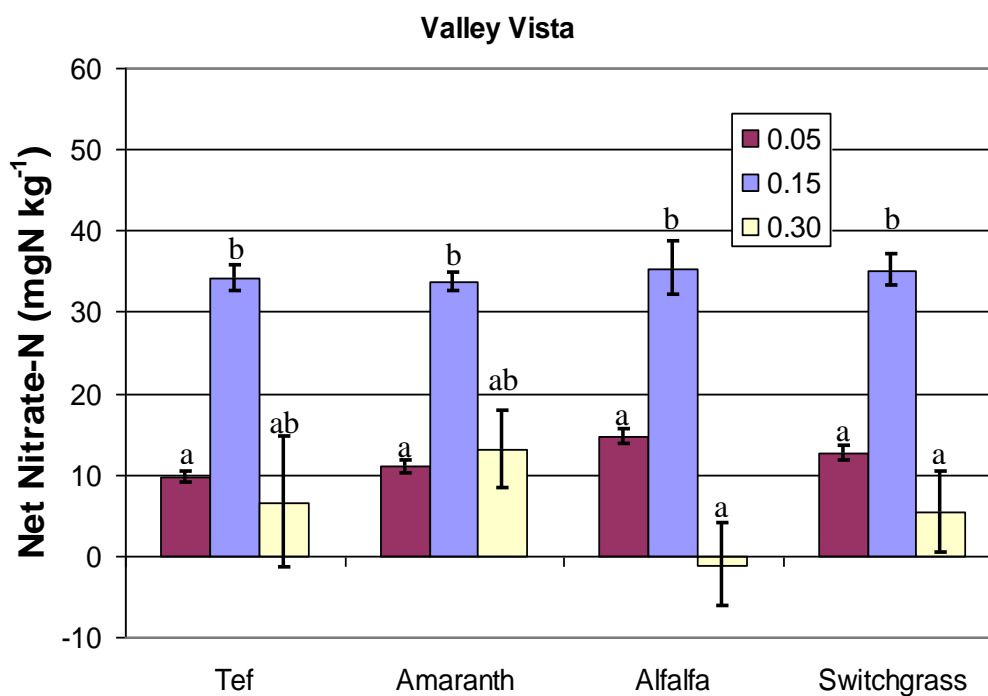


Figure 2.25: Average net nitrate-N in the post-planting Valley Vista field. Error bars represent standard error (n = 3). Letters represent significant differences between moisture treatments within each vegetation type but not between vegetation types.

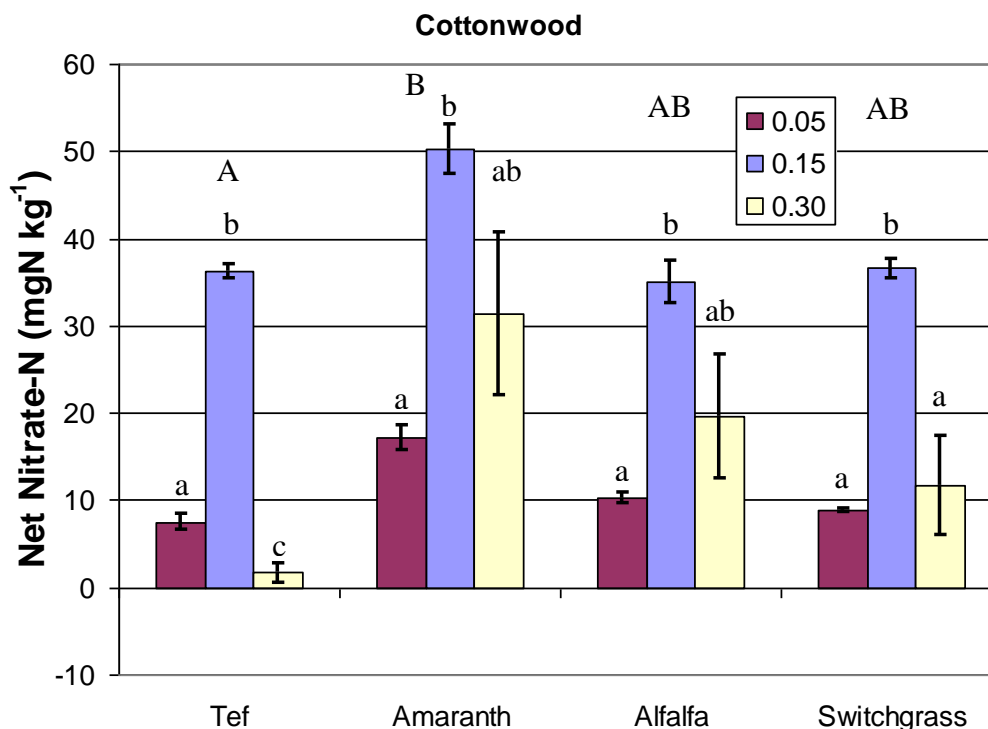


Figure 2.26: Average net nitrate-N in the post-planting Cottonwood field. Error bars represent standard error ( $n = 3$ ). Capital letters represent significant differences between vegetation types when combining the moisture treatments. Lower case letters represent significant differences between moisture treatments within each vegetation type but not between vegetation types.

#### *Net ammonium-N*

Figure 2.27 shows the average net ammonium-N concentrations for the pre-planting incubation. The MANOVA analysis showed that moisture and the moisture\*field interaction significantly affected the net ammonium-N in the pre-planting incubation (Table 2.4). In general, there was no significant net ammonium-N in the 0.05 moisture treatment but a net decrease of net ammonium-N in the 0.15 and 0.30 moisture treatments occurred. Overall, the net ammonium-N concentrations for the 0.05, 0.15, and 0.30 moisture treatments were  $1.78 \pm 0.86$ ,  $-2.96 \pm 0.30$ , and  $-2.74 \pm 0.31$  mgN kg<sup>-1</sup> respectively.

For the moisture\*field interaction there were no consistent differences in the pre-planting incubation. In this incubation, net ammonium-N concentrations were significantly higher in the Valley Vista alternative field compared to the Wildlife Area revegetation field in the 0.05 moisture treatment. The Valley Vista alternative field was the only field to have a significant increase in net ammonium-N content over this incubation period in the 0.05 moisture treatment. There were no significant differences in net ammonium-N concentrations between any of the fields in the 0.15 or 0.30 moisture treatments.

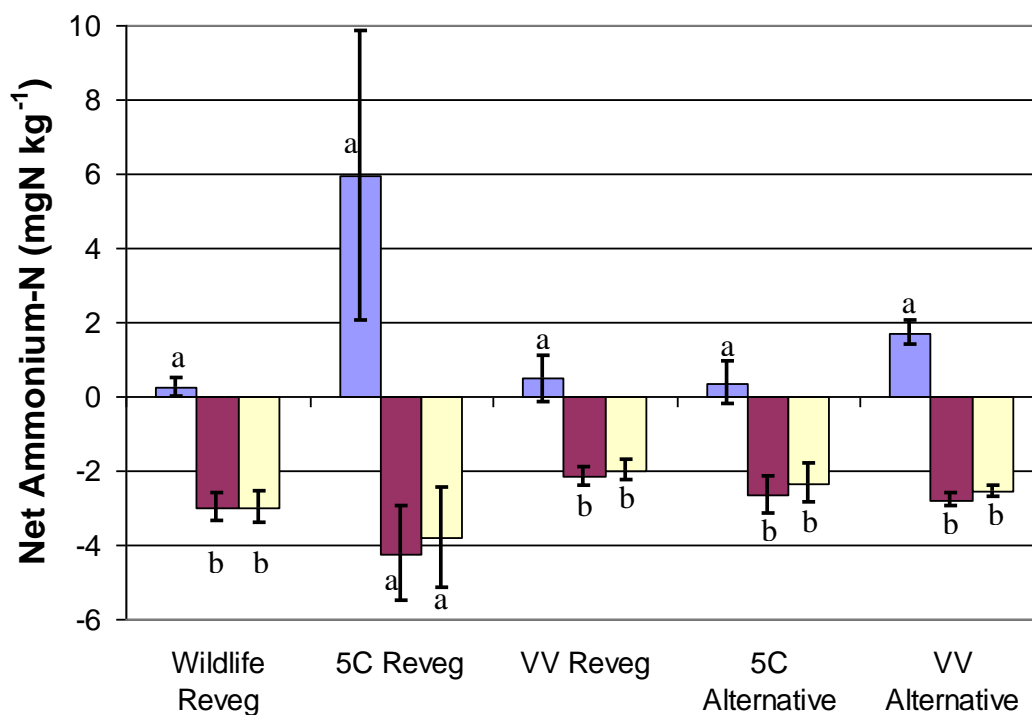


Figure 2.27: Average net ammonium-N for the pre-planting incubation soils (Wildlife revegetation, Cottonwood (5C) revegetation, Valley Vista (VV) revegetation, Cottonwood alternative, Valley Vista alternative). Error bars represent standard error (n = 5). Letters represent significant differences between moisture treatments within each field but not between fields.

Figures 2.28 and 2.29 show the average net ammonium-N concentrations for the post-planting incubation for the Valley Vista and Cottonwood fields. The MANOVA



analysis showed that moisture, field, vegetation type, and the field\*vegetation type interaction significantly affected net ammonium-N concentrations in the post-planting incubation (Table 2.5). In contrast with the MANOVA results the t-test showed no significant differences in net ammonium-N concentrations between moisture treatments. Overall, the net ammonium-N concentrations for the 0.05, 0.15, and 0.30 moisture treatments were  $-2.81 \pm 0.18$ ,  $-2.73 \pm 0.18$ , and  $-2.53 \pm 0.20$  mgN kg<sup>-1</sup> respectively.

The overall net ammonium-N concentration were similar for the Valley Vista ( $-2.85 \pm 0.10$  mgN kg<sup>-1</sup>) and Cottonwood ( $-2.53 \pm 0.19$  mgN kg<sup>-1</sup>) fields. Valley Vista's net ammonium-N concentration was significantly more negative than that of the pre-planting Valley Vista alternative field. Cottonwood's net ammonium-N loss was not significantly different than that of the pre-planting Cottonwood alternative field.

Overall, amaranth showed the largest net ammonium-N concentration decrease ( $-3.63 \pm 0.19$  mgN kg<sup>-1</sup>) followed by alfalfa ( $-2.87 \pm 0.20$  mgN kg<sup>-1</sup>), switchgrass ( $-2.30 \pm 0.15$  mgN kg<sup>-1</sup>), and tef ( $-1.96 \pm 0.06$  mgN kg<sup>-1</sup>) in the post-planting incubation. Net ammonium-N concentrations for tef and switchgrass were statistically similar. In the Valley Vista field, alfalfa showed the largest net ammonium-N concentration decrease ( $-3.67 \pm 0.03$  mgN kg<sup>-1</sup>) followed by switchgrass ( $-2.92 \pm 0.06$  mgN kg<sup>-1</sup>), amaranth ( $-2.83 \pm 0.02$  mgN kg<sup>-1</sup>), and tef ( $-1.99 \pm 0.04$  mgN kg<sup>-1</sup>). Net concentrations were similar for amaranth and switchgrass. In the Cottonwood field, amaranth showed the largest net ammonium-N concentration decrease ( $-4.43 \pm 0.03$  mgN kg<sup>-1</sup>) followed by alfalfa ( $-2.06 \pm 0.03$  mgN kg<sup>-1</sup>), tef ( $-1.94 \pm 0.12$  mgN kg<sup>-1</sup>), and switchgrass ( $-1.69 \pm 0.05$  mgN kg<sup>-1</sup>). Tef was similar to alfalfa and switchgrass. There were significant differences between all the vegetation across fields except for tef. For the remaining three comparisons, net

ammonium-N concentrations in Valley Vista soils were higher for alfalfa and switchgrass and lower for amaranth compared to Cottonwood soils.

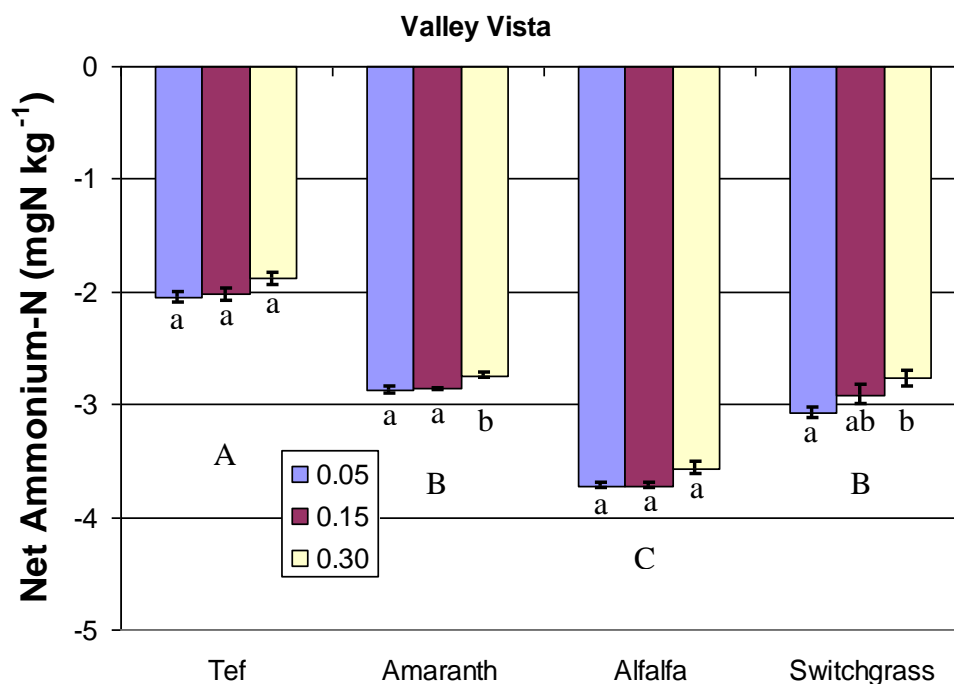


Figure 2.28: Average net ammonium-N for the post-planting Valley Vista field. Error bars represent standard error ( $n = 3$ ). Capital letters represent significant differences between vegetation types when combining moisture treatments. Lower case letters represent significant differences between moisture treatments within each vegetation type but not between vegetation types.

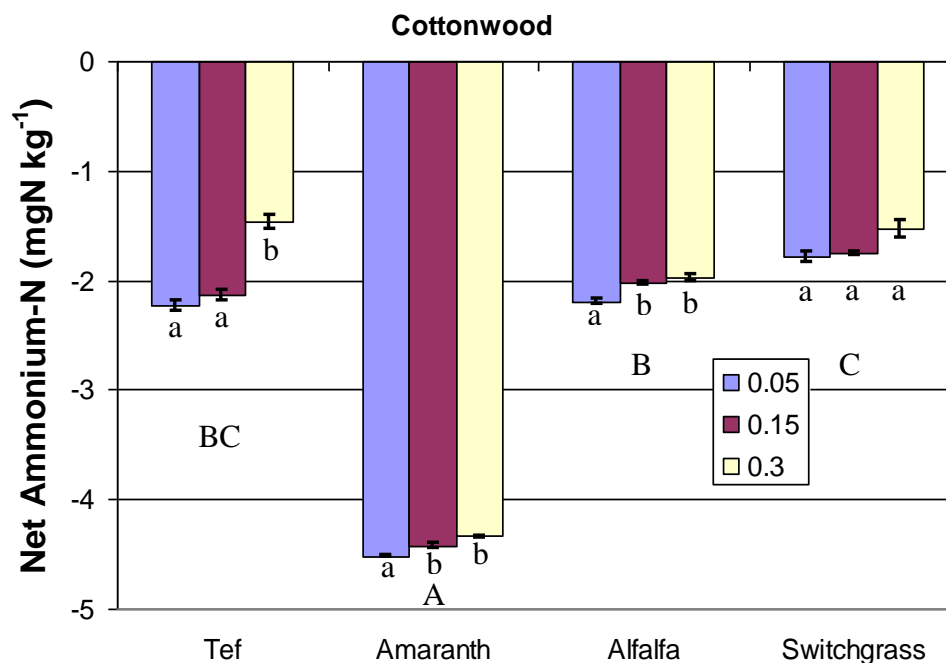


Figure 2.29: Average net ammonium-N for the post-planting Cottonwood field. Error bars represent standard error ( $n = 3$ ). Capital letters represent significant differences between vegetation types when combining moisture treatments. Lower case letters represent significant differences between moisture treatments within each vegetation type but not between vegetation types.

### *Multiple regression*

The multiple regression analysis showed that the cumulative C production per gram soil (Table 2.8) over the incubation period was affected by moisture and percent clay in the pre-planting incubation ( $R^2 = 50.8\%$ ), where the percent clay affected the cumulative C production negatively. Moisture and percent clay were significant factors in the post-planting incubation ( $R^2 = 27.4\%$ ), where percent clay affected the cumulative C production per gram of soil negatively (Table 2.9). The cumulative C production per gram C was significantly affected by moisture and percent clay in the pre-planting incubation ( $R^2 = 48.8\%$ , Table 2.8). Moisture and percent clay were also significant factors (Table 2.9) in the post-planting incubation ( $R^2 = 33.6\%$ ) affecting the cumulative

C production per gram C. Moisture was the only significant factor in the post-planting incubation, affecting the rate constant negatively and explaining 34.1% of the overall variability. There were no significant factors for the rate constant in the pre-planting incubation ( $R^2 = 5.8\%$ ).

Moisture, percent clay (negative correlation), percent total N, and C/N ratio were significant factors affecting the net total extractable N concentrations in the pre-planting incubation ( $R^2 = 70.4\%$ ; Table 2.8). There were no significant factors (Table 2.9) for the net total extractable N concentrations in the post-planting incubation ( $R^2 = 8.1\%$ ).

Moisture, percent clay (negative correlation), total N, and C/N ratio affected the net nitrate-N concentrations significantly (Table 2.8) in the pre-planting incubation ( $R^2 = 69.7\%$ ) but there were no significant factors (Table 2.9) affecting the net nitrate-N concentrations in the post-planting incubation ( $R^2 = 9.4\%$ ). The multiple regression analyses (Table 2.8) revealed that moisture negatively affected the net ammonium-N concentrations in the pre-planting incubation ( $R^2 = 25.2\%$ ). Moisture, total N, total C, C/N, and percent (of total N) extractable N were significant factors affecting the net ammonium-N concentrations in the post-planting incubation ( $R^2 = 82.7\%$ ; Table 2.9).

Table 2.8: Linear multiple regression results for the pre-planting incubation.

| Factor                 | Rate Constant | Cum $C_s$ | Cum $C_c$ | Net Total N | Net Nitrate | Net Ammonium |
|------------------------|---------------|-----------|-----------|-------------|-------------|--------------|
| Moisture               | ns            | ****      | ****      | ****        | ****        | ****(-)      |
| %Clay                  | ns            | **(-)     | ****(-)   | ****(-)     | ****(-)     | ns           |
| %Silt                  | ns            | ns        | ns        | ns          | ns          | ns           |
| Initial total N        | ns            | ns        | ns        | ****        | ****        | ns           |
| Initial total C        | ns            | ns        | ns        | ns          | ns          | ns           |
| Initial C/N            | ns            | ns        | ns        | **          | *           | ns           |
| Initial %Extractable N | ns            | ns        | ns        | ns          | ns          | ns           |

ns = not significant ( $p > 0.05$ ), \* =  $p < 0.05$ , \*\* =  $p < 0.01$ , \*\*\* =  $p < 0.001$ , \*\*\*\* =  $p < 0.0001$ , (-) designates negative relationship

Table 2.9: Linear multiple regression results for the post-planting incubation.

| Factor                 | Rate Constant | Cum C <sub>s</sub> | Cum C <sub>c</sub> | Net Total N | Net Nitrate | Net Ammonium |
|------------------------|---------------|--------------------|--------------------|-------------|-------------|--------------|
| Moisture               | ****(-)       | ***                | ***                | ns          | ns          | *            |
| %Clay                  | ns            | **(-)              | **(-)              | ns          | ns          | ns           |
| %Silt                  | ns            | ns                 | ns                 | ns          | ns          | ns           |
| Initial total N        | ns            | ns                 | ns                 | ns          | ns          | ****         |
| Initial total C        | ns            | ns                 | ns                 | ns          | ns          | ****(-)      |
| Initial C/N            | ns            | ns                 | ns                 | ns          | ns          | ****         |
| Initial %Extractable N | ns            | ns                 | ns                 | ns          | ns          | ****(-)      |

ns = not significant ( $p > 0.05$ ), \* =  $p < 0.05$ , \*\* =  $p < 0.01$ , \*\*\* =  $p < 0.001$ , \*\*\*\* =  $p < 0.0001$ , (-) designates negative relationship

## DISCUSSION

In this study, we used constant temperature laboratory incubations of soils collected prior to and after one cropping cycle to explore the effects of soil moisture, soil texture, and vegetation type on the C and N transformations from three sites in the Walker Basin of northwestern Nevada.

### *Moisture effects*

We hypothesized that moisture would stimulate microbial activity and thus rates of C and N fluxes. In general, in the pre- and post-planting incubations, C fluxes increased with increasing moisture content and moisture was a significant factor in both MANOVA and multiple regression analyses. The Valley Vista alternative field, in both incubations, showed significantly higher cumulative C mineralization in the 0.15 and 0.30 moisture treatments than the 0.05 moisture treatment. The Cottonwood alternative field, in the pre-planting incubation, generally showed higher cumulative C mineralization in the 0.30 moisture treatment than the 0.05 moisture treatment. The Cottonwood alternative field, in the post-planting incubation, showed higher cumulative

C mineralization in the 0.15 and 0.30 moisture treatments than the 0.05 moisture treatment. Our results are consistent with Howard and Howard (1993) who described a quadratic response of the log transform of the C respiration rate versus moisture content by weight (Figures 2.30, 2.31, and 2.32). From these response curves, it appears that the optimal moisture level for C mineralization in our soils was between the 0.15 and 0.30 moisture range. In our study, however, we did not include higher moisture treatments. The post-planting Valley Vista amaranth and post-planting Cottonwood alfalfa soils were the only soils not to show optimal moisture contents between 0.15 and 0.30 by weight. Error bars were not included in the figures because differences between the fields and vegetation were generally not large.

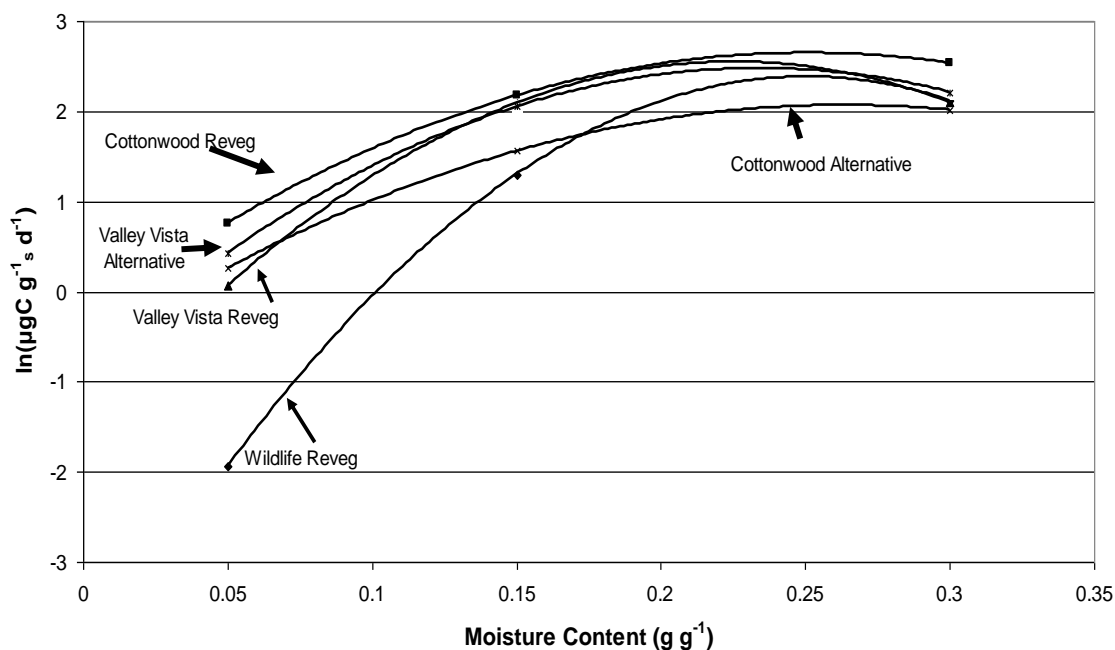


Figure 2.30: Relationship between the C Respiration Rate and soil moisture in the pre-planting incubation.

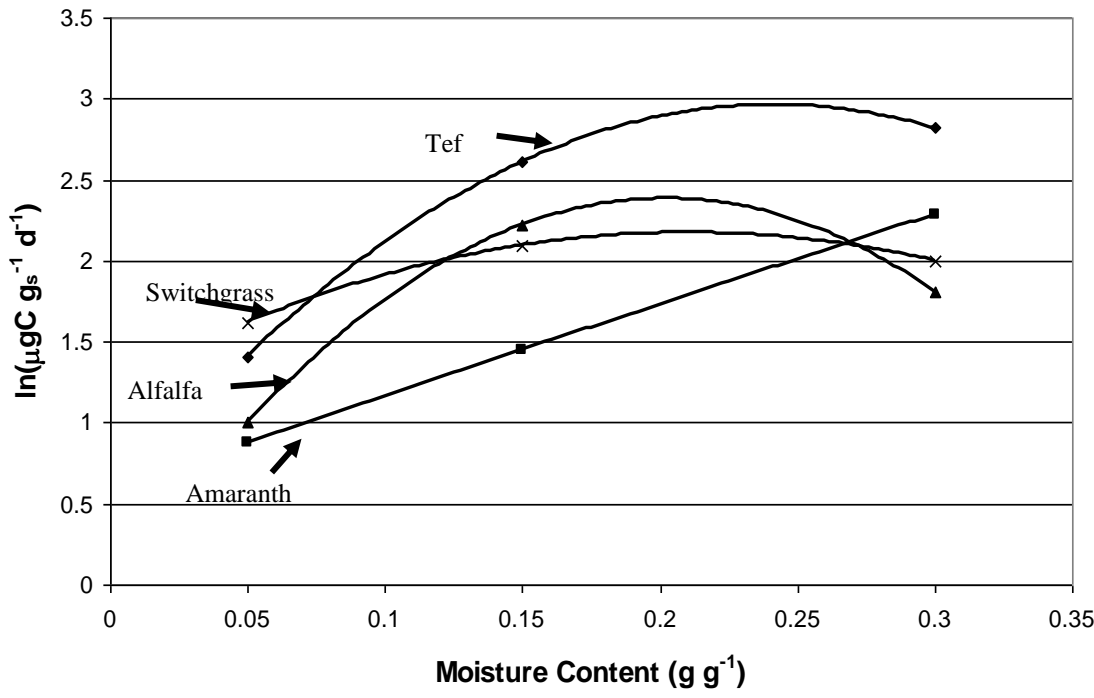


Figure 2.31: Relationship between the C Respiration Rate and soil moisture in the post-planting Valley Vista field

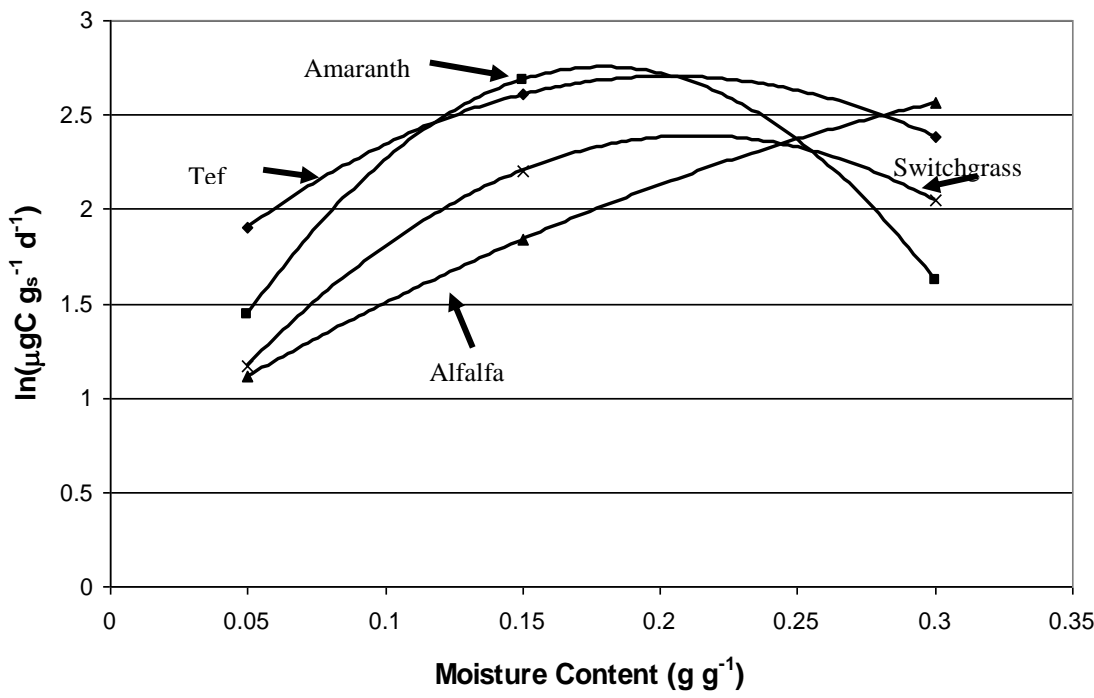


Figure 2.32 Relationship between the C Respiration Rate and soil moisture in the post-planting Cottonwood field

In general, for the pre- and post-planting incubation, trends in the exponential decay  $\text{CO}_2$ -C respiration rate constants were opposite to those in the cumulative respiration, i.e. rate constants were highest in the 0.05 moisture treatment. These results indicate that at lower moisture contents, respiration rates level off at lower cumulative respiration values than at higher moisture contents. For the low moisture treatment, the microbial respiration most likely is limited because of the lack of water which induces osmotic stress and decreases substrate availability (Strong et al, 1998; Cookson et al., 2006). This lack of water, then results in higher respiration rate constants (faster decay of respiration) and less ability to maintain respiration rates. As for the higher moisture treatments, there is more water available to allow for microbial movement and substrate diffusion in the soil to obtain organic matter, maintain respiration rates over a longer period of time, cumulatively respire more C, and result in lower respiration rate constants (slower decay of respiration). Our results are consistent with other studies showing that at low moisture contents  $\text{O}_2$  uptake and  $\text{CO}_2$  evolution are low but rapidly increase with increasing moisture (Howard and Howard, 1993; Cookson et al., 2006; Dilustro et al., 2005). The uptake of  $\text{O}_2$  decreases once the availability of  $\text{O}_2$  decreases because of an increase in the water filled pore space which can occur at various moisture contents depending on the soil pore space (Howard and Howard, 1993). However, in our study we did not employ high enough moisture contents to see this decrease. The responses of N fluxes to moisture show different patterns than the C fluxes. In general, for the pre-planting incubation, the net total extractable N and nitrate-N concentrations increased with increasing moisture in the Cottonwood and Valley Vista alternative fields. In contrast, in the post-planting Cottonwood and Valley Vista alternative fields, the net



extractable N and nitrate concentrations were highest in the 0.15 moisture treatment and saw a dramatic drop off of net extractable N concentration in the 0.30 moisture treatment. Only total N in the Cottonwood alternative field significantly increased from pre- to post-planting. In the Valley Vista alternative field, there was no change in total C or N from pre- to post-planting. There was also no significant difference between the incubations with respect to pre-incubation percent extractable N. However, the pre- and post-incubation percent extractable N was significantly higher in the pre-planting Cottonwood and Valley Vista alternative soils than the post-planting Cottonwood and Valley Vista alternative soils. Substantial amounts of denitrification were not expected at these moisture contents but potentially, some denitrification may have occurred in the higher moisture treatments. Still, the C mineralization results did not indicate the occurrence of anoxic conditions at the higher moisture levels since generally respiration increased with increasing moisture level. However, we do not have conclusive evidence regarding the absence of anoxic conditions since we did not measure redox potential and/or oxygen concentrations in the incubation jars.

The difference between pre- and post-planting incubations may have been caused by changes in the microbial community composition or changes in organic matter inputs during the growing season. Plants are known to exert strong selective pressures on microbial communities which, over the growing season, may have changed the microbial community composition in the post-planting soils (Bardgett et al., 1999). Prior to planting and the beginning of the irrigation cycle, the soils most likely experienced some degree of moisture stress. Moisture stress is also known to affect soil microbial community structure and function (Cookson et al., 2006) which could have led to the

differences in the N transformations observed between the two incubations. N transformations are known to be closely linked to the quantity and quality of C available in the soil (Holub et al., 2005). As mentioned previously, there was no observed difference in total C between the two incubations (when comparing the same fields). Overall, the post-planting incubation soils respired a higher percentage of total C than the pre-planting incubation indicating that there was more labile organic matter in the post-planting incubation soils. The difference between the incubations, therefore, may have resulted from discrepancies in the quality of available C which was not directly measured in this study. Since C mineralization still increased with increasing moisture in the post-planting incubation, there must not have been any moisture stress and therefore microbial activity was higher at the higher moisture levels.

Generally, in both incubations the ammonium-N pool decreased at most moisture levels. The decrease in ammonium concentrations was most likely a result of larger amounts of ammonium being converted into nitrate through nitrification compared to the amounts of ammonium produced through the mineralization of organic matter. However, the decreases in the ammonium concentrations were quite small compared to the overall net inorganic-N changes in the two incubations (~3% in the pre-planting incubation and ~12% in the post-planting incubation). In the pre-planting incubation ammonium-N concentrations decreased in the 0.15 and 0.30 moisture treatments while all moisture treatments showed significant decreases in ammonium concentrations in the post-planting incubation. This difference between the incubations may have also been caused by differences in soil microbial community composition in response to organic matter inputs from vegetation and/or differences in moisture regimes (Cookson et al., 2006).

*Texture effects*

The texture effects were encapsulated in the “field” parameter used in the MANOVA analyses, however texture was not the only factor that this parameter contained (e.g. differences in total C and N and other factors that were not directly measured). In the pre-planting incubation, field significantly affected all C and N fluxes. The major difference in texture between the fields existed primarily between the Wildlife Area revegetation and the other four fields with the Wildlife area revegetation field having much higher clay and silt contents and lower sand contents. Generally, the Wildlife Area revegetation soils showed lower C and N fluxes as originally hypothesized despite having higher total C and N contents. The multiple regression analysis suggested that lower C fluxes were due to the higher percent clay content in the Wildlife Area revegetation. The multiple regression analysis also indicated that both clay and silt significantly affected the C fluxes. In the pre-planting incubation, clay and silt appeared to have the most effect on C mineralization at low moisture contents with declining effects as moisture increased. Figure 2.33 shows the correlation between percent clay and silt versus cumulative C respiration per gram of soil at the 0.05 moisture treatment ( $R^2 = 0.92$  for clay and 0.93 for silt). This relationship became weaker as moisture content increased; the  $R^2$  values were 0.46 for clay and 0.48 for silt in the 0.15 moisture treatment and 0.02 for clay and 0.03 for silt in the 0.30 moisture treatment. Clay and silt are known to influence soil microbial community structure and function by mediating soil moisture and organic matter availability in semi-arid environments (Cookson et al.,

2006). However, from our results it appears that clay and silt play a smaller role in the soil C respiration as moisture increases.

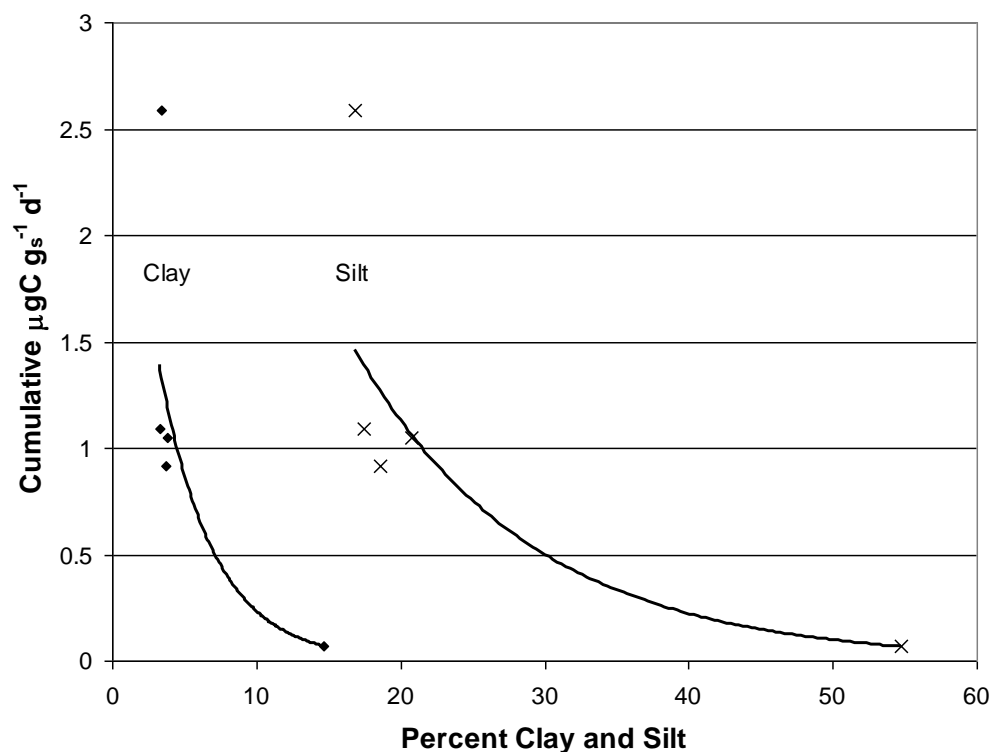


Figure 2.33: Average cumulative C respiration per gram of soil versus clay and silt content for the 0.05 moisture treatment in the pre-planting incubation

Similar to the C respiration, the multiple regression analysis showed that the higher percent clay content most likely caused lower N fluxes in the Wildlife Area revegetation compared to the other four sites. Cookson et al. (2006) reported a negative influence of clay on gross N fluxes, where clay contents ranged from 3 to 29% by weight. The range of percent clay in the pre-planting incubation was 3 to 15% by weight. Hassink (1994) found that soils with higher clay contents versus sand contents were able to accumulate more organic matter where clay contents ranged from 1 to 54% by weight. Our results appear to agree with Hassink's findings where higher amounts of total C were

found in the Wildlife Area revegetation soils versus the other four fields. However, in other laboratory studies clay content appeared to have a weak effect on C and N mineralization (Giardina et al., 2001) where clay contents ranged from 7 to 39% by weight. Pare and Gregorich (1999), on the other hand, reported that N mineralization, in soils with clay ranging from 3 to 54% by weight, was usually more rapid in low clay soils than in loam or high clay, which appears to be in agreement with our results.

In the post-planting incubation, the MANOVA analysis showed that field significantly affected the N fluxes and the respiration rate constant. However, the average N fluxes and C respiration rate constant in the Valley Vista field were not significantly different from those in the Cottonwood field. The multiple regression analysis showed that clay significantly affected the two cumulative CO<sub>2</sub> production rates negatively. The significant effect of clay is somewhat surprising since the percent contents were small and the relative difference in clay between the two fields was also very small (< 16%). We therefore believe that in this case clay may have been confounded by other factors.

#### *Vegetation effects*

Vegetation significantly affected most of the C and N fluxes in the post-planting incubation. We speculated that the effects of vegetation were mediated through changes in organic matter quality and/or quantity (Holub et al., 2005). The effect of vegetation can be assessed by looking into differences in the cumulative C respiration per gram of total C since these numbers provide information about the relative quality of organic matter. Tef produced the highest rates of cumulative C respiration production per gram

of C compared to the other three vegetation types indicating that organic matter derived from Tef following one growing season was most easily decomposable. Pre- and post-planting measurements of total C (for the Valley Vista and Cottonwood alternative fields) showed no significant increase, supporting the notion that differences in organic matter quality explained patterns observed between vegetation types. Tef also produced the largest amount of aboveground biomass of the vegetation studied (see next chapter). Although there were differences in net ammonium concentrations between the vegetation types, these differences did not result in differences in net total extractable N concentrations. Net total extractable N concentration changes were dominated by nitrate (~88%) where these concentrations were similar between vegetation types.

To assess the overall effects of vegetation on C and N fluxes we compared post-planting with pre-planting incubations for the Valley Vista and Cottonwood fields. Generally, the post-planting incubation had higher C fluxes and lower N fluxes than the pre-planting incubation indicating that the amount of available N or the quality of organic-N may have decreased over the growing season since total C and N generally did not change (Holub et al., 2005). Based on the respiration measurements the amount of initial C respired during the post-planting incubation was larger (5%) than during the pre-planting incubation (1%) indicating the inputs of more labile C. However, these changes were not detectable when measuring total soil C.

Moisture significantly affected net ammonium-N concentrations negatively in both incubations. Generally, in both the pre- and post-planting incubations we found a net gain in total extractable N concentrations. Springob and Kirchmann (2003) describe a critical C/N ratio of fifteen where lower ratios result in higher N mineralization rates and

higher ratios result in lower N mineralization rates. We observed differences in C/N ratio between pre- and post-planting incubations but in both cases the C/N ratios were below fifteen and therefore not expected to result in significant mineralization differences.

## CONCLUSIONS

Moisture was the most commonly significant factor affecting the C and N fluxes in this study for both incubations. For the C fluxes in both incubations, the 0.15 and 0.30 by weight moisture treatments led to the highest flux rates. For the N fluxes in the pre-planting incubation, the 0.30 by weight moisture treatment generally resulted in the highest fluxes of N. However, for the N fluxes in the post-planting incubation, the 0.15 moisture treatment generally resulted in the highest fluxes of N. Differences observed in optimal moisture content between C and N fluxes as well as differences in the optimal moisture content for N fluxes between the two incubations may be a result of differences in microbial community or soil organic matter quality.

Field, which includes texture, affected many of the C and N fluxes in both incubations. For the pre-planting incubation, higher percent clay in the Wildlife Area revegetation soils predominantly led to lower C and N fluxes. The clay particles appeared to be physically protecting the organic matter in this field from decomposition and led to higher total C and N contents. In the post-planting incubation, percent clay was a significant factor, but the relatively small differences in clay content between the two fields did not result in significant differences in C and N fluxes. Generally higher C fluxes were found in the tef plots versus the other vegetation types in the post-planting incubation. Tef also produced the largest amount of aboveground biomass of the four

vegetation types studied. There were not as many differences with respect to N fluxes between the vegetation types in this incubation. Generally, the post-planting incubation had higher C fluxes and the pre-planting incubation had higher N fluxes. This occurred because N fluxes in the post-planting incubation experienced a dramatic drop between the 0.15 and 0.30 moisture treatments which was unexpected but may be caused by changes in microbial communities and/or organic matter quality over the growing season.

From this study, we would expect moisture in the field to continue to play a pivotal role in the C and N fluxes within these soils. Also, we would expect texture to have small to no effect on the C and N fluxes because of the existing small differences in texture between the Valley Vista and Cottonwood alternative fields. Vegetation may only play a minor role in the C and N fluxes within the first few growing seasons but as time goes on this influence could increase as distinct microbial communities develop. Future incubation studies may need to quantify the amount and quality of available C and N in the soils versus total C and N as well as soil microbial community structure to obtain a more complete understanding of the ongoing processes.

#### ACKNOWLEDGEMENTS

This project was funded by a grant under Public Law 109-103, Section 208(a), through the U.S. Bureau of Reclamation (Cooperative Agreement 06FC204044). We gratefully acknowledge the assistance of Britt Johnson for helping with the laboratory incubations, Jeramie Memmott for help in using the Lachat



Autoanalyzer, and Todd Caldwell for help in using the Saturn DigiSizer. We also would like to thank Wally Miller and Robert Blank for reviewing drafts of this work.

## REFERENCES

- Bardgett, R.D., Mawdsley, J.L., Edwards, S., Hobbs, P.J., Rodwell, J.S., Davies, W.J. (1999) Plant species and nitrogen effects on soil biological properties of temperate upland grasslands. *Functional Ecology* **13**, 650-660.
- Barrios, E., Delve, R.J., Bekunda, M., Mowo, J., Agunda, J., Rarnisch, J., Trejo, M.T., Thomas, R.J. (2006) Indicators of soil quality: A South-South development of a methodological guide for linking local and technical knowledge. *Geoderma* **135**, 248-259.
- Campbell, C.A. (1978) Soil organic carbon, nitrogen and fertility. P. 173-271. In: M.Schnitzer and S.U. Khan (eds.) Soil organic matter. Developments in Soil Sciences 8. Elsevier, New York.
- Cookson, W.R., Marschner, P., Clark, I.M., Milton, N., Smirk, M.N., Murphy, D.V., Osman, M., Stockdale, E.A., Hirsch, P.R. (2006) The influence of season, agricultural management, and soil properties on gross nitrogen transformations and bacterial community structure. *Australian Journal of Soil Science* **44**, 453-465.
- Dilustro, J.J., Collins, B., Dunca, L., Crawford, C. (2005) Moisture and soil texture effects on soil CO<sub>2</sub> efflux components in southeastern mixed pine forests. *Forest Ecology and Management* **204**, 85-95.
- Franzluebbers A.J. (1999) Potential C and N mineralization and microbial biomass from intact and increasingly disturbed soils of varying texture. *Soil Biology & Biochemistry*, **31**, 1083-1090.
- Giardina, C.P., Ryan, M.G., Hubbard, R.M., Binkley, D. (2001) Tree Species and Soil Textural Controls on Carbon and Nitrogen Mineralization Rates. *Soil Science Society of America Journal* **65**, 1272-1279.
- Golchin, A., Clarke, P., Oades, J.M., Skjemstad, J.O. (1995) The effects of cultivation on the composition of organic matter and structural stability of soils. *Australian Journal of Soil Research* **33**, 975-993.
- Grace, P. and Oades, J.M. (1994) Long-term field trials in Australia. In: Leigh, R.H., Johnson, A.E. (eds) Long-term experiments in agriculture and ecological science. CAB International, Wallingford, UK, pp 53-81.
- Hassink, J. (1994) Effects of soil texture and grassland management on soil organic C and N and rates of C and N mineralization. *Soil Biology & Biochemistry*, **26**, 1221-1231.
- Holub, S.M., Lajtha, K., Spears, J.D.H., Toth, J.A., Crow, S.E., Caldwell, B.A., Papp, M., Nagy, P.T. (2005) Organic matter manipulations have little effect on gross and net nitrogen transformations in two temperate forest mineral soils in the USA and central Europe. *Forest Ecology and Management* **214**, 320-330.

- Howard, D.M. and Howard, P.J.A. (1993) Relationships between CO<sub>2</sub> evolution, moisture content and temperature for a range of soil types. *Soil Biology & Biochemistry* **25**, 1537-1546.
- Komatsuzaki, M. and Ohta, H. (2007) Soil management practices for sustainable agro-ecosystems. *Sustainability Science* **2**, 103-120.
- Lemenih, M., Karlton, E., Olsson, M. (2005) Soil organic matter dynamics after deforestation along a farm field chronosequence in southern highlands of Ethiopia. *Agriculture Ecosystems and Environment* **109**, 9-19.
- Lomander, A., Kätterer, T., Andrén, O. (1998a) Carbon dioxide evolution from top- and subsoil as affected by moisture and constant and fluctuating temperature. *Soil Biology & Biochemistry* **30**, 2017-2022.
- Motavalli, P.P., Palm, C.A., Elliot, Parton, W.J., Elliot, E.T., Frey, S.D. (1994) Comparison of laboratory and modeling simulation methods for estimating soil carbon pools in tropical forest soils. *Soil Biology & Biochemistry* **26**, 935-944.
- Norberg O.S., Shock C., Saunders L., Feibert E., Eldredge E.P., Roseberg R., Charlton B., Smith J. (2005) Teff (*Eragrostis tef*), An Irrigated Warm Season Annual Forage Crop. Oregon State University, Malheur Experiment Station, Ontario, OR.
- Orchard, V.A. and Cook, F.J. (1983) Relationship between soil respiration and soil moisture. *Soil Biology & Biochemistry* **15**, 447-453.
- Pare, T. and Gregorich, E.G. (1999) Soil Textural Effects on Mineralization of Nitrogen from Crop Residues and the Added Nitrogen Interaction. *Communications in Soil Science and Plant Analysis* **30**, 145-157.
- Springob, G. and Kirchmann, H. (2008) Bulk soil C to N ratio as a simple measure of net mineralization from stabilized soil organic matter in sandy arable soils. *Soil Biology & Biochemistry* **35**, 629-632.
- Stanford, G., and Smith, S.J. (1972) Nitrogen mineralization potentials of soils. *Soil Science Society of America Journal* **36**, 465-472.
- Strong, D.T., Sale, P.W.G., Helyar, K.R. (1998) The influence of the soil matrix on nitrogen mineralization and nitrification. I. Spatial variation and a hierarchy of soil properties. *Australian Journal of Soil Research* **36**, 429-447.
- U.S. Department of Agriculture, NRCS. 2008. The Plants Database (<http://plants.usda.gov>, 15 July 2008). National Plant Data Center, Baton Rouge, LA 70874-4490 USA.
- U.S. Department of Agriculture, Soil Conservation Service (1984). Soil Survey of Lyon County Area, Nevada. U.S. Government Printing, Washington, DC.
- Wang, W.J., Dalal, R.C., Moody, P.W., Smith, C.J. (2003) Relationships of soil respiration to microbial biomass, substrate availability and clay content. *Soil Biology & Biochemistry* **35**, 273-284.

**CHAPTER 3: SHORT-TERM EFFECTS OF SOIL MOISTURE AND  
VEGETATION TYPE ON RATES OF SOIL C RESPIRATION: A FIELD STUDY**

**ABSTRACT**

Alternative crops are being considered to reduce the need for irrigation in the Walker River Basin, a semi-arid region in northwestern Nevada. Limited information, however, exists on the effects of these changes in land use on C and N mineralization. The aim of this study was to explore the effects of moisture, temperature (soil and air), and vegetation type on soil C respiration and net changes in inorganic-N contents in two alternative agricultural fields of the semi-arid region of northwestern Nevada. Four alternative crops were considered for each field: tef, switchgrass, amaranth and alfalfa. One field received three irrigation regimes (50%, 75% and 100% of estimated plant water use) while the other field only received the 50% irrigation treatment. Moisture was the primary driver for CO<sub>2</sub>-C respiration with higher moisture levels resulting in higher CO<sub>2</sub>-C respiration rates. The number of days since last irrigation application appeared to negatively affect the CO<sub>2</sub>-C respiration rates in our soils. Field was the primary driver for inorganic-N fluxes with the Valley Vista field producing net positive changes and the Cottonwood field producing net negative changes over the establishment growing season. Soil temperature was not widely significant for this study but when it was significant it affected the C and N transformations negatively. Texture did not play a significant role in the C and N transformations because of relatively small differences in texture between the two fields. Total above-ground biomass appeared to affect the C respiration rates positively and the net changes in inorganic-N negatively. The effects of vegetation type on the C and N transformations were not consistent over the establishment growing

season. In successive growing seasons, vegetation type and biomass may have more of an effect on the C and N fluxes. Further study is needed to follow the effects of these factors over time and learn how much each is contributing and changing.

## INTRODUCTION

Soil CO<sub>2</sub> efflux, or soil respiration, integrates all components of soil CO<sub>2</sub> production, including respiration of soil organisms and plant roots. Soil respiration represents an important efflux of carbon (C) from terrestrial ecosystems. Three C pools have been recognized as sources of CO<sub>2</sub> efflux from soil and include: (1) the soil organic matter (SOM), (2) above- and belowground dead plant residues, and (3) organic substances released by living roots such as exudates, secretions, and sloughed-off root cells (Kuzyakov, 2006). Typically (1) and (2) are combined and are referred to as heterotrophic respiration while (3) is referred to as autotrophic respiration. Both heterotrophic and autotrophic respirations are dependent on environmental conditions.

SOM, which includes a variety of C compounds originating from plants, microbes, and other organisms, helps to maintain soil fertility and plays a variety of roles in the nutrient, water, and biological cycles. SOM is one of the most important indicators of soil quality (Komatsuzaki and Ohta, 2007; Lemenih et al., 2005) and is critical for its function of supporting crop growth naturally and provides a place for water, air, and biological ecosystems to exist in the soil (Komatsuzaki and Ohta, 2007). The activity of the microbial community in a soil is an indication of the presence of sufficient quantities of organic matter. A soil with higher amounts of microbial activity is considered

healthier and better quality for agricultural purposes (Barrios et al., 2006). Declines in soil organic C (SOC) caused by the cultivation of soils has been observed in many long-term experiments (Grace and Oades, 1994; Golchin et al., 1995). Decreasing SOC causes low soil fertility and reduced cation exchange capacity, resulting in additional fertilizer input requirements to maintain economical yield (Komatsuzaki and Ohta, 2007).

Cultivated soils have been observed to be less capable of restoring organic matter, due to faster decomposition rates of SOC in response to tillage when compared to a forested ecosystem (Komatsuzaki and Ohta, 2007). Long-term studies have consistently shown that these high C losses can be partly mitigated by manuring, adequate fertilization, and crop rotation for maintaining agronomic productivity that increases C inputs into the soil (Duff et al., 1995; Mitchell et al., 1996; Reeves, 1997). Carbon mineralization is affected by many environmental and soil properties including temperature, moisture, available organic matter, soil texture, and microbial community structure among other factors (Cookson et al., 2006; Fierer and Schimel, 2002; Ford et al., 2007; Franzluebbers, 1999; Giardina et al., 2001; Hassink, 1994; Pare and Gregorich, 1999; McLauchlan, 2006).

Tang et al. (2006) report that soil temperature and soil moisture are two of the most important environmental parameters controlling variations in soil CO<sub>2</sub> efflux, however, the relationships between soil respiration and these two parameters vary in different ecosystems. In semi-arid regions, such as the western region of Australia, microbial activity is primarily mediated by moisture availability and not soil temperature (Murphy et al., 1998ab). However, soil temperature can greatly influence microbial activity, and microbial community structure, when moisture is not limiting (Cookson et al., 2006; Cookson et al., 2002; Zogg et al., 1997). Dilustro et al. (2005) reported the

effects of soil temperature, moisture, and texture on soil CO<sub>2</sub> efflux. In their study, the overall pattern of soil CO<sub>2</sub> efflux was related primarily to soil temperature. However, they mention that soil moisture extremes can limit CO<sub>2</sub> efflux as well, where microbial respiration is limited by lack of water when soil moisture is low and by blocked soil pores when soil moisture is high, which limits oxygen and the release of CO<sub>2</sub> (Bouma and Bryla, 2000). Microbial activity generally increases with temperature between 5 and 35°C (Wennman and Kätterer, 2006). Temperatures outside of this range generally result in lower decomposition rates. Because SOM decomposition as well as root respiration depend on temperature and moisture it is not surprising that soil respiration is highly dependent on these factors.

Soil texture can influence soil CO<sub>2</sub> efflux through its effects on soil moisture, temperature, nutrient availability, and soil C residence times (Dilustro et al., 2005). Rates of C mineralization are typically more rapid in soils with lower clay contents whereas higher organic matter contents have been found in clayey soils (Franzluebbers, 1999; Hassink, 1994). However, based on a parallel study conducted within the laboratory, the effects of texture on these soils over the establishment growing season were expected to be weak because of relatively small differences.

Soil respiration can also be strongly correlated with vegetation productivity (leaf production or leaf area index) (Reichstein et al., 2003). Root-derived CO<sub>2</sub>-C does not only vary with plant species but also with plant phenology (Fu et al., 2002). Several studies show that root activity and/or root vitality decrease with plant maturity despite increasing root biomass (Keith et al., 1986; Kuzyakov and Domanski, 2000; Fu et al., 2002; Swinnen et al., 1994). This dependence of root respiration to vegetation stage

explains why rhizosphere respiration has been observed to contribute more to soil respiration in the vegetative and flowering stages than in the grain-filling and maturing stages (Fu et al., 2002). To the best of our knowledge no relationship between plant biomass and root respiration has been established.

The contribution of root respiration to the total soil CO<sub>2</sub> efflux in mixed pine stands was reported to be between 4 and 10% in sandy soils, and between 12.3 and 15% in clayey soils (Dilustro et al., 2005). In croplands, the root contribution to soil respiration was 12-38% (Jia et al., 2006). A review of the literature reported the average contribution of root respiration to total soil CO<sub>2</sub> efflux to be 48.6% for forested systems, with observations ranging from < 10 to > 90% (Hanson et al., 2000). It is difficult to measure root respiration in situ because of variable environmental conditions as well as difficulties distinguishing root from microbial respiration. Environmental conditions that limit or accelerate the diffusion of CO<sub>2</sub> from soils or the surface boundary layer can create non-equilibrium total soil CO<sub>2</sub> efflux rates that differ from soil CO<sub>2</sub> production rates (Hanson et al., 2000). This means that the total CO<sub>2</sub> coming out of the soil may not be a direct product of root or microbial respiration but may contain some CO<sub>2</sub> that was trapped in the soil and was released due to the environmental conditions.

The structure and functional diversity of microbial communities in the soil is tightly related to plant species composition above-ground, which provides an important link between above- and belowground processes (Kourtev et al., 2003). The input of C through primary productivity has been indicated to be driving soil respiration to a large extent (Högberg et al., 2001). Previous studies have shown clearly that structurally and functionally distinct microbial communities develop under different plant species

(Degens and Harris, 1997; Bossio et al., 1998; Marilley and Aragno, 1999). A more recent study has even shown that plant species can significantly alter soil microbial communities within three months (Kourtev et al., 2003). In that case, both community structure and function were affected which affected the N concentrations, pH, and N mineralization in the soil.

The effect of vegetation type on soil quality is of particular interest in the semi-arid region of northwestern Nevada. Agricultural fields in northern Nevada provide a unique opportunity to study the effects vegetation, moisture, and soil temperature under semi-arid conditions. As water is typically limited in these regions, crops often experience periods of stress between irrigation applications. In this study, two alternative agricultural fields in the Mason Valley of the Walker River Basin of northwestern Nevada were used to primarily explore the effects of moisture, temperature (soil and air), and vegetation on soil C respiration during the initial establishment growing season. Net changes in inorganic nitrogen (N), and total C and N contents were also measured to provide a secondary index of soil productivity.

We tested three hypotheses relevant to the role of moisture, temperature, and vegetation on soil C respiration as well as net changes in soil inorganic N concentrations.

H1: The soils with higher moisture contents will exhibit higher C respiration rates and net changes in N contents

H2: Temperature will affect the soil C respiration depending on the soil moisture condition



H3: The soil with the most biomass will exhibit higher C respiration rates and net changes of inorganic N because of higher inputs of C and N into the soil through the roots

## METHODS AND MATERIALS

### *Field Sites*

The two field sites were located near Yerington, NV (Figures 3.1 and 3.2). The Valley Vista (VV) site (*Lat: 38° 51' 00.45" N Long: 119° 10' 59.20" W*) was located approximately 13 km south of Yerington, NV (Figure 3.2). This site had been used for alfalfa production when the vegetation was removed prior to ripping and disking of the fields. The majority of the soils belong to the Malpais complex soils (60%), which are found on alluvial fans and colluvial slopes bordering mountains, while other soils belong to the Tocan sandy loam 2-4% slopes (20%), and Tocan sandy loam 0-2% slopes (20%) which are commonly found on fan remnants and beach terraces (USDA, 1984). The Cottonwood Ranch (5C) site (*Lat: 38° 50' 50.33" N Long: 119° 11' 00.57" W*) was located approximately 150 m south of the Valley Vista (Figure 3.2). This site had not been in production for several years and was used primarily as grazing land for burros and llamas. This site consists of 100% Malpais complex 2-15% slopes soils, having a sandy texture (USDA, 1984). Soils here were highly compacted and void of vegetation prior to ripping and disking. All sites were equipped with sprinkler irrigation systems. Each field was separated into an area designated for alternative crops while another area was used for revegetation trials with native plant species. For this study, only the alternative crop fields were examined from the two sites.

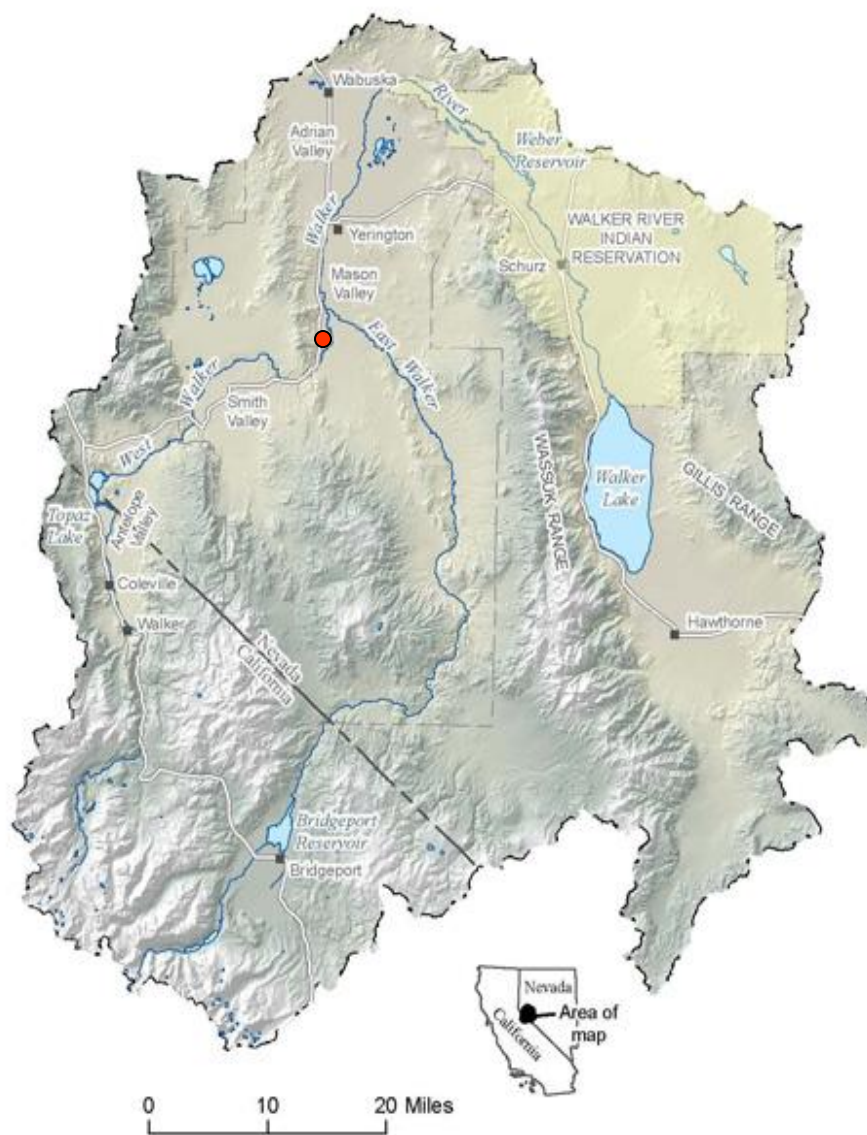


Figure 3.1: Map of the Walker River Basin. The red dot indicates the general location of the two sites used for this study. Courtesy of the USGS.

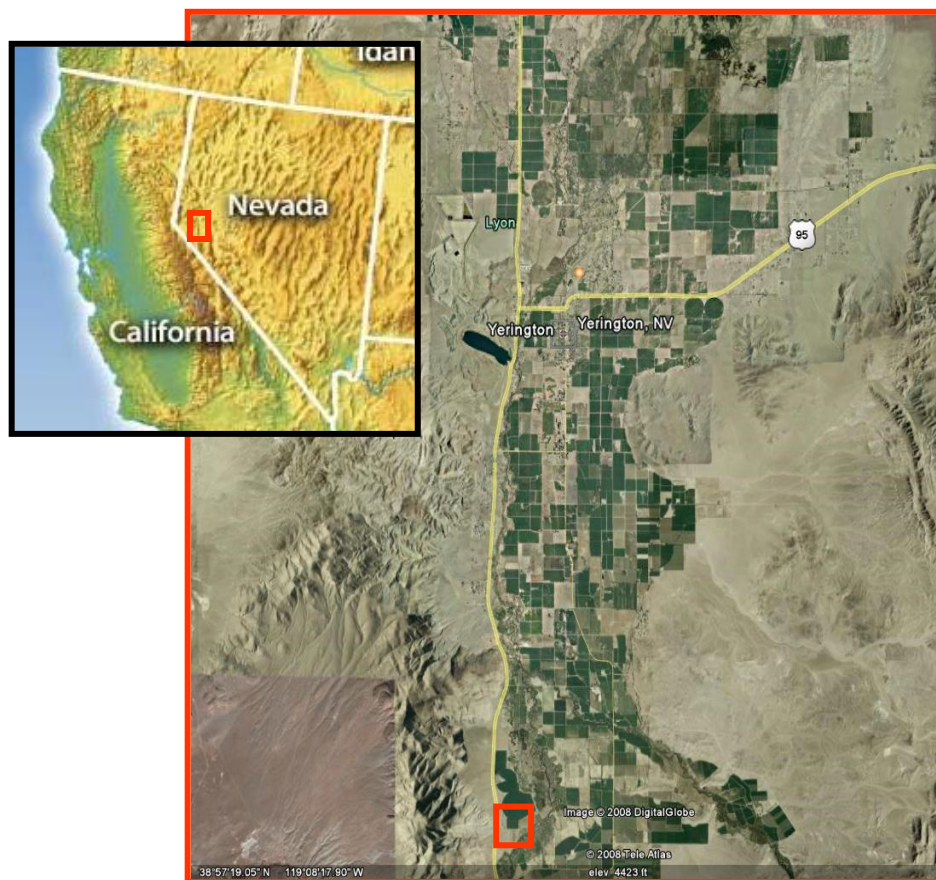


Figure 3.2: Map showing locations of field sites. Red square indicates Valley Vista and Cottonwood Ranch sites. Inset map shows area location. Courtesy of Google Earth

The alternative crop fields consisted of fifteen vegetation types (Table 3.1) in 135 24' x 30' plots where one of each vegetation type plot is randomly located in each of the nine rows (Figure 3.3). For our study we focused on four crops: Tef (*Erograstis tef*), Amaranth (*Amaranthus cruentus*), Alfalfa (*Medicago sativa*) and Switchgrass (*Panicum virgatum*). Tef, amaranth, and switchgrass were chosen to represent the different types of crop planted (grass versus grain) while alfalfa is a crop currently grown in many parts of western Nevada. Tef is a summer cereal crop commonly grown in Ethiopia that is well adapted to arid conditions (USDA, NRCS, 2008). Excess water and fertilizer have actually been shown to decrease grain quality and not increase yield (Norberg et al.,

2005). Tef is very nutritious and can be used for either human consumption or as cattle feed. Amaranth has historically been used as an American Indian food source and is well adapted to drought conditions as well as requiring little to no fertilizer (USDA, NRCS, 2008). Amaranth can also be used either for human consumption or as cattle feed. Despite its potential use and adaptation to arid conditions, a major downside for Amaranth production today is the lack of approved herbicides for use (USDA, NRCS, 2008). Alfalfa is a N fixer and a perennial forage crop typically produced in regions characterized by hot dry summers and cold winters such as Nevada. Switchgrass is a warm-season, perennial sod-forming grass native to the United States. It is tolerant of moderately saline or acidic soils and can be farmed in a similar manner as traditional forage (USDA, NRCS, 2008).

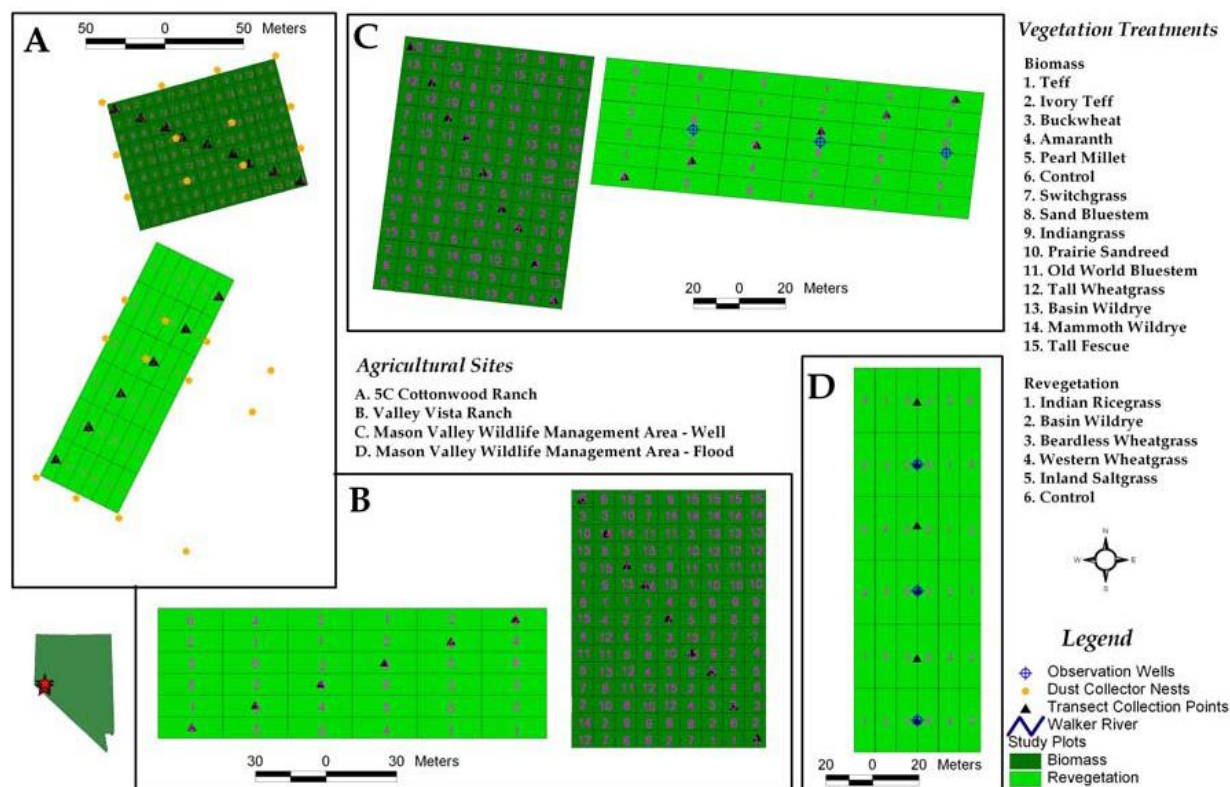


Figure 3.3: Layout and orientation of the agricultural fields (A & B). The alternative field is shown in the darker green within each box. Courtesy of Erin Carroll-Moore.

Table 3.1: Species of vegetation planted in alternative fields. \* indicates species used in this study.

|           |   |
|-----------|---|
| <b>*1</b> | <b>Dessie Tef (<i>Erograstis tef</i>)</b>                   |
| <b>2</b>  | <b>White seed Tef (<i>Erograstis tef</i>)</b>               |
| <b>3</b>  | <b>Buckwheat (<i>Fagopyrum esculentum</i> Moench)</b>       |
| <b>*4</b> | <b>Amaranth (<i>Amaranth cruentus</i>)</b>                  |
| <b>5</b>  | <b>Pearl millet (<i>Pennisetum glaucum</i> (L) R.BR.)</b>   |
| <b>*6</b> | <b>Alfalfa (<i>Medicago sativa</i>)</b>                     |
| <b>*7</b> | <b>Switchgrass (<i>Panicum virgatum</i>)</b>                |
| <b>8</b>  | <b>Sand bluestem (<i>Andropogon hallii</i>)</b>             |
| <b>9</b>  | <b>Indiangrass (<i>Sorghastrum nutans</i>)</b>              |
| <b>10</b> | <b>Prairie Sandreed (<i>Calamovilfa longifolia</i>)</b>     |
| <b>11</b> | <b>Bluestem (old world) (<i>Bothriochloa ischaemum</i>)</b> |
| <b>12</b> | <b>Tall wheatgrass (<i>Elytrigia elongate</i>)</b>          |
| <b>13</b> | <b>Basin wildrye (<i>Leymus cinereus</i>)</b>               |
| <b>14</b> | <b>Mammoth wildrye (<i>Leymus racemosus</i>)</b>            |
| <b>15</b> | <b>Tall Fescue (<i>Festuca arundinacea</i>)</b>             |

### *Irrigation regime*

Original plans called for the nine rows in each field to be divided into three groups of three rows each receiving 50%, 75%, and 100% of estimated vegetation water requirement respectively. However, due to a water shortage, only the Valley Vista field received the three irrigation treatments while all plots in the Cottonwood field received

the same amount of irrigation (50%). Irrigation amounts in the Valley Vista field totaled 11.67 million liters (includes all three irrigation treatments) while the Cottonwood field received 6.88 million liters of water.

#### *Field measurements*

Between June 6<sup>th</sup> and August 28<sup>th</sup>, 2008, seven trips were made to the Valley Vista and Cottonwood Ranch sites to conduct soil CO<sub>2</sub> efflux measurements. During each trip, soil CO<sub>2</sub> respiration and soil moisture were measured in 72 plots (4 vegetation types x 9 rows x 2 fields) with the exception of one day (June 11<sup>th</sup>) where only proposed 100% irrigation regime plots were measured. Soil CO<sub>2</sub> respiration measurements were collected with a static chamber (0.48 L) equipped with a Vaisala GMT CO<sub>2</sub> analyzer. The static chamber was placed on a 15.24 cm diameter PVC ring, which was installed in each plot prior to the emergence of the crops. Soil respiration rates were calculated based on the rate of increase in CO<sub>2</sub> concentrations inside the chamber. Each measurement lasted approximately one minute. All measurements were taken between 10:30 AM and 3:30 PM to limit changes in ambient temperature. Soil moisture was measured with a Delta-T HH1 Theta Meter equipped with a ML2 Theta Probe for the first four trips and a Decagon ECH2O-5TE moisture and temperature probe for the last three sampling dates. On the last three sampling dates, soil temperature was also measured in each plot with the Decagon probe. Air temperature and relative humidity data were collected between June 6<sup>th</sup> and August 12<sup>th</sup> by a HOBO H8 Pro Temp/RH sensor (Onset Computer Corporation, Bourne MA) only in the Valley Vista field.

Vegetation samples were taken on August 20 and 21, 2008, to assess the total biomass and C and N content of vegetation in each plot at the end of the establishment

growing season. Aboveground vegetation was cut inside a 1.36 m diameter circle surrounding the soil respiration PVC rings. Biomass was separated into crops and weeds. All samples were dried at 70°C until constant weight. Biomass samples were ground and analyzed for total C and N content.

Soil core samples were taken from the two fields in late June to early July (pre-planting) and on August 28, 2008 (post-planting), using a bucket auger to a depth of 10 cm. The pre-planting soils samples were taken from five random plots in each of the fields. The post-planting samples were taken from the vegetation-specific plots in each field (72 total). All soil samples were air dried and sieved using a two-millimeter mesh sieve. Soil  $\text{NH}_4^+$  and  $\text{NO}_3^-$  concentrations were measured following KCl extractions using a SampleTek Vacuum auto-extractor. Five grams of soil was placed into a 50 mL filtered plastic syringe to which 50mL of a 2 M KCl solution was added and allowed to soak into the soil for 30 minutes. After 30 minutes the soils were extracted over a 30 minute time period. Once the extractions were completed the extract was injected into a 20 mL vial and frozen until analyzed. The extracts were analyzed for  $\text{NH}_4^+$  and  $\text{NO}_3^-$  using a Lachat Quickchem autoanalyzer at the Desert Research Institute of Reno. Soil and vegetation samples were analyzed for total C and N at the Soil Water and Forage Analytical Laboratory at Oklahoma State University using a Leco CHN analyzer. Bulk density cores were taken on October 23, 2008, using a 5.4 cm diameter, 3 cm tall ring. Particle size analysis of the soils was conducted with a Micrometrics Saturn DigiSizer 5200 Laser Particle Size Analyzer in the Soil Characterization Laboratory at the Desert Research Institute of Reno.

### *Statistical methods*

Effects of irrigation regime, vegetation type, field, and date on C respiration rate ( $\mu\text{molCO}_2 \text{ m}^{-2} \text{ s}^{-1}$ ), net change in total inorganic-N,  $\text{NO}_3^-$ , and  $\text{NH}_4^+$  ( $\text{mgN kg}^{-1}$ ) were explored using a Multi-way Analysis of Variance (MANOVA) with all interactions. Results were considered significant if  $p < 0.05$ . Two-sample t-tests assuming unequal variances were also run to determine differences among vegetation pairs and between the two fields. Results were considered different if  $p$  (two-tail)  $< 0.05$ . The effects of moisture, texture, above-ground vegetation biomass (crops and weeds), total N, total C, fifteen minute air and soil temperature ( $^{\circ}\text{C}$ ), and relative humidity on C respiration rate, net change in total inorganic-N,  $\text{NO}_3^-$ , and  $\text{NH}_4^+$  content were determined using linear multiple regression. Factors used in the multiple regression that were only measured at the end of the growing season (e.g. percent total N and percent total C in soil and biomass, and net change in inorganic-N) were coupled with C respiration rates that were also only measured at the end of the growing season. Both MANOVA and multiple regression analyses were carried out using DataDesk® version 6.1.

## RESULTS

### *Soil characteristics*

The Valley Vista soils had significantly higher percent clay and silt and significantly lower percent sand than the Cottonwood soils (Table 3.2). The only significant difference among vegetation types occurred in the Cottonwood field, where the alfalfa soils (3.51%) had statistically higher percent clay content than the amaranth soils (3.03%).



Table 3.2: Pre-and post-planting soil characteristics

|                               |               | Valley Vista | Cottonwood  |
|-------------------------------|---------------|--------------|-------------|
| Clay (%)                      | Pre-Planting  | 3.86 ± 0.60  | 3.44 ± 0.16 |
|                               | Post-Planting | 3.85 ± 0.08  | 3.26 ± 0.07 |
| Silt (%)                      | Pre-Planting  | 20.4 ± 1.40  | 16.9 ± 0.71 |
|                               | Post-Planting | 20.7 ± 0.47  | 17.4 ± 0.28 |
| Sand (%)                      | Pre-Planting  | 75.7 ± 1.95  | 79.7 ± 0.55 |
|                               | Post-Planting | 75.4 ± 0.53  | 79.3 ± 0.32 |
| Total C (g kg <sup>-1</sup> ) | Pre-Planting  | 6.94 ± 0.86  | 4.64 ± 0.56 |
|                               | Post-Planting | 5.54 ± 0.24  | 5.27 ± 0.34 |
| Total N (g kg <sup>-1</sup> ) | Pre-Planting  | 0.70 ± 0.08  | 0.50 ± 0.05 |
|                               | Post-Planting | 0.68 ± 0.03  | 0.69 ± 0.03 |
| C/N                           | Pre-Planting  | 10.0 ± 0.49  | 9.21 ± 0.42 |
|                               | Post-Planting | 8.17 ± 0.17  | 7.51 ± 0.21 |

As discussed in the methods section, initial soil total C and N concentrations were measured in different plots than those used for the respiration measurements since at the time of sampling vegetation type had not been assigned to the various plots. Total C and N content were similar between the Valley Vista and Cottonwood soils prior to planting and at the end of the first growing season (Table 3.2). Total C and N were similar for all vegetation types at the end of the growing season at the Valley Vista site. Overall, total N content in the Cottonwood soil significantly increased over the growing season. In the Cottonwood field, there were no significant differences in total C between vegetation types but amaranth and switchgrass showed significant increases in total N over the growing season. Pre-planting C/N ratios were the same in both fields (Table 3.2). The post-planting C/N ratio, however, was higher in the Valley Vista than Cottonwood soils.

Both fields experienced a significant decrease in C/N ratio over the establishment growing season except for the Cottonwood amaranth plots.

*Moisture*

Soil moisture was typically higher in the Valley Vista 100% and 75% irrigation treatments than the 50% irrigation treatments in the Valley Vista and Cottonwood fields after approximately mid-July (Figure 3.3).

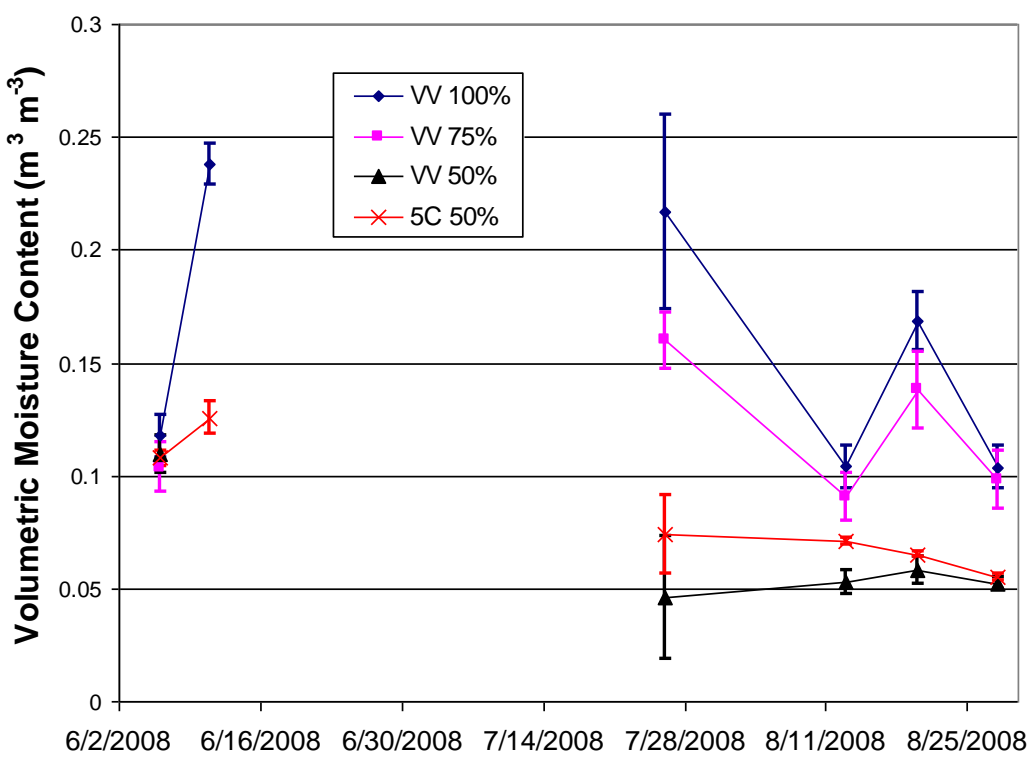


Figure 3.3: Volumetric moisture content by irrigation treatment over the growing season at the Valley Vista (VV) and Cottonwood (5C) sites.

Soil moisture was typically at its highest content on June 11<sup>th</sup> in both fields (Figure 3.4).

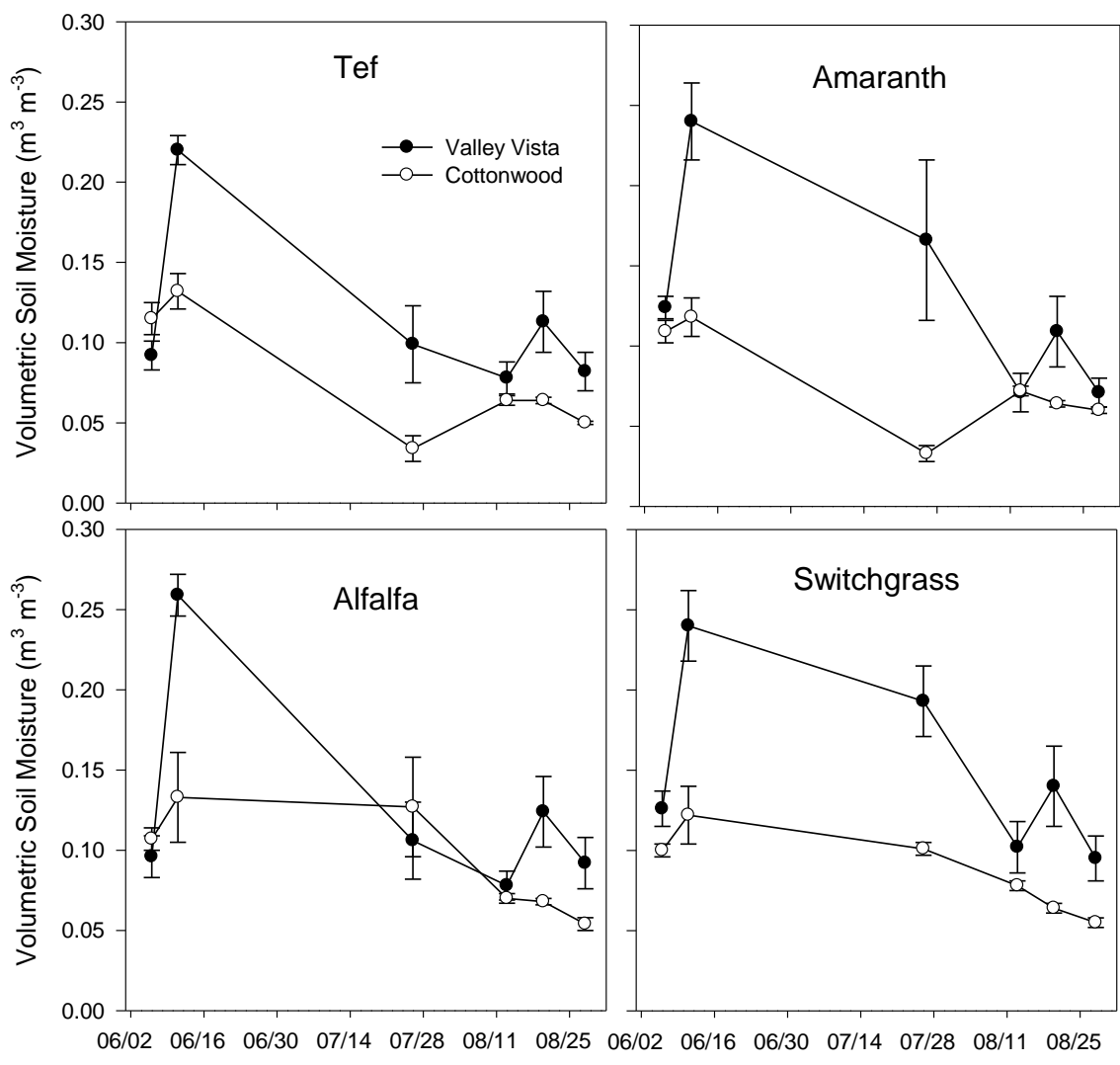


Figure 3.4: Average soil moisture contents over the 2008 growing season at the Valley Vista and Cottonwood sites for the four vegetation types. Error bars represent standard error (n = 3 to 9).

Over the growing season the Valley Vista 100% irrigation treatment showed the highest moisture content ( $0.150 \pm 0.008 \text{ m}^3 \text{ m}^{-3}$ ) followed by the Valley Vista 75% ( $0.112 \pm 0.007 \text{ m}^3 \text{ m}^{-3}$ ), Cottonwood 50% ( $0.108 \pm 0.004 \text{ m}^3 \text{ m}^{-3}$ ), and Valley Vista 50% ( $0.067 \pm 0.005 \text{ m}^3 \text{ m}^{-3}$ ) irrigation treatments (Figure 3.5).

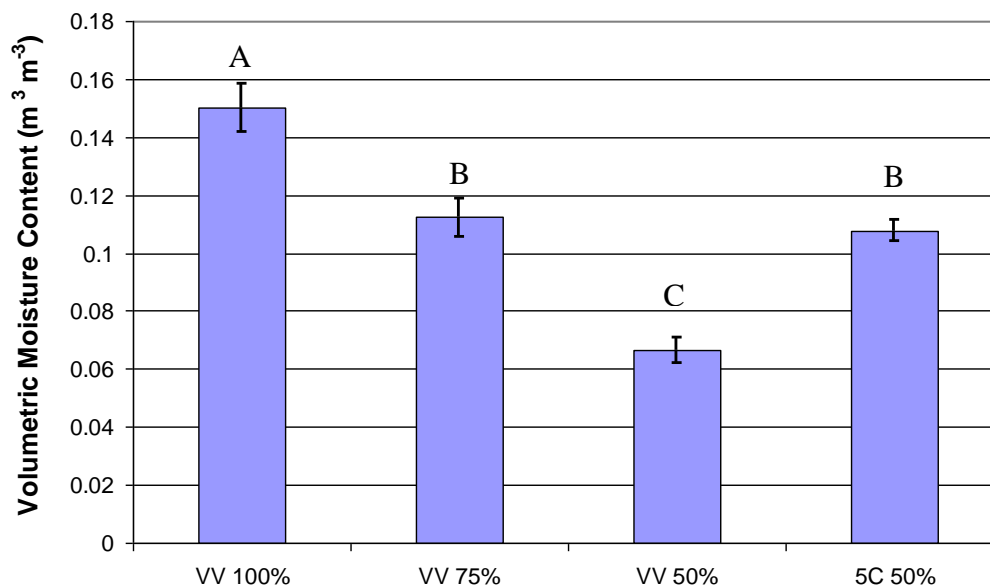


Figure 3.5: Overall average volumetric moisture contents over the growing season by irrigation treatment at the Valley Vista (VV) and Cottonwood (5C) sites. Letters represent significant differences between irrigation treatments.

Overall, soil moisture varied more by date and field than by vegetation. However, the Valley Vista switchgrass ( $0.130 \pm 0.010 \text{ m}^3 \text{ m}^{-3}$ ) had a significantly higher average moisture content over the growing season than the Valley Vista tef ( $0.101 \pm 0.008 \text{ m}^3 \text{ m}^{-3}$ ; Figure 3.6). There were no significant differences in the Cottonwood field. Switchgrass soils ( $0.105 \pm 0.006 \text{ m}^3 \text{ m}^{-3}$ ) showed significantly higher overall moisture content over the growing season than the tef soils ( $0.088 \pm 0.005 \text{ m}^3 \text{ m}^{-3}$ ) when both fields were combined.

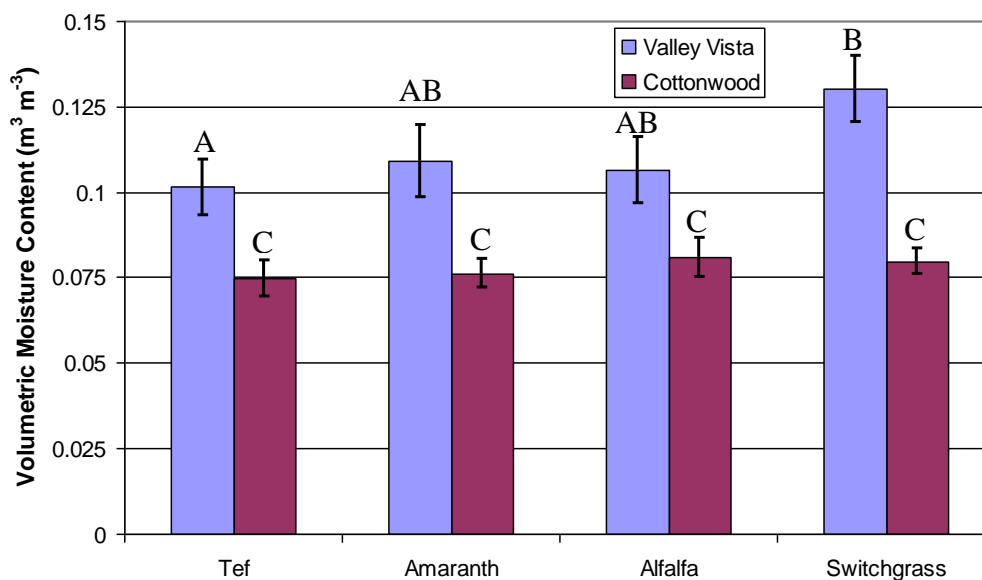


Figure 3.6: Overall average moisture contents ( $\text{m}^3 \text{m}^{-3}$ ) over the growing season. Error bars represent standard error ( $n = 39$  to  $42$ ). Letters represent significant differences between vegetation types.

### *Temperature and Relative Humidity*

The average fifteen minute air temperature measured using the HOBO sensor at the Valley Vista site from June 6<sup>th</sup>, 2008 to August 12<sup>th</sup>, 2008 was 22.4°C. The maximum temperature during this time period was 38.0°C and the minimum was -0.6°C. The average fifteen minute soil temperature, measured at a depth of 10 cm, at the Valley Vista site from the same time period was 30.3°C. The maximum soil temperature during this time period was 40.4°C and the minimum was 16.1°C. The average relative humidity during this time period was 31.0% with a maximum of 87.7% and a minimum of 4.5%. Figure 3.7 shows the daily average air and soil temperature (°C) and percent relative humidity. The average soil temperature measured between 10:30 AM and 3:30 PM, at a depth of approximately 5cm on August 13<sup>th</sup>, August 21<sup>st</sup>, and August 28<sup>th</sup>, 2008, was 36.6°C in the Valley Vista field and 40.1°C in the Cottonwood field as measured using the Decagon probe. The maximum soil temperature was 46.0°C in the Valley Vista field

and 49.4°C in the Cottonwood field during this time period. The minimum soil temperature was 24.8°C in the Valley Vista field and 26.8°C in the Cottonwood field.

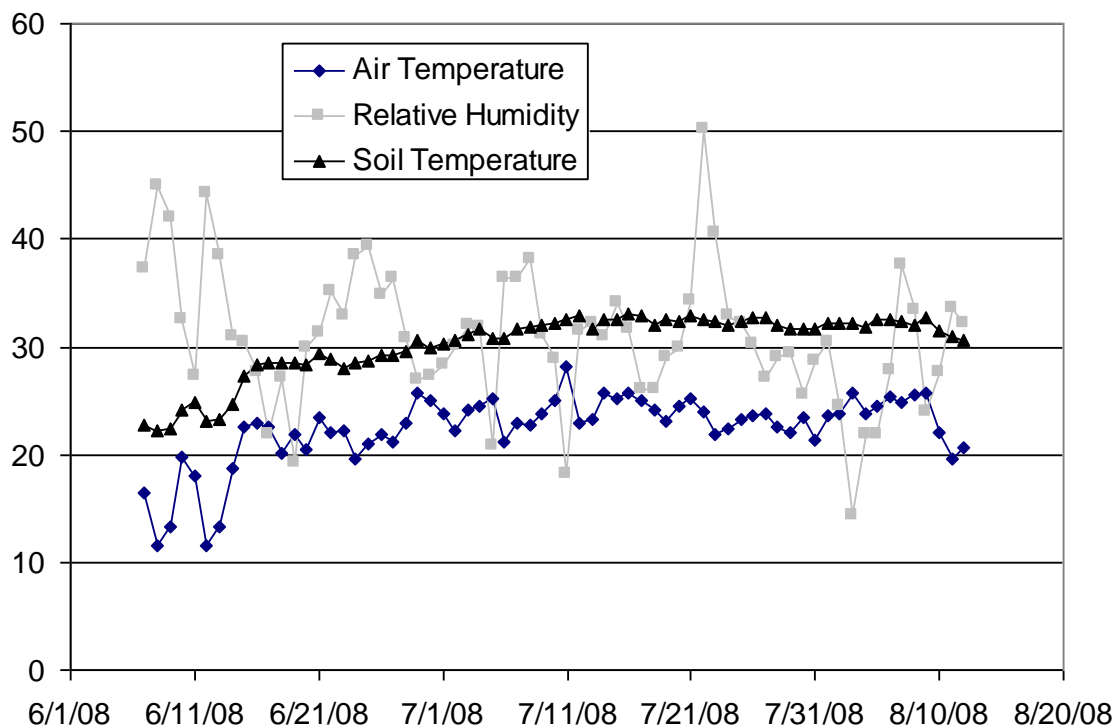


Figure 3.7 Average daily temperature (°C) and relative humidity (%) values measured with the HOBO sensor.

### *C Fluxes*

#### *C Respiration rate*

The MANOVA analysis (Table 3.3) showed that soil respiration varied by irrigation treatment, date, and vegetation type. Soil respiration rates were higher in the Valley Vista 100% and 75% irrigation treatments than the 50% irrigation treatment in the Valley Vista and Cottonwood fields after approximately mid-July (Figure 3.8) as evidenced by the significant irrigation\*date interaction.

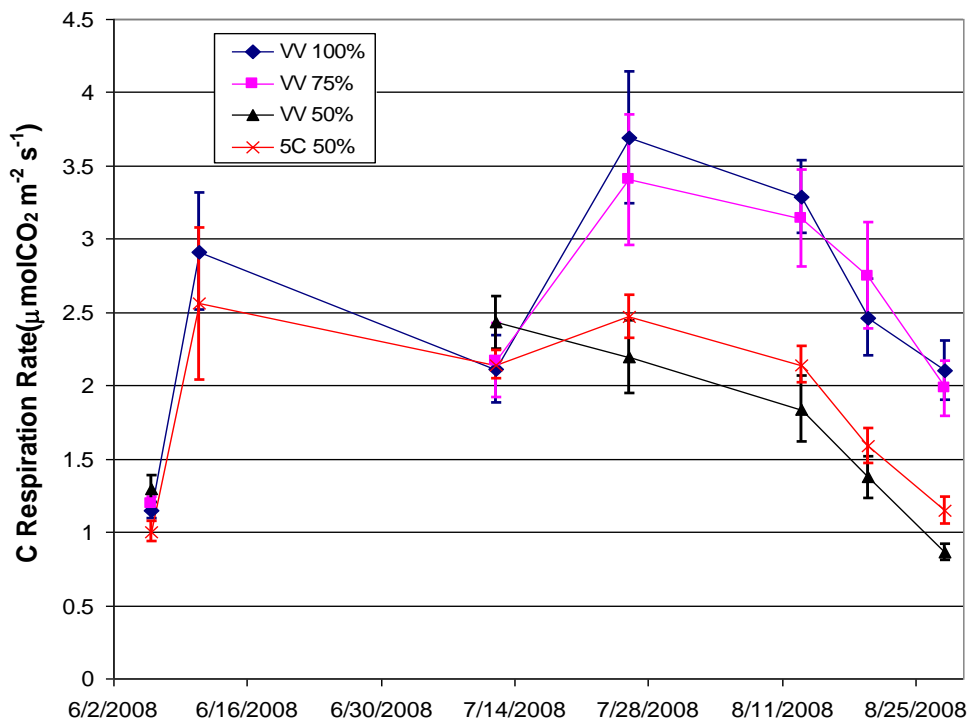


Figure 3.8: CO<sub>2</sub>-C respiration rate by irrigation treatment over the growing season at the Valley Vista (VV) and Cottonwood (5C) sites.

Respiration rates during the second through the fifth trips were significantly higher than during the other three trips when combining the irrigation treatments. Soil respiration was highest on June 11<sup>th</sup>, but this average was not significantly different than July 12<sup>th</sup>, July 26<sup>th</sup>, or August 13<sup>th</sup> (Fig. 3.8). Respiration rates were lowest during the first and last trip. All soils in the Valley Vista field experienced their lowest observed C respiration rate at the beginning of the growing season (June 6, 2008).

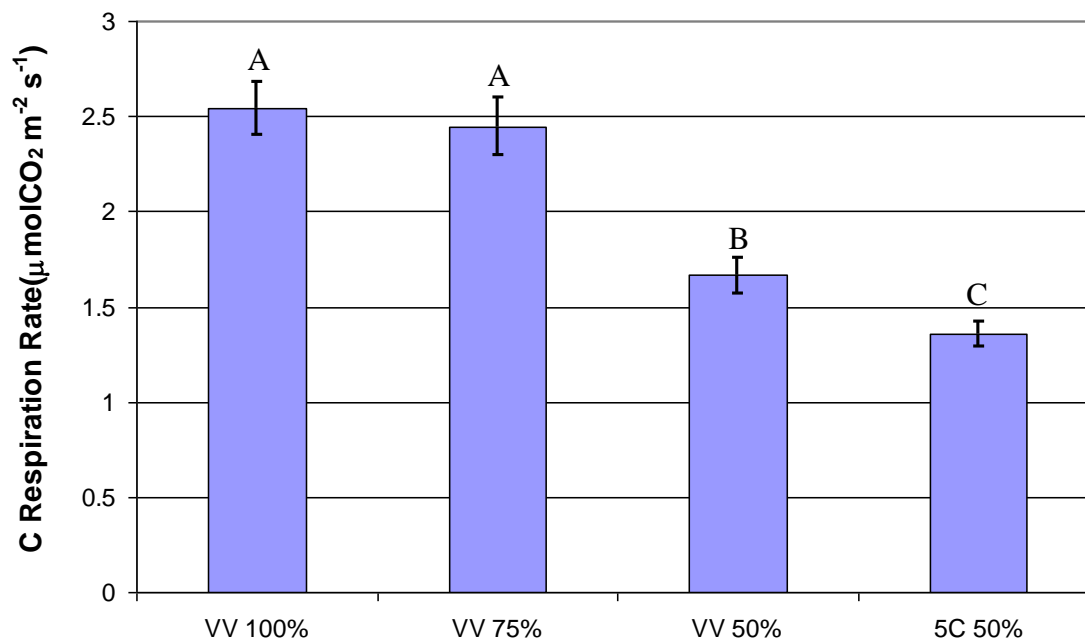


Figure 3.9: Overall average  $\text{CO}_2$ -C respiration rate by irrigation treatment over the growing season at the Valley Vista (VV) and Cottonwood (5C) sites. Letters represent significant differences between irrigation treatments.

The MANOVA results also showed that the vegetation\*date interactions was significant, indicating that effects of vegetation on C respiration varied by measurement date. Tef experienced its peak on June 11<sup>th</sup>, amaranth and alfalfa on July 26<sup>th</sup>, and switchgrass on August 20<sup>th</sup> (Fig. 3.10). In general, in the Cottonwood field, the low respiration rate occurred either on the first or last trip and the peak respiration rate occurred on the third trip.



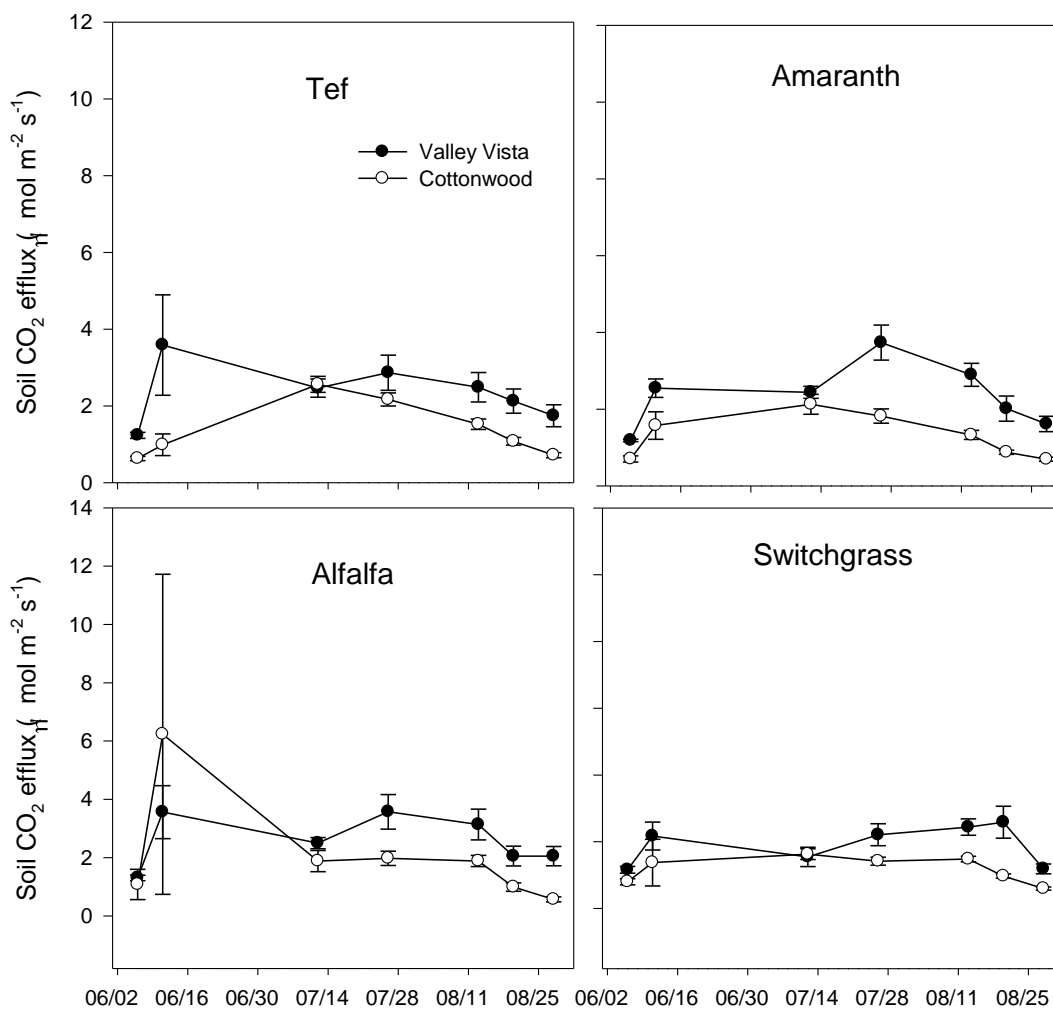


Figure 3.10: Average soil CO<sub>2</sub> efflux rates for the four vegetation types at the Valley Vista and Cottonwood fields. Error bars represent standard errors (n = 9).

Overall, alfalfa had the highest season-averaged respiration rate ( $2.05 \pm 0.15$   $\mu\text{molCO}_2 \text{ m}^{-2} \text{ s}^{-1}$ ) and switchgrass the lowest ( $1.52 \pm 0.08$   $\mu\text{molCO}_2 \text{ m}^{-2} \text{ s}^{-1}$ ) over the establishment growing season (Figure 3.11).

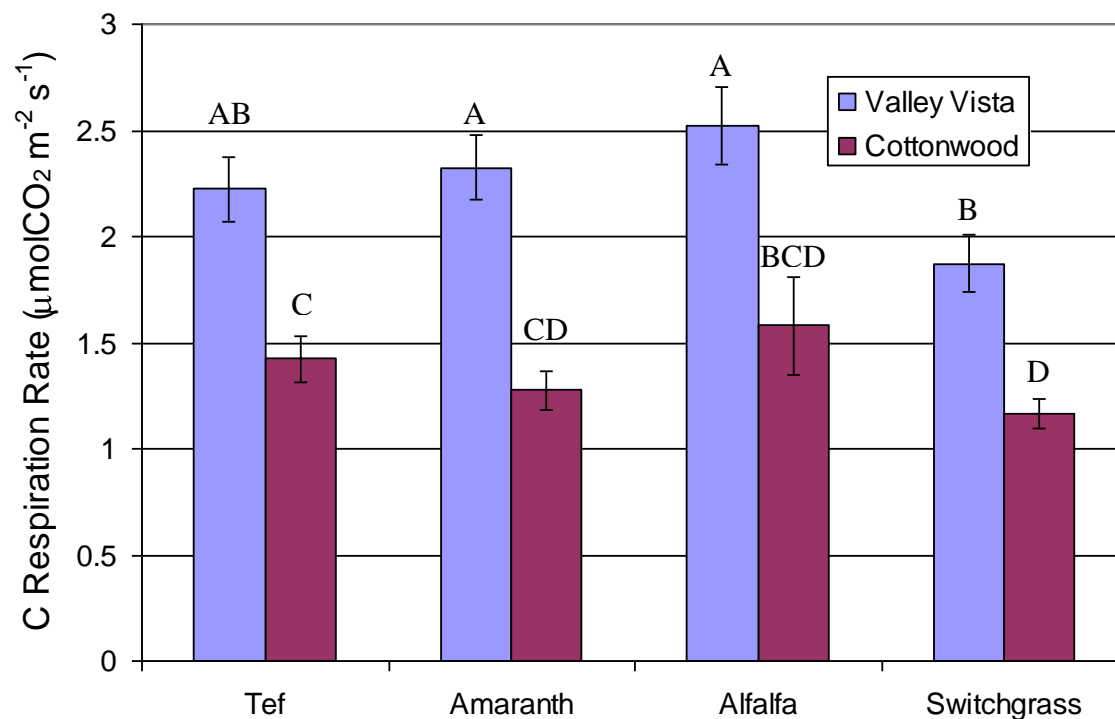


Figure 3.11: Overall average C respiration rate over the establishment growing season. Error bars represent standard error (n = 54 to 57). Letters represent significant differences between vegetation types in either field.

Table 3.3: MANOVA results from main factors

| Factor           | C Respiration Rate | Net Total Inorg-N | Net Nitrate N | Net Ammonium N |
|------------------|--------------------|-------------------|---------------|----------------|
| Vegetation (VT)  | ***                | ns                | ns            | ns             |
| Field (Fld)      | ns                 | ****              | ****          | ns             |
| Date (Dat)       | ****               | na                | na            | na             |
| Irrigation (Irr) | ***                | ns                | ns            | ns             |
| VT*Fld           | ns                 | *                 | *             | ns             |
| VT*Dat           | **                 | na                | na            | na             |
| VT*Irr           | ns                 | ns                | ns            | ns             |
| Fld*Dat          | ns                 | na                | na            | na             |
| Fld*Irr          | ns                 | ns                | ns            | ns             |
| Dat*Irr          | ****               | na                | na            | na             |
| VT*Fld*Dat       | ns                 | na                | na            | na             |
| VT*Fld*Irr       | ns                 | ns                | ns            | ns             |
| VT*Dat*Irr       | ns                 | na                | na            | na             |
| Fld*Dat*Irr      | ns                 | na                | na            | na             |
| VT*Fld*Dat*Irr   | ns                 | na                | na            | na             |

\*\*\*\* =  $p < 0.0001$ ; \*\*\* =  $p < 0.001$ ; \*\* =  $p < 0.01$ ; \* =  $p < 0.05$ ; ns = not significant; na = not applicable (e.g. no date factor for N fluxes because these were only measured at the end of the growing season)

## N Fluxes

### Net total extractable N

The MANOVA results (Table 3.3) show that only field and the vegetation\*field interaction were significant factors affecting the net total extractable N concentrations. The Valley Vista 50% irrigation treatment showed a net increase in extractable N concentration while the Cottonwood 50% irrigation treatment showed a net decrease (Figure 3.12). Overall, at the Valley Vista site, the soils showed an average net increase in total extractable N of  $4.16 \pm 1.09 \text{ mgN kg}^{-1}$ .

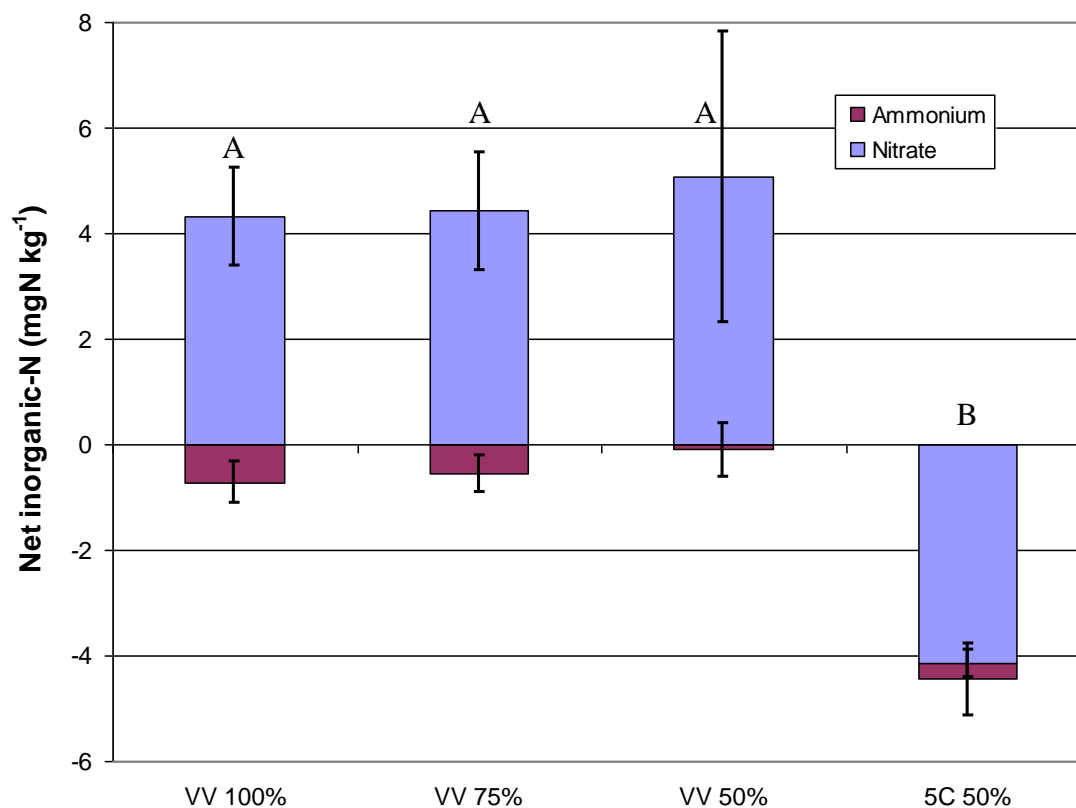


Figure 3.12: Net change in total extractable inorganic-N concentration by irrigation treatment at the Valley Vista (VV) and Cottonwood (5C) sites. Letters represent significant differences between irrigation treatments.

Among the Valley Vista soils, the change in inorganic N was significantly higher in alfalfa ( $7.12 \text{ mgN kg}^{-1}$ ) than amaranth ( $0.92 \text{ mgN kg}^{-1}$ ; Figure 3.13). In the Cottonwood field, the soils showed an overall decrease in total extractable N of  $-4.44 \pm 0.85 \text{ mgN kg}^{-1}$ . Among the Cottonwood soils, there were no significant differences between the various vegetation types. Net change in total inorganic-N was not affected by vegetation but in both fields amaranth showed a different behavior from the other vegetation types. Amaranth had no significant net change in total inorganic-N while the other vegetation types generally either had a net increase or decrease in total inorganic-N over the growing season.

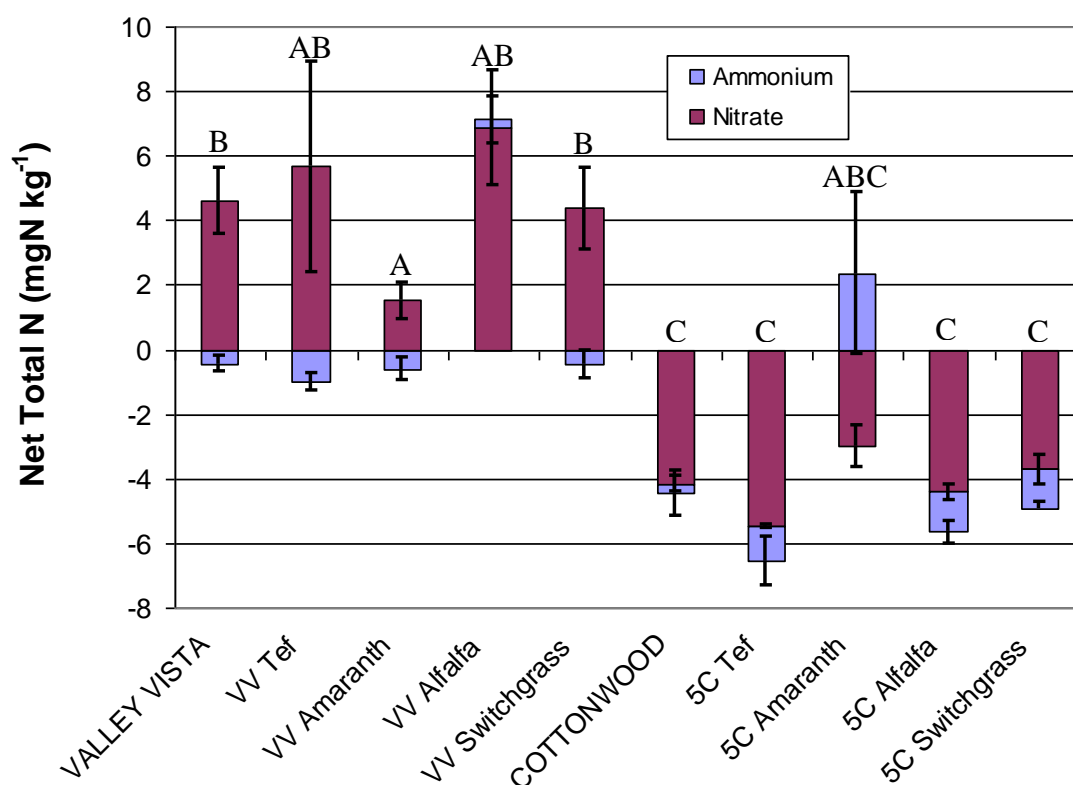


Figure 3.13: Net total extractable N (nitrate + ammonium) following the establishment growing season at the Valley Vista (VV) and Cottonwood (5C) sites. Error bars represent standard error (n = 9). Letters represent significant differences between fields and vegetation types.

*Net nitrate and ammonium*

The MANOVA analysis (Table 3.3) revealed that only field and the vegetation\*field interaction significantly affected the net nitrate-N concentrations. The patterns in the net change in nitrate-N concentrations were very similar to those of the net change in total extractable N. The 50% irrigation treatment in the Valley Vista soils showed in a net increase in nitrate-N concentration ( $5.08 \pm 2.75 \text{ mgN kg}^{-1}$ ) but a net decrease in the Cottonwood soils ( $-4.15 \pm 0.26 \text{ mgN kg}^{-1}$ ; Figure 3.14). The Valley Vista soils, overall, showed an average increase in net nitrate-N content of  $4.61 \pm 1.01 \text{ mgN kg}^{-1}$  (Figure 3.15). The amaranth soils showed the smallest net increase in the Valley Vista field ( $1.51 \pm 0.56 \text{ mgN kg}^{-1}$ ) and the smallest net decrease in the Cottonwood field ( $-2.98 \pm 0.67 \text{ mgN kg}^{-1}$ ).

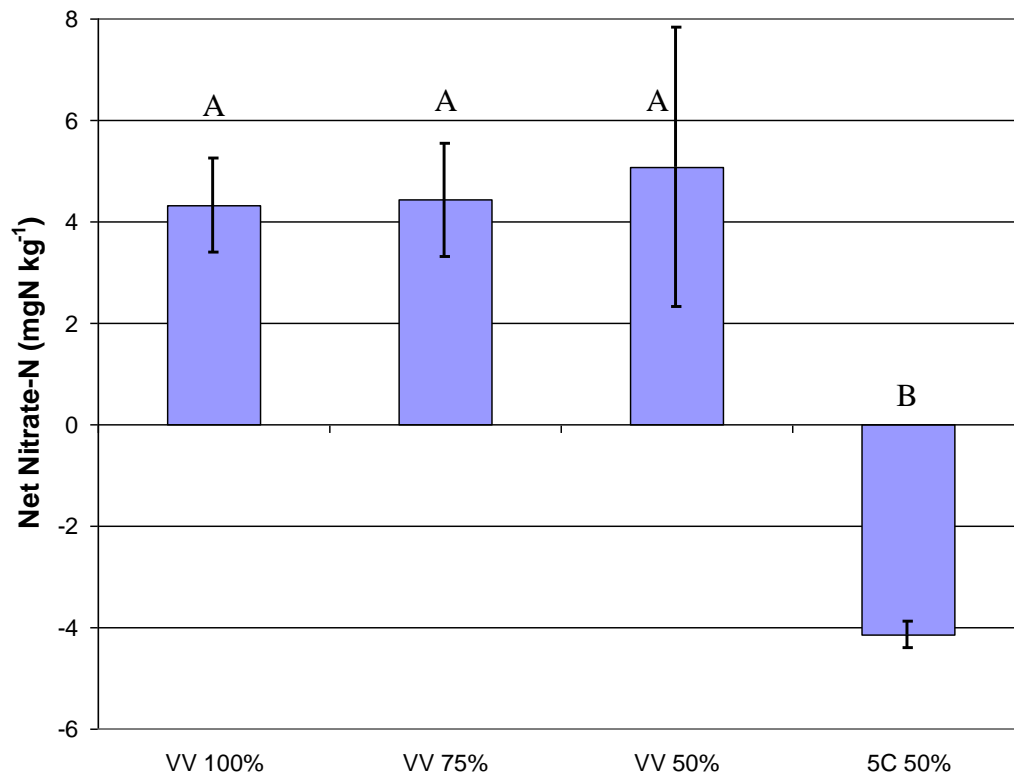


Figure 3.14: Net change in nitrate-N concentrations over the growing season by irrigation treatment at the Valley Vista (VV) and Cottonwood (5C) sites. Letters represent significant differences between irrigation treatments.

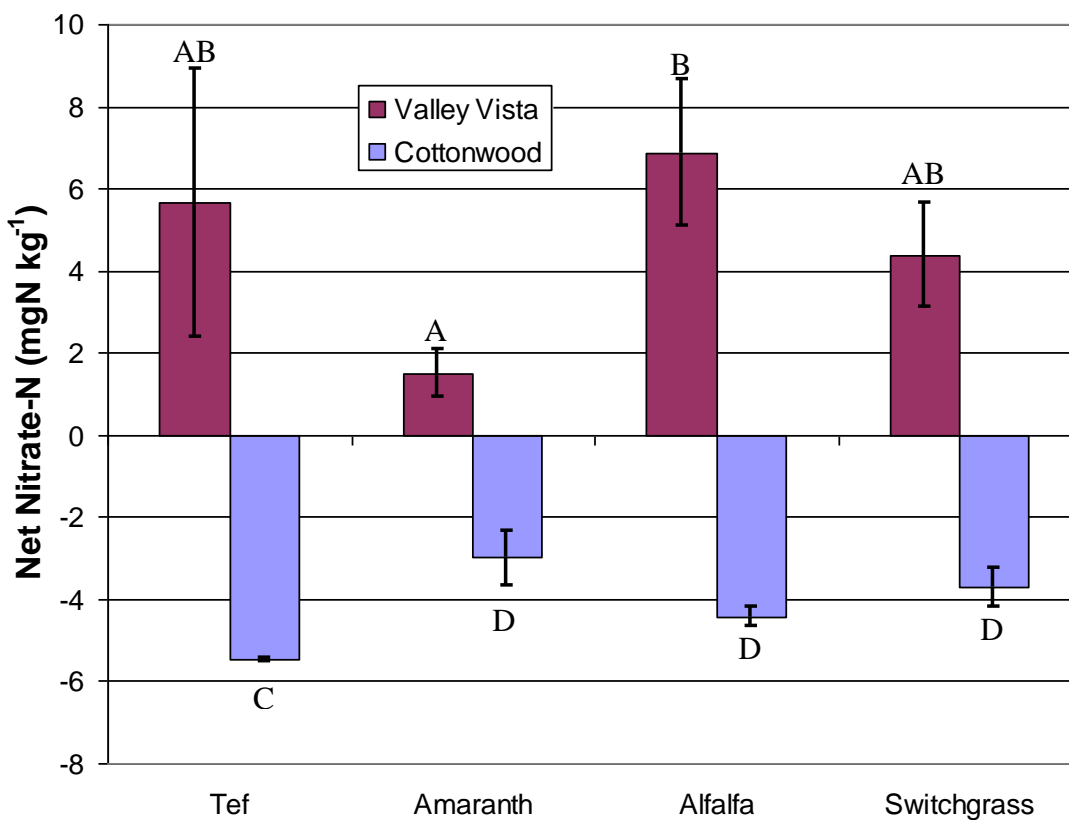


Figure 3.15: Net nitrate-N concentrations following the establishment growing season. Error bars represent standard error (n = 9). Letters represent significant differences between fields and vegetation types.

There were no significant factors affecting the net ammonium-N concentrations (Table 3.3). Change in ammonium in the 50% irrigation treatments were similar for the Valley Vista ( $-0.10 \pm 0.51$  mgN kg<sup>-1</sup>) and Cottonwood fields ( $-0.29 \pm 0.68$  mgN kg<sup>-1</sup>; Figure 3.16). The overall net change in ammonium-N concentration was  $-0.45 \pm 0.24$  mgN kg<sup>-1</sup> at the Valley Vista site (Figure 3.17).

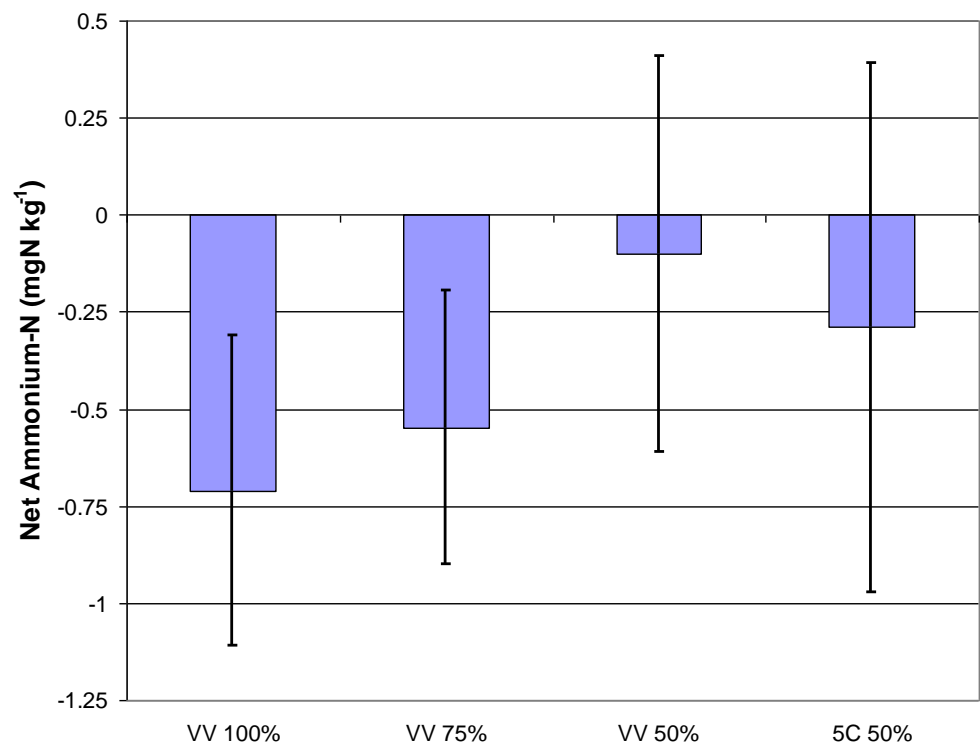


Figure 3.16: Net change in ammonium-N concentrations over the growing season by irrigation treatment at the Valley Vista (VV) and Cottonwood (5C) sites.

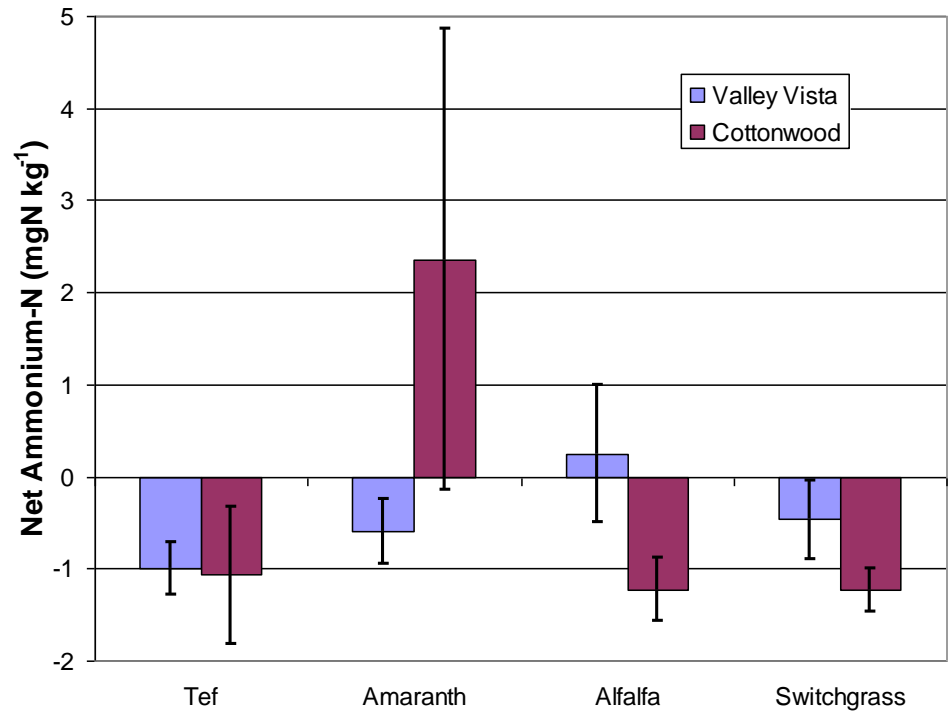


Figure 3.17: Net ammonium-N concentrations following the establishment growing season. Error bars represent standard error (n = 9).



### Biomass

Biomass was the same in all irrigation treatments in the Valley Vista field (Figure 3.18). The Cottonwood soils (50% irrigation treatment), however, showed significantly higher amounts of biomass than the Valley Vista 50% irrigation treatment.

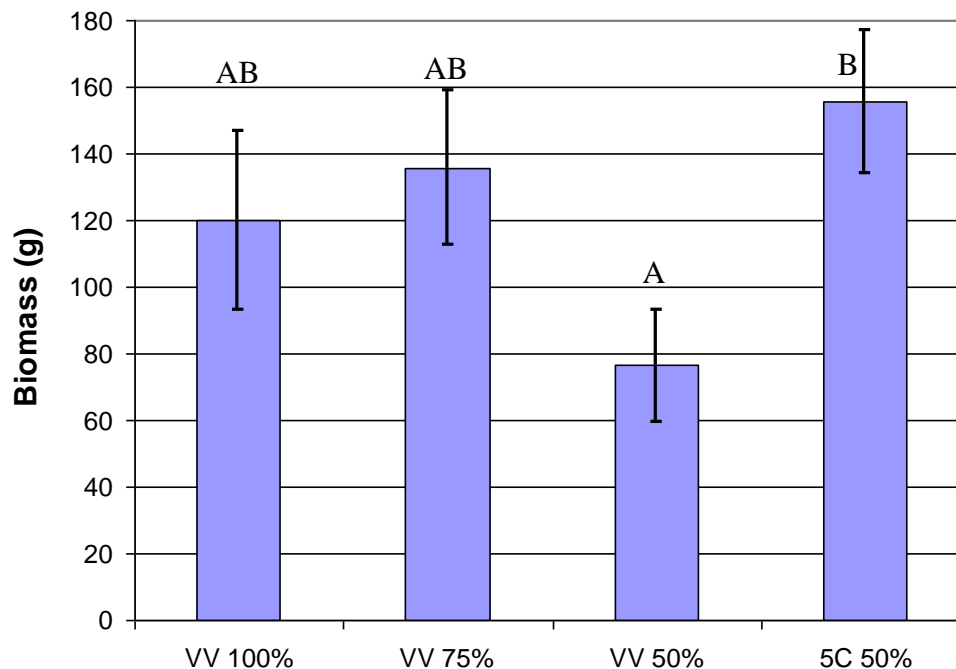


Figure 3.18: Above-ground biomass by irrigation application at the Valley Vista (VV) and Cottonwood (5C) sites. Letters represent significant differences between irrigation treatments.

In the Valley Vista field, tef had a significantly higher biomass than amaranth, alfalfa, and switchgrass (Fig. 3.19). The same was true at the Cottonwood site but amaranth biomass was also higher than alfalfa and switchgrass. The Cottonwood tef had the largest average biomass ( $307.3 \pm 28.8$  g) while the Cottonwood switchgrass had the lowest average biomass ( $37.3 \pm 5.6$  g) across all fields. Both tef and amaranth biomass was higher at the Cottonwood site than at the Valley Vista site while switchgrass biomass was lower. Alfalfa biomass was similar in both fields.

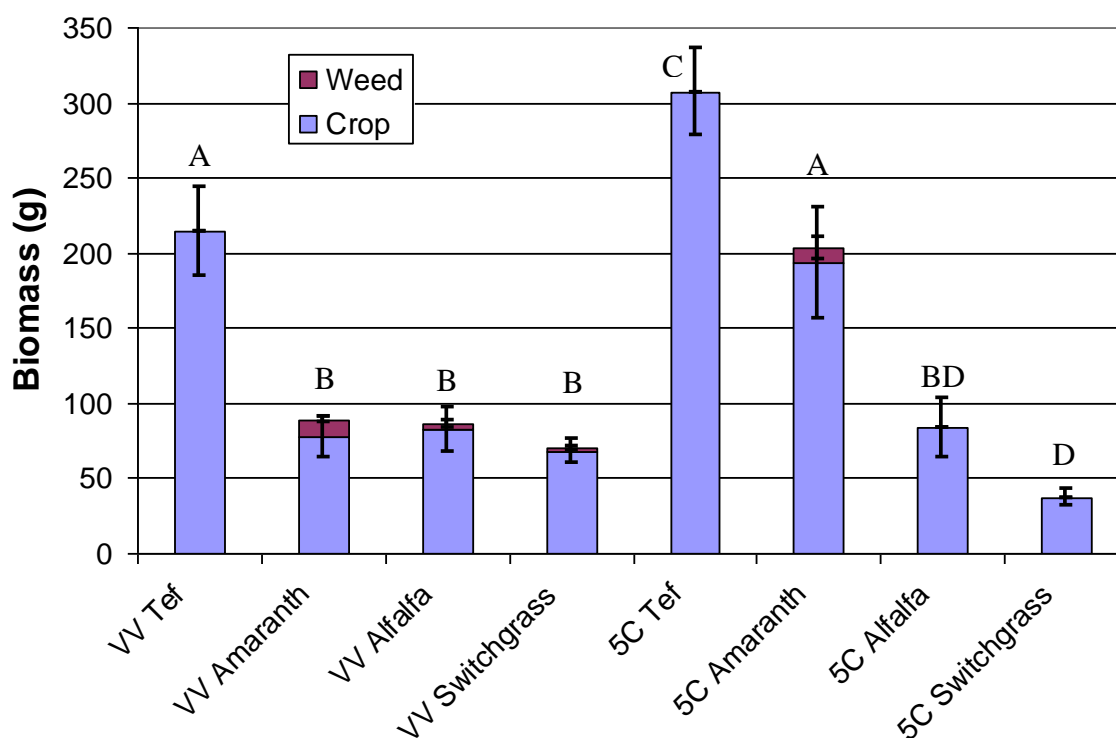


Figure 3.19: Average biomass (g) within a 1.45 m<sup>2</sup> area around the PVC respiration rings at the Valley Vista (VV) and Cottonwood (5C) sites. Error bars represent standard error (n = 9). Letters represent significant differences between vegetation types in either field.

Table 3.4 shows the average percent total N of the aboveground biomass at the end of the establishment growing season. The weighted total N content was calculated by summing the crop biomass multiplied by the crop percent N and the weed biomass multiplied by the weed percent N. In both fields, alfalfa had the highest and tef the lowest crop and total N contents. Within each field, the biomass N concentrations were statistically different between each of the vegetation. However, we found no differences between fields when comparing biomass N concentrations for the same vegetation types.

Table 3.4: Average biomass percent N contents

| Field        | Vegetation  | Crop | Weed | Total |
|--------------|-------------|------|------|-------|
| Valley Vista | Tef         | 0.90 |      | 0.90  |
|              | Amaranth    | 1.40 | 1.53 | 1.42  |
|              | Alfalfa     | 2.48 | 1.46 | 2.45  |
|              | Switchgrass | 1.86 | 1.60 | 1.85  |
| Cottonwood   | Tef         | 0.68 |      | 0.68  |
|              | Amaranth    | 1.43 | 1.83 | 1.49  |
|              | Alfalfa     | 2.24 |      | 2.24  |
|              | Switchgrass | 1.70 |      | 1.70  |

### *Multiple regression*

Linear multiple regression analysis (Table 3.5) revealed that the CO<sub>2</sub>-C respiration rate for these soils was only significantly affected by soil moisture (positively) and percent relative humidity (negatively) when moisture, texture, air temperature, and relative humidity were included. These variables, however, explained only 20.8% of the observed variability in soil respiration. A regression of natural log transformed respiration rate data resulted in a slightly higher R<sup>2</sup> of 26.4%. When conducting a regression using data obtained at the end of the growing season, moisture, vegetation biomass, and soil temperature significantly affected the C respiration rate (R<sup>2</sup> = 64.2%) with soil temperature affecting the rate negatively when moisture, texture, biomass (vegetation and weed), percent total N, percent total C, and soil temperature were included. Regression of natural log transformed respiration rate data resulted in a slightly lower R<sup>2</sup> of 63.2%.

Table 3.5: Linear multiple regression results from main factors.

| Factor    | C Respiration Rate |        | Net Total Inorg-N |    | Net Nitrate |        | Net Ammonium |      |
|-----------|--------------------|--------|-------------------|----|-------------|--------|--------------|------|
|           | A                  | B      | C                 | D  | C           | D      | C            | D    |
| Moisture  | *                  | ****   | ns                | *  | *           | *      | ns           | ns   |
| %Clay     | ns                 | ns     | ns                | ** | ns          | na     | ns           | ns   |
| %Silt     | ns                 | ns     | ns                | na | ns          | na     | ns           | na   |
| %Sand     | ns                 | ns     | ns                | na | ns          | na     | ns           | na   |
| Air Temp  | ns                 | na     | na                | na | na          | na     | na           | na   |
| %RH       | *(-)               | na     | na                | na | na          | na     | na           | na   |
| Vbiomass  | na                 | *      | ns                | na | ns          | *(-)   | ns           | ns   |
| Wbiomass  | na                 | ns     | ns                | *  | ns          | na     | ****         | **** |
| %N        | na                 | ns     | ns                | na | ns          | na     | ns           | na   |
| %C        | na                 | ns     | ns                | ** | ns          | *      | ns           | ns   |
| Soil Temp | na                 | ***(-) | ns                | na | *(-)        | ***(-) | ns           | *    |

\*\*\*\* =  $p < 0.0001$ ; \*\*\* =  $p < 0.001$ ; \*\* =  $p < 0.01$ ; \* =  $p < 0.05$ ; ns = not significant; na = not applied.

Two separate analyses were run for the C respiration rate for parameters measured periodically over the growing season (A) and those that could only be measured at the end of the growing season (B). Step-wise regression analyses were conducted on the N fluxes, where the two highest  $R^2$  analyses are shown (C & D).

A step-wise multiple regression analysis was conducted on the three N fluxes.

Multiple regression analysis (Table 3.5) revealed that there were no significant factors affecting the net total extractable N ( $R^2 = 41.2\%$ ) concentrations when moisture, texture, biomass (vegetation and weed), percent total N, percent total C, and soil temperature were included as main factors. Moisture, percent clay, weed biomass, and percent total C significantly affected the net total extractable N concentrations when all other factors were excluded ( $R^2 = 36.9\%$ ) (Note: only these first two regression results are shown in the table). When percent clay, weed biomass, and percent total N were analyzed all three were significant factors ( $p = 0.004$ ,  $0.0314$ , and  $0.0127$  respectively) but the regression coefficient was only 27.5%. Air temperature and percent relative humidity were not included in the regressions of the net N fluxes because these values were not available at the end of the growing season when the net inorganic-N concentrations were measured.

Moisture and soil temperature significantly affected the net nitrate-N concentrations (Table 3.5) with soil temperature affecting it negatively when moisture,

texture, biomass (vegetation and weed), percent total N, percent total C, and soil temperature were included as main factors ( $R^2 = 47.3\%$ ). When moisture, vegetation biomass, percent total C, and soil temperature alone were analyzed all four factors were significant with vegetation biomass and soil temperature affecting the net nitrate-N concentrations negatively ( $R^2 = 43.4\%$ ) (Note: only these first two regressions are shown in the table). Moisture ( $p = 0.0324$ ), percent total N ( $p = 0.0261$ ), and soil temperature ( $p = 0.0001$ ) significantly affected the net nitrate-N concentrations with soil temperature being negatively correlated ( $R^2 = 37.4\%$ ).

Only weed biomass ( $p < 0.0001$ ) significantly affected the net ammonium-N concentrations ( $R^2 = 31.2\%$ ) when moisture, texture, biomass (vegetation and weed), percent total N, percent total C, and soil temperature were used in a multiple regression analysis (Table 3.7). Soil temperature ( $p = 0.0365$ ) became significant when percent silt, percent sand, and percent total N were taken out of the multiple regression ( $R^2 = 30.1\%$ ) (Note: only these first two regressions are shown in the table). Weed biomass ( $p < 0.0001$ ) and percent total N ( $p = 0.0428$ ) were significant factors when only these two factors were used in the regression ( $R^2 = 26.5\%$ ).

## DISCUSSION

In this study, two alternative agricultural fields in the Walker Basin of northwestern Nevada were used to explore the effects of moisture, soil and air temperature, texture, and vegetation on soil  $\text{CO}_2$ -C respiration. In addition, we looked at

changes in soil and vegetation total C and N contents following one cropping cycle to provide a second index of soil productivity.

### *Moisture effects*

We hypothesized that higher moisture contents would lead to higher CO<sub>2</sub>-C respiration rates and net inorganic-N concentrations. Moisture significantly affected all the C and N fluxes except for net change in ammonium-N concentrations. Higher soil moistures led to higher C respiration rates, as hypothesized, which is in agreement with other studies (Cookson et al., 2006; Tang et al., 2006). Fay et al. (2000) suggested that the length of time between rainfall events (or irrigation applications in our case) controls the soil CO<sub>2</sub> flux which may explain the temporal variability in soil respiration and moisture contents we observed. C respiration measurements were taken at various times after irrigation application ranging from about two days to five weeks. Overall, the average daily respiration rate showed an exponential decrease with increasing days since last irrigation application for both fields (Figure 3.20) similar to the study by Fay et al (2000).

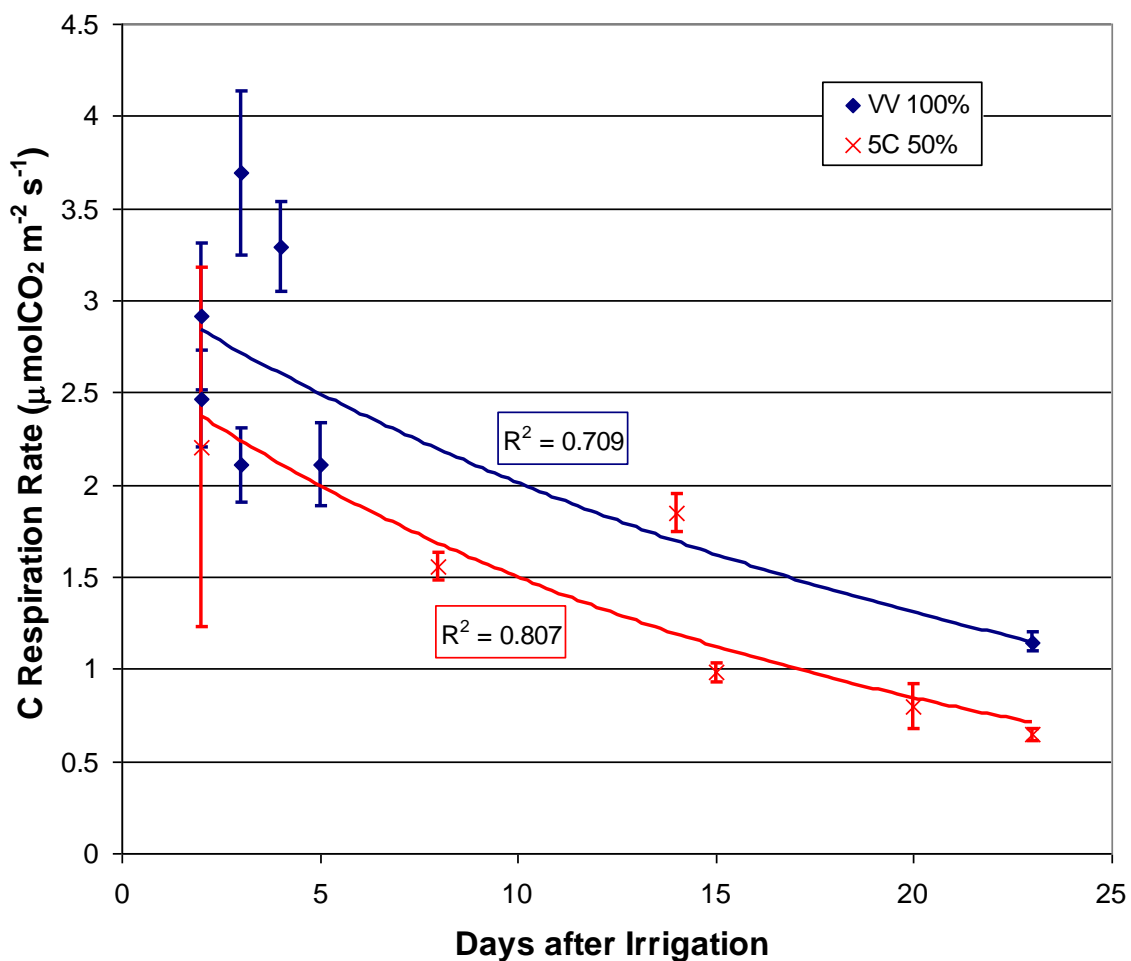


Figure 3.20: Relationship between average daily  $\text{CO}_2$  respiration rate and days since last irrigation application in the Valley Vista (VV) and Cottonwood (5C) fields

Moisture also appeared to impact N fluxes positively in these fields according to the multiple regression analysis. The inorganic-N fraction was dominated by nitrate-N. In general, however, changes in inorganic N concentrations were more dependent on field than moisture (see below).

### *Temperature effects*

Temperature was expected to affect the C and N fluxes positively when moisture was not limiting. Soil temperature was a significant factor for the CO<sub>2</sub>-C respiration rates and the net nitrate-N concentrations but it affected these negatively, which is opposite of what we predicted in our second hypothesis. This effect is probably a result of high soil temperatures exacerbating the moisture stress in the soil. Overall, the Cottonwood field had a higher average soil temperature than the Valley Vista field over the growing season while simultaneously having a lower average moisture content. Direct correlation of soil temperature and moisture was not very good when including all measurements ( $R^2 = 0.237$ ), but when comparing average soil temperatures with specific moisture content ranges a correlation exists. The average soil temperature that corresponded with soil moistures less than 0.10 by volume was 38.2° C, while the average temperature for soil moistures between 0.10 and 0.20 by volume was 32.8° C. Finally, the average temperature for soil moistures higher than 0.20 by volume was 29.5° C. As a result, it appears that in general higher temperatures corresponded with lower moisture contents. Our results agree with Cookson et al. (2006) who reported that the microbial activity in the semi-arid arable regions of Western Australia was mediated primarily by moisture availability and not soil temperature. These authors found that soil temperature was a minor factor, affecting the respiration negatively. They further described that microbial activity is only positively correlated with soil temperature when moisture is not limiting. Interestingly, the net ammonium-N concentrations were significantly affected by the weed biomass and soil temperature according to the multiple regression analysis, but as mentioned before there was no net change in ammonium-N. Therefore, it is doubtful that



these relationships are ecologically relevant. Together with moisture, soil temperature significantly affected the N fluxes despite only being significant for half of the multiple regression analyses. This indicates that there were other factors not measured that were affecting the N fluxes which could include the kind of organic matter present (labile versus stable), the microbial community composition, and interactions between roots and soil microbes (Dijkstra et al., 2009; Rasmussen et al., 1998; Holub et al., 2005; Fornara et al., 2009). Air temperature did not significantly affect the C respiration rates.

#### *Vegetation and biomass effects*

The soil with the most biomass was expected to exhibit higher CO<sub>2</sub>-C respiration rates and net inorganic-N concentrations because of higher inputs of C and N into the soil through root exudation and respiration. Vegetation significantly affected CO<sub>2</sub>-C respiration in these fields, but the effects of vegetation were not consistent among the fields. There was no clear pattern of which vegetation type showed the highest respiration rate during the growing season despite differences in biomass amounts. In the Valley Vista field, alfalfa showed the highest respiration rate over the growing season and switchgrass showed the lowest respiration rate. In the Cottonwood field, there were no significant differences between the vegetation types. As a result, our third hypothesis was not confirmed. Also, there was no clear pattern of when the soils would experience their peak respiration according to the vegetation type that was being grown which may have been related to differences in growth stages for the various vegetation types.

Differences in biomass amounts did not lead to any significant differences in the CO<sub>2</sub>-C respiration rates. Differences in the respiration rates between vegetation and

fields may also have been caused by differences in root biomass and/or photosynthetic C uptake which were not measured. Unlike our study, vegetation has been shown to be strongly and consistently correlated with soil respiration (Fu et al., 2002; Kourtev et al., 2003; Reichstein et al., 2003). The vegetation in our study may not have been given enough time to distinguish themselves from each other with respect to soil respiration. In addition, root respiration, which was not measured directly, may also be a major control over respiration in our soils as well. In croplands, the root contribution to soil respiration has been reported to be 12-38% (Jia et al., 2006).

Vegetation biomass affected the net nitrate-N concentrations negatively. Higher amounts of above-ground biomass in the Cottonwood versus the Valley Vista 50% irrigation treatment may partly explain differences in the net change in total inorganic-N concentrations over the establishment growing season. This difference in net inorganic-N concentrations may have been caused by higher plant uptake from the soil in the Cottonwood field. Tef had the highest average biomass amount at the end of the growing season and also had the largest negative net change in nitrate-N concentrations and one of the largest negative net total inorganic-N concentrations among the Cottonwood soils.

#### *Field and Texture effects*

Field did not significantly affect the C respiration rates in this study. However, field did influence the net inorganic-N concentrations. The Valley Vista field experienced a net gain in nitrate-N over the growing season whereas the Cottonwood field experienced a net loss in nitrate-N. The net increase in nitrate-N concentration at the Valley Vista is likely due to higher rates of nitrification versus leaching and plant

uptake. A net decrease in nitrate content at the Cottonwood site could have been caused by higher rates vegetation uptake versus rates of mineralization (Harrison et al., 2008). There is no evidence to suggest higher leaching losses in the Cottonwood field compared to the Valley Vista, where no significant difference in infiltration rate or wetting depth was found between the two fields (Miller and Carroll-Moore, 2009). Volatilization of N out of the soil is unlikely to represent a significant N loss unless the soil moisture rises above 60-70% water-filled pore space (WFPS; Ruser et al., 2006). The maximum WFPS throughout our study was 59%. However, some denitrification losses may have occurred immediately following irrigation events.

Neither of the fields showed a significant change in ammonium-N over the growing season which means that the inputs (mineralization) were equal to the outputs (nitrification and uptake by soil microbes and plants). Ammonium is the preferred form of inorganic N taken up by heterotrophic microorganisms in the soil (Davidson et al., 1990) while plants assimilate either form of inorganic N (Harrison et al., 2008).

Texture was not expected to play a significant role in the C and N transformations in this study because of small differences in particle distribution between the two fields. Texture was not widely a significant factor in this study as expected. In fact, percent clay content was the only texture fraction to significantly affect one of the dependent variables, where it only affected the net total inorganic-N concentrations positively. Differences in clay content (3.85 versus 3.26%) were most likely too small to cause a significant difference in the C and N fluxes between the two fields, which is similar to other findings (McLauchlin, 2006). In a laboratory study, the texture of these soils did significantly affect the cumulative CO<sub>2</sub>-C respired, however this is most likely due to the

lower variability observed in laboratory studies compared to field studies. Because of the relatively small difference in clay contents, the “field” factor in the MANOVA analysis was most likely dominated by moisture differences rather than texture differences. There was no significant difference in salinity between the two fields (Miller and Carroll-Moore, 2009). Many studies have shown higher amounts of organic C and total N in clayey versus non-clayey soils (Hassink, 1994; Cookson et al., 2006; Dilustro et al., 2005). However in our study, there were no significant differences in soil total C and N accumulation between the two fields. Therefore, one year of measurements may have been too short to detect relatively small changes in soil total C and N given the spatial variability in these numbers.

## CONCLUSIONS

For agricultural areas in the southwestern United States, a balance must be found between increasing water efficiency for crop production while simultaneously maintaining economic production levels and soil quality. In our study, moisture was the primary driver for CO<sub>2</sub>-C respiration with higher moisture levels resulting in higher CO<sub>2</sub>-C respiration rates. Field was the primary driver for inorganic-N fluxes with the Valley Vista field producing net positive changes and the Cottonwood field producing net negative changes over the establishment growing season potentially related to differences in plant biomass and thus N uptake between fields. The number of days since last irrigation application appeared to negatively affect the CO<sub>2</sub>-C respiration rates in our soils. Soil temperature was not widely significant for this study but when it was

significant it affected the C and N transformations negatively. High soil temperatures corresponded with low moisture contents which suggested an indirect effect of temperature on moisture. The difference in percent clay content between the two fields studied was most likely too small to yield significant differences in C mineralization and inorganic-N fluxes between the fields.

Still, differences between the two fields were observed in soil respiration, inorganic-N accumulation and plant production. These differences may have been caused by factors that were not measured in this study such as differences in the kind of organic matter (labile versus stable), microbial community composition, and/or interactions between the roots and soil microbes. Total above-ground biomass appeared to affect the C respiration rates positively and the net changes in inorganic-N negatively. The effects of vegetation type on the C and N transformations were not consistent over the establishment growing season. No significant changes were observed in soil total C and N over the initial establishment growing season most likely because of the relatively short duration of the study.

In successive growing seasons, effects of vegetation type and biomass on the C and N fluxes may become more apparent. Root biomass and the contribution of roots to soil respiration were not measured directly in this study. Future studies in this area should include these measurements to obtain a more complete understanding of the C and N fluxes. Still, at least in the short-term, none of the alternative crops grown appeared to have immediate detrimental effects on soil quality versus the traditionally grown alfalfa. Tef and amaranth also showed great promise for the future of alternative agriculture in the area at least when assessing their impact on soil productivity.

## ACKNOWLEDGEMENTS

This project was funded by a grant under Public Law 109-103, Section 208(a), through the U.S. Bureau of Reclamation (Cooperative Agreement 06FC204044). We gratefully acknowledge the assistance of Britt Johnson and Ryan Loux for helping with field work, Jeramie Memmott for help in using the Lachat Autoanalyzer, Todd Caldwell for help in using the Saturn DigiSizer, and Jay Arnone III, Richard Jasoni, and Jessica Larsen for providing air and soil temperature and relative humidity data. We also would like to thank Wally Miller and Robert Blank for reviewing drafts of this work.

## REFERENCES

- Barrios, E., Delve, R.J., Bekunda, M., Mowo, J., Agunda, J., Ramisch, J., Trejo M.T., Thomas, R.J. (2006) Indicators of soil quality: A South-South development of a methodological guide for linking local and technical knowledge. *Geoderma* **135**, 248-259.
- Bossio, D., Scow, K., Gunapala, N. (1998) Determinants of soil microbial communities: effects of agricultural management, season, and soil type on phospholipids fatty acid profiles. *Microbial Ecology* **36**, 1-12.
- Bouma, T.J. and Bryla, D.R. (2000) On the assessment of root and soil respiration for soils of different textures: interactions with soil moisture contents and soil CO<sub>2</sub> concentrations. *Plant and Soil* **227**, 215-221.
- Cookson, W.R., Cornforth, I.S., Rowarth, J.S. (2002) Winter soil temperature (2-15°C) effects on nitrogen transformations in clover green manure amended or unamended soils: a laboratory and field study. *Soil Biology & Biochemistry* **34**, 1401-1415.
- Cookson, W.R., Marschner, P., Clark, I.M., Milton, N., Smirk, M.N., Murphy, D.V., Osman, M., Stockdale, E.A., Hirsch, P.R. (2006) The influence of season, agricultural management, and soil properties on gross nitrogen transformations and bacterial community structure. *Australian Journal of Soil Research* **44**, 453-465.
- Davidson E., Stark J., Firestone M. (1990) Microbial production and consumption of nitrate in an annual grassland. *Ecology*, **71**, 1968-1975.

- Degens, B. and Harris, J. (1997) Development of a physiological approach to measuring the catabolic diversity of soil microbial communities. *Soil Biology & Biochemistry* **29**, 1309-1320.
- Dijkstra, F.A., Bader, N.E., Johnson, D.W., Cheng, W. (2009) Does accelerated soil organic matter decomposition in the presence of plants increase plant N availability? *Soil Biology & Biochemistry* **41**, 1080-1087.
- Dilustro, J.J., Collins, B., Dunca, L., Crawford, C. (2005) Moisture and soil texture effects on soil CO<sub>2</sub> efflux components in southeastern mixed pine forests. *Forest Ecology and Management* **204**, 85-95.
- Duff, B., Rasmussen, P.E., Smiley, R.W. (1995) Wheat/fallow systems in semi-arid regions of the Pacific NW America. In: Barnett, V., Payne, R., Steiner, R. (eds) *Agricultural sustainability: economic, environmental and statistical considerations*. Wiley, Chichester, UK, pp 87-109.
- Fay, P.A., Carlisle, J.D., Knapp, A.K., Blair, J.M., Collins, S.L. (2000) Altering rainfall timing and quantity in a mesic grassland ecosystem: design and performance of rainfall manipulation shelters. *Ecosystems* **3**, 308-319.
- Fierer N., Schimel J.P. (2002) Effects of drying-rewetting frequency on soil carbon and nitrogen transformations. *Soil Biology & Biochemistry*, **34**(6), 777-787.
- Ford D.J., Cookson W.R., Adams M.A., Grierson P.F. (2007) Role of soil drying in nitrogen mineralization and microbial community function in semi-arid grasslands of north-west Australia. *Soil Biology & Biochemistry*, **39**, 1557-1569.
- Fornara, D.A., Tilman, D., Hobbie, S.E. (2009) Linkages between plant functional composition, fine root processes and potential soil N mineralization rates. *Journal of Ecology* **97**, 48-56.
- Franzluebbers A.J. (1999) Potential C and N mineralization and microbial biomass from intact and increasingly disturbed soils of varying texture. *Soil Biology & Biochemistry*, **31**, 1083-1090.
- Fu, S., Cheng, W., Susfalf, R. (2002) Rhizosphere respiration varies with plant species and phenology: A greenhouse pot experiment. *Plant and Soil* **239**, 133-140.
- Giardina, C.P., Ryan, M.G., Hubbard, R.M., Binkley, D. (2001) Tree Species and Soil Textural Controls on Carbon and Nitrogen Mineralization Rates. *Soil Science Society of America Journal* **65**, 1272-1279.
- Golchin, A., Clarke, P., Oades, J.M., Skjemstad, J.O. (1995) The effects of cultivation on the composition of organic matter and structural stability of soils. *Australian Journal of Soil Research* **33**, 975-993.
- Grace, P. and Oades, J.M. (1994) Long-term field trials in Australia. In: Leigh, R.H., Johnson, A.E. (eds) *Long-term experiments in agriculture and ecological science*. CAB International, Wallingford, UK, pp 53-81.
- Hanson, P.J., Edwards, N.T., Garten, C.T., Andrews, J.A. (2000) Separating root and soil microbial contributions to soil respiration: a review of methods and observations. *Biogeochemistry* **48**, 115-146.
- Harrison, K.A., Bol, R., Bardgett, R.D. (2008) Do plant species with different growth strategies vary in their ability to compete with soil microbes for chemical forms of nitrogen? *Soil Biology & Biochemistry* **40**, 228-237.

- Hassink J. (1994) Effects of soil texture and grassland management on soil organic C and N and rates of C and N mineralization. *Soil Biology & Biochemistry*, **26**, 1221-1231.
- Högberg, P., Nordgren, A., Buchmann, N., Taylor, A.F.S., Ekblad, A., Högberg, M.N., Nyberg, G., Ottosson-Löfvenius, M., Read, D.J. (2001) Large-scale forest girdling shows that current photosynthesis drives soil respiration. *Nature* **411**, 789-792.
- Holub, S.M., Lajtha, K., Spears, J.D.H., Toth, J.A., Crow, S.E., Caldwell, B.A., Papp, M., Nagy, P.T. (2005) Organic matter manipulations have little effect on gross and net nitrogen transformations in two temperate forest mineral soils in the USA and central Europe. *Forest Ecology and Management* **214**, 320-330.
- Jia, B., Zhou, G., Wang, F., Wang, Y., Yuan, W., Zhou, L. (2006) Partitioning root and microbial contributions to soil respiration in *Leymus chinensis* populations. *Soil Biology & Biochemistry* **38**, 653-660.
- Komatsuzaki, M. and Ohta, H. (2007) Soil management practices for sustainable agroecosystems. *Sustainability Science* **2**, 103-120.
- Keith, H., Oades, J.M., Martin, J.K. (1986) Input of carbon to soil from wheat plants. *Soil Biology & Biochemistry* **18**, 445-449.
- Kourtev, P.S., Ehrenfeld, J.G., Häggblom, M. (2003) Experimental analysis of the effect of exotic and native plant species on the structure and function of soil microbial communities. *Soil Biology & Biochemistry* **35**, 895-905.
- Kuzyakov, Y. (2006) Sources of CO<sub>2</sub> efflux from soil and review of partitioning methods. *Soil Biology & Biochemistry* **38**, 425-448.
- Kuzyakov, Y.V. and Domanski, G. (2000) Carbon input by plants into soil. Review. *Journal of Plant Nutrition and Soil Science* **163**, 421-431.
- Lemenih, M., Karlton, E., Olsson, M. (2005) Soil organic matter dynamics after deforestation along a farm field chronosequence in southern highlands of Ethiopia. *Agriculture Ecosystems and Environment* **109**, 9-19.
- Marilley, L. and Aragno, M. (1999) Phylogenetic diversity of bacterial communities differing in degree of proximity of *Lolium perenne* and *Trifolium repens* roots. *Applied Soil Ecology* **13**, 127-136.
- McLauchlan, K.K. (2006) Effects of soil texture on soil carbon and nitrogen dynamics after cessation of agriculture. *Geoderma* **136**, 289-299.
- Mitchell, C.C., Arriaga, F.J., Entry, J.A., Novak, J.L., Goodman, W.R., Reeves, D.W., Rungen, M.W., Traxler, G.J. (1996) The old rotation, 1896-1996: 100 years of sustainable cropping research. Alabama Agricultural Experiment Station Bulletin, Auburn University, Alabama, pp 1-26.
- Miller, W.M., Carroll-Moore E. (2009) Effects of Alternative Agriculture in Western Nevada on Plant Soil and Water Interactions. *Draft report for Walker River Basin Project Task 5: Plant, Soil, and Water Interactions*.  
<http://www.nevada.edu/walker>
- Murphy, D.V., Fillery, I.R.P., Sparling, G.P. (1998a) Seasonal fluctuations in gross N mineralisation, ammonium consumption, and microbial biomass in a Western Australian soil under different land uses. *Australian Journal of Agricultural Research* **49**, 523-535.
- Murphy, D.V., Sparling, G.P., Fillery, I.R.P., McNeill, A.M., Braunberger, P. (1998b) Mineralisation of soil organic nitrogen and microbial respiration after simulated



- summer rainfall events in an agricultural soil. *Australian Journal of Soil Research* **36**, 231–246.
- Norberg O.S., Shock C., Saunders L., Feibert E., Eldredge E.P., Roseberg R., Charlton B., Smith J. (2005) Teff (*Eragrostis tef*), An Irrigated Warm Season Annual Forage Crop. Oregon State University, Malheur Experiment Station, Ontario, OR.
- Pare, T. and Gregorich, E.G. (1999) Soil Textural Effects on Mineralization of Nitrogen from Crop Residues and the Added Nitrogen Interaction. *Communications in Soil Science and Plant Analysis* **30**, 145-157.
- Rasmussen, P.E., Douglas Jr, C.L., Collins, H.P., Albrecht, S.L. (1998) Long-term cropping system effects on mineralizable nitrogen in soil. *Soil Biology & Biochemistry* **30**, 1829-1837.
- Reeves, D.W. (1997) The role of soil organic matter in maintaining soil quality in continuous cropping systems. *Soil & Tillage Research* **43**, 131-167.
- Reichstein, M., Rey, A., Freibauer, A., Tenhunen, J., Valentini, R., Banza, J., Casals, P., Cheng, Y., Grünzweig, J.M., Irvine, J., Joffre, R., Law, B.E., Loustau, D., Miglietta, F., Oechel, W., Ourcival, J.M., Pereira, J.S., Peressotti, A., Ponti, F., Qi, Y., Rambal, S., Rayment, M., Romanya, J., Rossi, F., Tedeschi, V., Tirone, G., Xu, M., Yakir, D. (2003) Modeling temporal and large-scale spatial variability of soil respiration from soil water availability, temperature and vegetation productivity indices. *Global Biogeochemical Cycles* **17**, 15.1-15.15.
- Ruser, R., Flessa, H., Russow, R., Schmidt, G., Buegger, F., Munch, J.C. (2006) Emission of N<sub>2</sub>O, N<sub>2</sub> and CO<sub>2</sub> from soil fertilized with nitrate: effect of compaction, soil moisture and rewetting. *Soil Biology & Biochemistry* **38**, 263-274.
- Swinnen, J., Van Veen, J.A., Merckx, R. (1994) <sup>14</sup>C pulse-labeling of field-grown spring wheat: an evaluation of its use in rhizosphere carbon budget estimations. *Soil Biology & Biochemistry* **26**, 161-170.
- Tang, X.L., Zhou, G.Y., Liu, S.G., Zhang, D.Q., Liu, S.Z., Li, J., Zhou, C.Y. (2006) Dependence of Soil Respiration on Soil Temperature and Soil Moisture in Successional Forests in Southern China. *Journal of Integrative Plant Biology* **48**, 654-663.
- U.S. Department of Agriculture, NRCS. 2008. The Plants Database (<http://plants.usda.gov>, 15 July 2008). National Plant Data Center, Baton Rouge, LA 70874-4490 USA.
- U.S. Department of Agriculture, Soil Conservation Service (1984). Soil Survey of Lyon County Area, Nevada. U.S. Government Printing, Washington, DC.
- Wennman, P., Kätterer, T. (2006) Effects of moisture and temperature on carbon and nitrogen mineralization in mine tailings mixed with sewage sludge. *Journal of Environmental Quality* **35**, 1135-1141.
- Zogg, G.P., Zak, D.R., Ringleberg, D.B., MacDonald, N.W., Pregitzer, K.S., White, D.C. (1997) Compositional and functional shifts in microbial communities due to soil warming. *Soil Science Society of America Journal* **61**, 475-481.

## CHAPTER 4: GENERAL SUMMARY

### INTERACTIONS BETWEEN SOIL MOISTURE, TEXTURE, AND VEGETATION TYPE UNDER LABORATORY CONDITIONS

We used two laboratory incubations to study the effects of moisture, texture, and vegetation type on C and N fluxes in agricultural fields of the semi-arid region of northern Nevada. Soils utilized in the incubations were sampled prior to (pre-planting) and following (post-planting) the establishment growing season.

Moisture was the dominant factor affecting the C and N fluxes in both incubations. There were, however, some differences with respect to which moisture treatment produced the highest mineralization rates. With respect to C mineralization, the optimal moisture content appeared to be between 0.15 and 0.30 g g<sup>-1</sup> in both incubations. In the pre-planting incubation, the optimal moisture content for N mineralization was around 0.30 g g<sup>-1</sup> but for the post-planting incubation it was 0.15 g g<sup>-1</sup>. There was no significant difference in pre-incubation total C and N contents between the two incubations as well as no difference in pre-incubation percent (of pre-incubation total N) extractable inorganic-N contents between the incubations. More N was mineralized in the pre-planting soils versus the post-planting soils. The differences between pre- and post-planting incubations may be explained by differences in organic matter quality and microbial community composition.

Field, which includes texture, was a significant factor in most cases for both incubations according to the MANOVA analysis. In the pre-planting incubation soils, higher clay and silt contents in the Wildlife Area revegetation field resulted in lower C

and N fluxes compared to the other four fields. However, the differences in texture between the Valley Vista and Cottonwood alternative fields were too small to cause any significant effect on C and N fluxes in the pre- and post-planting incubation.

Vegetation appeared to have a small effect on the C mineralization rates in the post-planting incubation. Tef produced the highest C mineralization rates of all the vegetation types in this incubation. In general, the post-planting incubation soils produced higher C mineralization rates but the pre-planting incubation soils produced higher N mineralization rates. Having vegetation growing on the soils appeared to have increased the ability of the soils to mineralize C which may be a result of an increased amount of organic matter. This increased decomposition did however not result in increased N mineralization and thus N availability.

From this study, we would expect moisture in the field to continue to play a pivotal role in the C and N fluxes within these soils. Also, we would expect texture to have no role in the two alternative fields and vegetation to have a more important role as time goes on when C inputs into the soil increase as the vegetation establishes itself.

#### INTERACTIONS BETWEEN SOIL MOISTURE, TEMPERATURE, AND VEGETATION TYPE UNDER FIELD CONDITIONS

In this study, C respiration rate measurements were used as an index of soil biological activity to assess the impacts of moisture, temperature, and vegetation type under field conditions. Changes in soil extractable N contents and biomass were also measured to serve as secondary indicator of soil quality. Similar to the laboratory incubations, moisture was the primary driver for C fluxes with higher moisture levels

resulting in higher C respiration rates. The number of days since the last irrigation application was found to negatively affect the CO<sub>2</sub>-C respiration rates in both fields. However, field was the primary driver for the inorganic-N fluxes. Soil temperature was not widely significant in the C and N fluxes throughout the field study and any significant correlations suggested an indirect effect of temperature on moisture. The difference in percent clay content between the two fields studied was most likely too small to yield significant discrepancies in C mineralization and inorganic-N fluxes between fields as expected from the laboratory results.

Significant differences between fields were observed in soil respiration, total inorganic-N accumulation and plant production. Other factors may have contributed to these differences including organic matter quality, microbial community composition, and/or interactions between the roots and soil microbes. Total aboveground biomass appeared to significantly affect the C fluxes in these fields where tef produced the largest amount of biomass and rates of CO<sub>2</sub>-C production. The effect of vegetation type was not consistent over the establishment growing season. No significant changes were observed in total soil C and N most likely because of the relatively short duration of the study.

#### IMPLICATIONS AND FUTURE WORK

Future studies should include (1) root biomass measurements to allow for calculation of N uptake by vegetation, (2) organic matter fractionation to assess differences in organic matter quality as affected by inputs from different plant species, and (3) microbial assays to determine how microbial communities respond to differences in irrigation and vegetation type. The short duration of this study only allows for

preliminary assessment of the effects of alternative crops on soils. Continuous planting for multiple years will most likely amplify effects of species in soils due to longer-term inputs of organic C from plants. This may have a cascading response to microbial processes which, in turn will affect nutrient cycling in these systems. Still, at least in the short-term, none of the alternative crops grown appeared to have immediate detrimental effects on soil quality versus the traditionally grown alfalfa. In fact, the tef and amaranth crops grew quite well over the establishment season without detrimentally impacting soil C and N transformations as measured in this study. As a result, these two alternative crops have high potentials for the future in this area.