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Factors Affecting Irrigation Water Use in Southwest Missouri and Soil Microbial Response to Irrigation and Crop Residue

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FACTORS AFFECTING IRRIGATION WATER USE IN SOUTHWEST MISSOURI AND SOIL MICROBIAL RESPONSE TO IRRIGATION AND CROP RESIDUE

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ABSTRACT

Sustainable use of water resources in Southwest Missouri requires a better understanding of factors that influence groundwater use by crop producers. The objective of this study was to assess the influence of weather patterns and edaphic factors on water used for agricultural irrigation. Groundwater withdrawal data from 14 high-use agricultural irrigation wells were monitored between 2009 and 2016 as part of the Southwest Missouri Irrigation Project. Stepwise and linear regression was used to assess the relationship of weather and edaphic factors in response to annual water use from each well. Precipitation volume, number of precipitation events, average maximum and minimum temperature, drought monitor index, soil organic matter, and infiltration rate all showed individual significance using linear regression. Stepwise model showed precipitation volume, soil organic matter, and average minimum temperature as significant factors. Along with assessing irrigation data, a study was conducted to measure soil microbial respiration response in relation to percent water filled pore space and crop residue. Treatments included 15, 30, 45, and 60 percent water filled pore space as well as corn, soybean, and wheat residues. A mixed model analysis of variance was used to describe soil microbial respiration response to treatments. Results showed no significant difference between crop residue types, percent water filled pore space, and their interaction.

KEYWORDS: irrigation, soil microbial respiration, weather factors, edaphic factors, crop residue, water filled pore space

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OVERVIEW

Agriculture accounts for 80 percent of the world's water consumption (Jury and Vaux 2005). Irrigating crops improves their quality as well as quantity and increases the amount of food available for the world's growing population. Irrigation makes it possible to grow crops in areas that otherwise would not be able to sustain crop growth due to a lack of precipitation and excessive temperatures. Irrigating crops can also improve the quality and quantity of cash crops in humid or sub-humid climates, as well as prevent plant water stress in the event of a drought (Troeh et al. 2004; Jury and Vaux 2005).

Irrigation is not only beneficial for crop growth but provides a healthy habitat for soil microbial communities by providing water in the soil profile. Soil microbes require water to move within the soil profile (Paul 2015). These microbes break down organic matter and free up nutrients, such as nitrogen and carbon (Young and Ritz 2000), that are needed to support crop growth.

Due to growing concerns with limited water resources throughout the world, understanding how to use water efficiently can have a great impact on how water resources are utilized. Water resources have been a topic of dispute for many states near Missouri, often leading to legal battles (Dzurik 2003). If water usage is better understood and adjustments are made to use water more efficiently, these disputes can be prevented. Managing water resources as efficiently as possible may save agricultural producers from costly legal disputes involving water usage.

CHAPTER 1 LITERATURE REVIEW

Introduction

Water is essential to sustaining human life, not only for hydration, but also for industrial use, recreation, and transportation, as well as agriculture production (Dzurik 2003). National concerns of energy, economic development, food production, and environmental quality are all dependent on water resources. However, use of water is often met with little concern for predictions of scarcity (Dzurik 2003).

Similar to other natural resources, water is unequally distributed both in space and time, causing problems both in excess and inadequate levels (Dzurik 2003). Previously, water resource management was addressed on an as-needed basis or by project planning; a method that fails to focus on long-term resources or consequences (Dzurik 2003).

Agriculture is the primary use of diverted water, however, when water scarcity arises, agricultural users are the first expected to reduce use (Fereres and Soriano 2007). With increased frequency of worldwide water shortages, it is important to develop irrigation methods that minimize water use and reduce the cost of irrigation. One such method, called deficit irrigation scheduling, supplies supplemental water equal to the water lost from evapotranspiration in order to avoid drought stress on crops. This is one of the many advances in agricultural research on irrigation techniques that can reduce agricultural water use (Jones 2004).

Government officials have reacted to the worldwide deterioration of soil and water resources. In the United States, the Natural Resource Conservation Service (NRCS), formally known as the Soil Conservation Service, was established to manage these resources (Troeh et al.

2004). On a state level, Missouri founded the Department of Natural Resources (MoDNR) on July 1, 1974 to protect soil, water, and air quality (MoDNR 2018).

Irrigation is an important agricultural input. In arid and semiarid climates, it facilitates production of crops that otherwise would not survive in dry conditions. In humid and sub-humid regions, irrigation increases in crop yield and improves crop quality (Troeh et al. 2004). However, increased erosion and soil salinity can have detrimental effects on the land, leading to the abandonment of fields and even regions (Brady and Weil 2004). Irrigation water also has the potential to contain harmful bacteria such as *Escherichia coli (E. coli)* (Solomon et al. 2002) and *Salmonella* (Islam et al. 2004).

Reducing tillage leaves residue from the previous crop on the soil surface, which reduces soil erosion and water runoff (Islam and Reeder 2014). Reducing runoff and soil erosion decreases water pollution by reducing inputs of soil and nutrients. Conservation tillage practices increase water infiltration rates, soil water holding capacity, and soil fertility levels (Rewcastle 2016). In comparison to conventional tillage systems, conservation tillage systems increase the accumulation of soil organic matter in the first 5 cm and enhance the microbial biomass near the soil surface (Alvarez et al. 1995; Paul 2015).

Irrigation

As early as 7000 B.C.E. the Egyptians and Mesopotamians began using flood irrigation techniques to provide water for their crops (Dzurik 2003). During the 12^{th} century, what is now southeastern Iraq was fertile cropland used to sustain a large population. The Euphrates and Tigris Rivers were used to irrigate crops; however, the soil did not naturally drain well, and artificial drains were not properly maintained. Salts from the irrigation water accumulated in soils, decreasing their productivity. When the soils could no longer sustain the population, the area was abandoned (Brady and Weil 2004). In 1948, Frank Zybach created the first prototype of an overhead center pivot irrigation system, which began the journey to modern day irrigation systems. Globally, irrigated agricultural land doubled from 1950 to 2000 while the total cultivated area increased by 12 percent (FAO 2011).

While irrigation is only required when insufficient precipitation prevents crops from maturing, many producers will also use irrigation to increase the quality and growth of crops. Depending upon seasonal precipitation, irrigation may be used to provide all of the water needs of the crop or be used as a supplement to the seasonal precipitation. Supplemental irrigation increases crop yields by reducing the risk of crop failure and plant stress, even when reasonable yields can be expected under normal conditions (Merrett 2002). In humid and sub-humid climates, supplemental irrigation is primarily used for high-value crops. Irrigation in arid or semi-arid regions allows barren soil to support food-producing cash crops.

On a global scale, the two main sources of water for irrigation are the diversion of surface water and the withdrawal of groundwater from aquifers or springs. There are five different methods in which water for irrigation is obtained: collection of rainwater, diversion of surface water from rivers or lakes, groundwater pumped from aquifers or springs, reusing household wastewater, as well as reusing irrigation water collected in drainage canals.

Although there are many benefits, irrigation is not free of problems. Supplying crops with irrigated water increases input expenses. Equipment costs increase, as wells often must be drilled and either diesel fuel or electric used to power pumps. Increased water benefits the crops, as well as weeds and insects which are a potential vector for spreading plant disease, increasing management costs. Greater yields also require more nutrients, increasing fertilizer costs.

Irrigation water can also bring with it unwanted nutrients, excess salts, as well as harmful bacteria (Troeh et al. 2004; Brady and Weil 2004; Solomon et al. 2002).

An estimated 20 percent of all irrigated land suffers from some degree of salinization (Merrett 2002). Irrigation can increase the accumulation of salts in the soil by transporting them through irrigated water. Over time an increase in the salinity of the soil will become harmful to cash crops (Troeh et al. 2004; Brady and Weil 2004). Crops grown in saline conditions have lower nitrate concentrations in their leaves, which results in a reduction in chloride ion uptake and ultimately reduced crop growth rates (Hu and Schmidhalter 2005). Arid climates are at a greater risk for salinization due to higher temperatures that evaporate water faster, leaving behind salts on the soil surface (Brady and Weil 2004).

Water contaminated with harmful bacteria and used for irrigation can cause the crop to become infected as well (Solomon 2002). Depending upon the degree to which the pathogen moves, surface and groundwater can be contaminated. Since these waters are often used for irrigation and untreated, it is possible for *Salmonella* and other pathogens to be transferred to new crops, creating a food safety risk for animals and humans alike (Islam et al. 2004; Jamieson et al. 2002; Solomon et al. 2002).

Tillage

Tillage is mechanical disturbance of the soil surface in order to prepare for a future seeding and manage weeds. Conventional tillage, conservation tillage, and no-till systems are all used in agriculture systems around the world (Troeh et al. 2004). Egyptian farmers used tools that cut into the top layer of soil breaking up plant residue on the surface. Greek farmers developed a plow system with wheels that could be pulled by large animals. Advances in plow technology continued throughout the years including the invention of the moldboard plow in 1763 by John Small (Jones 2016). For the next 70 years moldboard plows were made from cast iron, but soils with higher clay content and organic matter tended to stick to the blades.

Since the development of the moldboard plow, many advances have been made in equipment used for tillage. Disk plows were developed to be used on rocky soils and bury most of the previous crop residue, similar to the moldboard plow. Chisel plows are rip through the soil rather than inverting the soil. Other equipment like the skew treder and rod weeder keep more of the previous crop residue on the soil surface (Troeh et al. 2004).

Conventional tillage. Conventional tillage is any tillage method where less than 15 percent of the previous crop residue is left behind as ground cover (Brady and Weil 2004). Objectives of tillage are to prepare the seed and root bed while controlling weeds. With the preparation of the seedbed and unrestricted root growth, seed germination and early emergence are benefits of conventional tillage (Troeh et al. 2004). Suppressing weeds reduce the competition for sunlight and nutrients in early plant growth (Moteva et al. 2017).

While conventional tillage has many benefits, it is often considered to contribute to soil degradation (Moteva et al. 2017). Soil lifting and mixing increases the weight of the already heavy machinery, causing a counter-balance force to be placed on the soil surface. Over time this force creates a compacted subsurface layer of soil with a high bulk density and low pore space, known as a plow pan. Annual plowing of fine textured soils increases the probability of the formation of a plow pan below the normal tillage zone (Chen and Tessier 1997). Plant roots have a hard time penetrating plow pans due to the compaction and lack of pore space, making any water stored in the soil below the plow pan unavailable to crops. In drought situations, plow pans can exacerbate crop stress and increase the likelihood of crop failure. Crop stability is also an issue in compacted soils. Crops with shallow roots can be toppled by strong winds, causing moderate damage to complete crop failure (Chen and Tessier 1997).

Conservation tillage. Conservation tillage is any tillage system that leaves more than 30 percent cover on the soil from the previous crop. Since conventional tillage systems can be destructive to the environment, conservation tillage systems were developed to counteract these effects (Moteva et al. 2017; Paul 2015). Conservation tillage systems, including no-till, have been increasing in popularity amongst crop producers in the Midwestern United States over the past 20 years due to increased profitability and environmental advantages when compared to traditional tillage (Al-Kaisi and Yin 2005).

As of 2017, 90 percent of the cereal grain planted in the United States was under conservation tillage (Moteva et al. 2017). Advantages of conservation tillage systems include reduced soil erosion, reduced soil moisture and surface runoff, as well as improved soil fertility, increased humus balance, and increased crop productivity (Moteva et al. 2017). Increased soil organic matter, soil aggregation, and pore space are also benefits of conservation tillage systems. Organic matter accumulation within the first few centimeters of the soil profile (Alvarez et al. 1995), as well as total soil organic carbon accumulation, have been shown to increase under conservation tillage (Al-Kaisi and Yin 2005).

Tillage impacts on soil microorganisms. Microbial biomass and respiration are considered sensitive indicators of the soil microbial community in response to soil management (Alvarez et al. 1995). The microbial biomass in the upper 5cm of soil in a no-till system is approximately double that of the biomass conventional tillage systems of similar soil types (Alvarez et al. 1995; Paul 2015). Conventional tillage systems can negatively impact the population of microbes found in the surface layer of soil profiles. Bacteria and fungi in the soil are least affected by repeated tillage; however, nematodes and protozoa populations can be reduced as pore space decreases.

In no-till systems microbial respiration is related to carbon availability and is generally higher near the soil surface because of greater biologically activity, when compared to conventional tillage systems (Alvarez et al. 1995). Conservation tillage systems tend to have cooler and denser soil profiles as well as increased soil moisture, all of which result in greater organic matter, microbial activity, and biomass accumulation (Young and Ritz 2000). Size and distribution of pore space is also affected by tillage. Pore space indirectly regulates access to oxygen, substrate, and water for microbial organisms (Young and Ritz 2000).

Water Use

Many believe water scarcity is the biggest water problem facing the world today (Jury and Vaux 2005). When potential evaporation exceeds precipitation, a region is considered water scarce. In many areas of the world current water supplies are insufficient to meet the demands of environmental, industrial, urban, and agricultural use. Water use, including agricultural irrigation, increases as the world's population continues to grow (Jury and Vaux 2005).

In order to address water scarcity, agricultural water use needs to become more efficient. Improving irrigation scheduling and using advanced irrigation technology could make agricultural water use more efficient (Jones 2004). Irrigation scheduling is determined by the need for irrigation and can be measured by soil water content, soil water potential, or calculating the soil moisture content. Soil water potential is measured directly using tensiometers, psychrometers, or similar tools. Soil water content is also measured directly using neutron probes, gravimetric methods, or a capacitor (Jones 2004). Soil moisture content is estimated over a period of time, considering precipitation and irrigation as inputs, and soil water loss by drainage and evapotranspiration as outputs. While estimating soil moisture content is the most widely used method, research has found that it is not as accurate as directly measuring soil water content and potential (Jones 2004). By improving irrigation scheduling agriculture producers could see an increase in effective water use.

Tensiometers and other instruments can be used to accurately monitor soil water potential and indicate how much water should be applied to meet crop and soil water needs however, the cost of such instruments can be a major deterrent for many producers (Jones 2004). Using gravimetric methods to measure soil water content requires extensive calculations and accurate estimates of precipitation and runoff as well as evapotranspiration estimates. While this method gives an estimate of how much water should be applied, it is not as accurate as a direct measurement and varies according to crop type as well as growth stage and rooting depth. Although these techniques have improved irrigation there is still room for improvements that will help producers monitor irrigation needs more effectively, while still being cost effective (Jones 2004).

Scientists, law makers, the public, and agricultural producers must communicate and work together to solve our current water problems and prevent future problems (Jury and Vaux 2005). In the United States, regulations regarding water use vary from state to state. Kansas landowners with more than two acres are required to apply for a permit and report their water usage or face up to a $500 fine and six months in jail (KDOA 2016). Arkansas has similar laws requiring major water users to report water use. If a user fails to report, they face a fine of up to 500 and the cancellation of water rights if they do not report for two consecutive years (ANRC 2016). In Missouri, a major water user is defined as one who can withdraw or divert 70 gallons per minute or 100,000 gallons or more in 24 hours, regardless of water source or sources (MoDNR 2016a). Major water users are required to report their annual water use data; however, there are no penalties for not reporting water use (MoDNR 2016b).

Water resources are rarely an environmental concern in Missouri due to an adequate supply of clean water. However, groundwater level changes are observed and may be the result of natural causes such as precipitation and drought, or human activities drawing large amounts of ground water for surface level activities (MoDNR 2016b). Groundwater is drawn from aquifers, bodies of permeable rock that contain and transmit groundwater. Observation wells are used by government agencies to monitor aquifer levels. These wells show how environmental factors, such as precipitation, drought, earthquakes, tidal effects, and barometric pressure changes affect groundwater levels (MoDNR 2016b). During the 1950s, DNR began monitoring groundwater levels from observation wells across the United States. While some of these wells were drilled as monitoring wells, the majority were donated from businesses or individuals that no longer use them for a water supply. As of 2012, Missouri had 164 groundwater observation wells (MoDNR 2016b).

Crop water needs include water to meet the evapotranspiration requirements of a crop grown in a field in order to reach full potential, without restrictive soil conditions. Evapotranspiration is the transfer of water from the land to the atmosphere by the combination of evaporation from surfaces, including the soil, and transpiration from plants. Crop water requirements are dependent upon crop type, climate, soil, and environmental restrictions (Merrett 2002). Maintaining enough water in the soil profile for nutrient uptake by crops should also be considered when discussing crop water needs (Hu and Schmidhalter 2005).

Evapotranspiration should also be considered when determining water needs for optimal plant growth (Merrett 2002). During some months water lost through evapotranspiration is larger than what is returned by precipitation. In the Central and Eastern United States, the highest potential for evapotranspiration occurs during July and August when precipitation is also at a minimum, making irrigation often necessary during these times to meet crop water requirements (Shukla and Mintz 1982).

Having adequate soil moisture is very important to the uptake of nutrients for crops. Uptake of both potassium and phosphorous is limited by mild drought conditions (Hu and Schmidhalter 2005). Calcium levels are also affected by limited water in the soil profile, but not as drastically as potassium and phosphorous. Nitrogen mineralization may also be reduced under drought conditions, limiting the plants access to nitrogen. Without proper levels of these minerals a reduction is seen in crop growth (Hu and Schmidhalter 2005)

Conclusion

Advances in irrigation and tillage have increased both crop yield and quality. In some area's irrigation is necessary to maintain adequate soil moisture for plant growth, and in other areas it is used to supplement when precipitation is lacking. While irrigation is not without risks, the benefits often outweigh the risks by supporting healthy crops in areas where precipitation alone fails to do so.

Irrigation is also beneficial for soil microbes that need adequate water to thrive. The relationship between soil microbes and crops encourages appropriate soil water content for both soil microbes and crop health. However, it is crucial to remember that water is a natural resource that is unequally distributed, for this reason learning how to use it as efficiently as possible in times of plenty will prepare for periods of shortage situations in the future. Understanding what factors drive irrigation with further research will identify areas that can be improved upon to conserve this natural resource while still meeting crop and soil microbial needs. The following study was conducted in two parts. The first section examines irrigation use in relation to weather, edaphic factors, and crop production. The second section examines soil microbial response to percent water filled pore space and crop residue.

References

Al-Kaisi, M.M., and X. Yin. 2005. Tillage and crop residue effects on soil carbon and carbon dioxide emission in corn-soybean rotations. Journal of Environmental Quality 34:437-445.

Alvarez, R., D.A. Diaz, N. Barbero, O.J. Santanatoglia, and L. Boltta. 1995. Soil organic carbon, microbial biomass and CO2-C production from three tillage systems. Soil & Tillage Research 33:17-28.

ANRC (Arkansas Natural Resources Commission). 2016. Delinquent water-use registration. Arkansas Natural Resources Commission.

Brady, N.C., and R.R. Weil. 2004. The Nature and Properties of Soils 14th ed. Upper Saddle River, NJ: Pearson Prentice Hall.

Chen, Y., and S. Tessier. 1997. Techniques to diagnose plow and disk pans. Canadian Agricultural Engineering (April/May/June): 39(2).

Dzurik, A.A. 2003. Water Resources Planning 3rd ed. Lanham, MD: Rowman & Littlefield Publishers, Inc.

Fereres, E., and M.A. Soriano. 2007. Deficit irrigation for reducing agricultural water use. Journal of Experimental Botany 58(2):147-159.

FAO (Food and Agriculture Organization of the United Nations). 2011.The state of the world's land and water resources for food and agriculture (SOLAW)- Managing systems at risk, 1st ed:21-27. Rome and Earthscan, London.

Holden, J. 2014. Water Resources: An integrated approach. 1st ed:123-157. New York, NY: Routledge.

Hu, Y., and U. Schmidhalter. 2005. Drought and salinity: A comparison of their effects on mineral nutrition of plants. Journal of Plant Nutrition and Soil Science 168:541-549.

Islam, M., J. Morgan, M.P. Doyle, S.C. Phatak, P. Millner, and X. Jiang. 2004. Fate of Salmonella enterica serovar typhimurium on carrots and radishes grown in fields treated with contaminated manure composts or irrigation water. Applied and Environmental Microbiology, 70(4):2497-2502.

Islam, R., and R. Reeder. 2014. "No-till and conservation agriculture in the United States: An example from the David Brandt farm, Carroll, Ohio." International Soil and Water Conservation Research, 2(1):97-107.

Jamieson, R.C., R.J. Gordon, K.E. Sharples, G.W. Stratton, and A. Madani. 2002. Movement and persistence of fecal bacteria in agricultural soils and subsurface drainage water: A review. Canadian Biosystems Engineering, 44(1), 1-9.

Jones, A. 2016. "A Brief history of the plough." Society of Ploughmen, Society of Ploughmen. https://www.ploughmen.co.uk/about-us/history-of-the-plough.

Jones, H.G. 2004. Irrigation scheduling: Advantages and pitfalls of plant-based methods. Journal of Experimental Botany 55(407):2427-2436.

Jury, W.A., and H. Vaux Jr. 2005. The role of science in solving the world's emerging water problems, Proceedings of the National Academy of Sciences of the United States of America 102(November):44.

KDOA 2016 (Kansas Department of Agriculture). Water law basics. Kansas Department of Agriculture. 2016.

Merrett, S. 2002. Water for agriculture: Irrigation economics in international perspective. New York, NY: Tyler & Francis Inc.

MoDNR 2016a (Missouri Department of Natural Resources). PUB2337. Frequently asked major water user questions. Joe Gillman, Missouri Geological Survey Director. 2016.

MoDNR 2016b (Missouri Department of Natural Resources). Groundwater-level observation well network. MoDNR. 2016.

MoDNR 2018 (Missouri Department of Natural Resources). MoDNR40. Missouri Department of Natural Resources1974-2014 timeline: Celebrating 40 years of taking care of Missouri's resources. 2018.
.

Moteva, M., G. Kostadinov, V. Spalevic, V. Georgieva, V. Tanaskovik, and N. Koveva. 2017. Sweet corn-conventional tillage vs. no-tillage in humid conditions. Agriculture & Forestry 63(1):17-25.

Paul, E.A. 2015. Soil Microbiology, Ecology, and Biochemistry, 4th ed., 541-560. San Diego, CA: Academic Press, Elsevier.

Rewcastle, K. 2016. Reaping the benefits of conservation tillage: Implications of increased soil organic matter and aggregation in surface soils. Pursuit: The Journal of Undergraduate Research at the University of Tennessee 7(1):167-175.

Shukla, J., and Y. Mintz. 1982. Influence of land-surface evapotranspiration on the Earth's climate science, New Series 215(4539):1498-1501.

Solomon, E.B., S. Yaron, and K.R. Matthews. 2002. Transmission of Escherichia coli O157:H7 from contaminated manure and irrigation water to lettuce plant tissue and its subsequent internalization. Applied and Environmental Microbiology 68(1):397-400.

Troeh, F.R., J. Hobbs, D. Arthur, and R.L. Donahue. 2004. Soil and Water Conservation for Productivity and Environmental Protection, 4th ed., 218-219. Upper Saddle River, NJ: Pearson Prentice Hall.

Young, I.M., and K. Ritz. 2000. Tillage, habitat space and function of soil microbes. Soil & Tillage Research 53:201-213.

CHAPTER 2 FACTORS AFFECTING IRRIGATION WATER USE IN SOUTHWEST MISSOURI

Introduction

Agricultural irrigation is the main user of diverted water (Fereres and Soriano 2007). Water used for irrigation is diverted from rivers or groundwater. In many areas, including Southwest Missouri, groundwater is the main source of water for agricultural irrigation use, as well as urban and industrial use (Anderson 2003). Precipitation recharges the rivers as well as groundwater (Holden 2014). Precipitation also supplies crops with water, and recharges stored soil water (Brady and Weil 2004). However, precipitation, like all water, is unequally distributed both in space and time, leaving crops without adequate water for growth and development. For this reason, irrigation is necessary in arid and semi-arid environments to achieve optimal crop production. Irrigation may also be used in humid and sub-humid regions, like Missouri, for optimal crop growth during periods of inadequate precipitation (Dzurik 2003).

Generally, it is assumed that irrigation water use is driven by local weather factors such as precipitation and temperature, as well as other environmental factors. However, edaphic factors must be taken into consideration as well. Availability of soil water in the rooting zone, crop growth stage, and soil water holding capacity all influence crop water use. Lack of available water causes plant stress, which reduces growth and overall yield, ultimately reducing crop water use efficiency (Brady and Weil 2004).

Water use efficiency is important when considering crop water needs as well as the need for irrigation. Water use efficiency is typically defined as yield of the crop divided by the evapotranspiration that occurred between planting and harvest of the crop (Hatfield et al. 2001).

Factors that increase yield while reducing evapotranspiration increase crop water use efficiency and ultimately reduce water loss and irrigation needs (Hatfield et al. 2001). Reduced tillage, increased soil residue, increased soil water holding capacity, as well as decreased runoff can all have a positive effect on water use efficiency.

Southwest Missouri crop producers utilize groundwater resources to provide supplemental water during the crop growing season. However, there are few records of patterns of agricultural irrigation water use by crop producers in Southwest Missouri. A better understanding of factors affecting water use will help producers use water more efficiently. The objective of this study was to assess the influence of weather patterns, edaphic factors, and crop production on water used for agricultural irrigation in Barton, Dade, Lawrence, and Jasper counties in Southwest Missouri.

Materials and Methods

Flowmeters were attached to 14 high-use agricultural wells within the study area (Figure 1). Thirteen of the flowmeters were McCromerter brand model number MD308-400 to fit a 6 in pipe, and one meter was a McCromerter brand model number MD306-800 to fit 8 in pipes. Water readings in thousands of gallons were collected from each well from 2009 to 2014 between growing seasons of corn and soybeans. Of the 14 wells, two were monitored for 3 years, four were monitored for 4 years, four were monitored for 5 years, and four were monitored for 6 years, resulting in a total of 66 readings. Meter readings were collected by a representative from the Missouri Department of Natural Resources, typically between November and March. Data were also collected in July 2015 and November 2016 but were excluded from this study because a full growing season of irrigation water use was not represented for either year.

Daily precipitation and temperature values were collected from the National Oceanic Atmospheric Administration (NOAA 2017) for the 40 weather stations in the study area. Only weather stations with data sets at least 95 percent complete (347 days) for every year of the study period were considered. Eleven weather stations met this requirement. Well locations and weather stations were mapped using ARC-GIS software (Esri, Redlands, CA) and the nine stations nearest the study wells were identified (Table 1). The remaining two weather stations were excluded from the study due to their greater distance from the well sites. Some weather stations provided both precipitation and temperature data, while some only listed either precipitation or temperature. Weather data were associated with the closest well site, with some weather stations being used for multiple well sites (Table 1). Yearly and growing season (April 1 to September 30) data were determined for total precipitation, number of precipitation events, number of precipitation events over 25.4 mm, number of precipitation events between 6.35 mm and 25.4 mm, maximum temperature, and minimum temperature (Table 2). Drought monitor index, used to access the drought level from lack of precipitation, was also collected from the North Oceanic Atmospheric Administration.

Crop production fields associated with each well were identified using a combination of shapefiles provided from the Missouri Department of Natural Resources and satellite images from Google Earth. The shapefiles contained the location of the well, number of fields serviced by each well, and approximate acreage. Google Earth (2017) was used to identify irrigation circles from the center pivot systems in order to locate the associated fields for each well. Web Soil Survey (USDA-NRCS 2017) was used to determine the dominate soil series in each field.

Depth to limiting layer, infiltration class, soil water holding capacity for the A and B soil horizon, organic matter in the A horizon and percent clay in both the A and B soil horizon were collected from Web Soil Survey for each dominate soil series (Table 3).

Crop data were obtained from the United States Department of Agriculture National Agricultural Statistics Services. Total acres harvested data for corn (USDA-NASS 2017a), soybean (USDA-NASS 2017b), and winter wheat (USDA-NASS 2017c) were collected for each county from 2009 to 2014. Total acres harvested were assigned for corn, soybean, and winter wheat to each well based on the county in which the well resides.

Data were analyzed using linear regression (PROC REG, SAS 9.4) to model the relationship of factors described above with water use. Stepwise linear regression (PROC REG, SAS 9.4) was used to identify factors most important for explaining irrigation water use. The threshold for including a factor in the model was $p \leq 0.1$.

Results and Discussion

Using linear regression, each weather factor during the growing season for corn and soybean was assessed individually in response to groundwater withdrawal in thousands of gallons (Table 4). Drought monitor index, average maximum temperature, average minimum temperature, precipitation total, and number of precipitation events all showed individual significance, however, none explained more than 12 percent of the variation. The same weather factors were assessed against yearly totals as well (Table 5). All factors were individually significant with number of precipitation events explaining the most (24 percent) of the variation.

Combined linear regression models were assessed with weather factors for growing season (Table 6), yearly (Table 7), and growing season and yearly combined (Table 8). The combined linear regression model for growing season as well as the model for yearly showed number of precipitation events as the only significant factor. The yearly model explained the most variance of the data at 25 percent. The combined model that included both growing season and yearly data showed significance in the yearly drought monitor index as well as the number of precipitation events during the growing season and explained 23 percent of the variation.

Edaphic factors, organic matter, infiltration class, depth to limiting layer, water holding capacity, and percent clay in the B layer, were also assessed individually in a linear regression model (Table 9) in response to groundwater withdrawal. Soil organic matter was significant but only explained 3.5 percent of the variation of the data. Infiltration class was also significant but only explained 2.8 percent of the variation. The other three factors were not significant in response to groundwater withdrawal.

Using a stepwise regression model precipitation (mm), soil organic matter, and minimum temperature showed significance (Table 10). This model explained 28 percent of the variation of the data. Comparing these models, precipitation, soil organic matter, and temperature have an influence on groundwater withdrawal for agricultural irrigation. As both minimum and maximum temperature increases evapotranspiration rates increase and soil moisture decreases, and therefore producers will increase irrigation rates.

Significant edaphic factors included soil organic matter and infiltration class. As infiltration class increases irrigation decreases. As infiltration class increases water infiltrates the soil profile more easily and therefore reduces runoff and reduces the amount of irrigation necessary to saturate the soil profile and provide adequate soil moisture for optimal crop growth. An increase in soil organic matter improves infiltration and increases pore space, allowing more water to permeate the soil profile, decreasing the amount of irrigation necessary to obtain a soil moisture level needed for crop growth.

Total precipitation during the growing season, as well as the number of precipitation events also showed significance. As precipitation increases less ground water is necessary to supply the crop with enough irrigation water for optimal growing conditions. Number of precipitation events describe the number of days precipitation was seen during the growing season. When precipitation occurs, producers decrease irrigation because the soil moisture levels are naturally being recharged.

While weather and some edaphic factors do show a significant influence on groundwater withdrawal for agricultural irrigation, these factors poorly explained the variation in the data. Combined models showed very little significance of any factors and poorly explained the variation, suggesting that these factors all play a part in a producer's choice to irrigate. However, these factors do not fully explain the variation of the data collected. It is possible that other factors, such as operator behavior, have an influence on irrigation and groundwater use in Southwest Missouri.

Future Research

The data collection for this study was collected on a yearly basis, which may have poorly represented the groundwater use by these producers. Crop rotations and yields were not recorded during the data collection process which made adequately accessing crop type as a factor improbable. Crop type could show a significant impact on groundwater withdrawal because different crops have different water requirements. More information from producers about their practices during the growing season would have also been helpful in assessing this data set.

More research is needed to better understand how weather and edaphic factors and others influence groundwater withdrawal so this natural resource can be utilized efficiently. A more in-depth study monitoring weekly, rather than seasonally, irrigation use could give more insight to how these factors interact more directly with irrigation withdrawal. Crop rotations and yield should also be considered as a factor in future studies. Collecting additional information about practices of each producer should also be considered as a future research opportunity. Since future water shortages are unpredictable, it is crucial to manage water resources properly in times of excess rather than in times of shortage.

References

Anderson, J. 2003. The environmental benefits of water recycling and reuse. Water Science and Technology: Water Supply. 3(4):1-10.

Brady, C., and R.R. Weil. 2004. The Nature and Properties of Soils, 14th ed., 414-430. Upper Saddle River, NJ: Pearson Prentice Hall.

Dzurik, A.A. 2003. Water Resources Planning 3rd ed., 1-79. Lanham, MD: Rowman & Littlefield Publishers, INC.

Fereres, E., and M.A. Soriano. 2007. Deficit irrigation for reducing agricultural water use. Journal of Experimental Botany 58(2):147-159.

Google Earth. 2017. Maps showing Barton, Dade, Jasper and Lawrence counties in southwest Missouri. May 2017. Google Earth. http://earth.google.com/web.

Hatfield, J.L., T.J. Sauer, and J.H. Prueger. 2001. Managing soils to achieve greater water use efficiency: A Review Journal of Agronomy 93:271-280.

NOAA (National Oceanic and Atmospheric Administration). 2017. Climate Data Online: Dataset Discovery, March 2017. https://www.ncdc.noaa.gov/cdo-web/datasets#GHCND.

USDA-NASS (United States Department of Agriculture - National Agricultural Statistics Service). 2017a. Missouri corn county estimates, June 2017. http://www.nass.usda.gov.

USDA-NASS (United States Department of Agriculture - National Agricultural Statistics Service). 2017b. Missouri soybean county estimates, June 2017. http://www.nass.usda.gov.

USDA-NASS (United States Department of Agriculture - National Agricultural Statistics Service). 2017c. Missouri wheat county estimates, June 2017. http://www.nass.usda.gov.

USDA-NRCS (United States Department of Agriculture-National Resource Conservation Service). 2017. Web soil survey. May 2017. https: websoilsuvrey.sc.egov.usda.gov.

Table 1. Weather stations utilized within the study area, the data points used, and the number of wells represented by each weather station.

Weather station	Use	Number of wells
Lamar 0.3 ESE	Precipitation	1
Lamar 7N	Temperature	1
Lockwood MO US	Precipitation and temperature	5
Mount Vernon 1.3 NNW	Precipitation	1
Mount Vernon Missouri MO US	Temperature	1
Carthage 1.5 MO US	Precipitation	1
Joplin Airport	Temperature	1
Lamar 7	Precipitation and temperature	4
Lockwood MO US	Precipitation and temperature	2

Table 2. Summary of weather factors during corn and soybean growing seasons collected from the nine weather stations within the study area. N=66

Factor	Minimum	Maximum	Mean
Precipitation (mm)	360	1008	691
Maximum temperature (°C)	24	30	28
Minimum temperature (°C)	13	18	16
Number of precipitation events	26	69	51
Number of precipitation events over 25.4 mm	2	14	9
Number of precipitation events between 6.35 mm and 25.4 mm	5	27	18

Table 3. Summary of soil characteristics from fields within the study area. N=14

Soil texture	Number of associated wells	Depth to limiting layer (cm)	Water holding capacity (cm/cm)	Percent organic matter	Percent clay
Barden silt loam	5	200	0.23	2.5	21.0
Carytown silt loam	1	76	0.14	1.7	18.5
Creldon silt loam	2	61	0.23	2.6	18.3
Dapue silt loam	1	200	0.20	1.5	15.4
Maplegrove silt loam	2	200	0.23	2.5	14.0
Parsons silt loam	3	35	0.22	3.3	20.0

Table 4. Summary of linear regression for each individual factor during the corn and soybean growing season in response to groundwater withdrawal. N=66

Factor	R^2 value	Pr > F
Minimum temperature (°C)	0.0498	0.0398
Maximum temperature (°C)	0.0723	0.0165
Drought monitor index	0.1249	0.0021
Precipitation total (mm)	0.0003	0.1709
Number of precipitation events	<0.0001	0.2273
Number of precipitation events over 25.4 mm	-0.0147	0.8106

Table 5. Summary of linear regression for each individual factor assessed as an entire year in response to groundwater withdrawal. N=66

Factor	R^2 value	Pr > F
Minimum temperature (°C)	0.0838	0.0105
Maximum temperature (°C)	0.0858	0.0098
Drought monitor index	0.1385	0.0012
Precipitation total (mm)	0.1784	0.0002
Number of precipitation events	0.2436	<0.0001

Table 6. Combined linear regression model for all weather factors during the growing season of corn and soybean in response to groundwater withdrawal. N=66

Factor	R^2 value	Pr > F
Minimum temperature (°C)	-	0.7595
Maximum temperature (°C)	-	0.8777
Drought monitor index	-	0.5723
Precipitation total (mm)	-	0.3359
Number of precipitation events	-	0.0494
Combined model	0.2202	-

Table 7. Combined linear regression model for all weather factors assessed yearly in response to groundwater withdrawal. N=66

Factor	R^2 value	Pr > F
Minimum temperature (°C)	-	0.9246
Maximum temperature (°C)	-	0.7935
Drought monitor index	-	0.2066
Precipitation total (mm)	-	0.9130
Number of precipitation Events	-	0.0353
Combined model	0.2459	-

Table 8. Combined linear regression model for all weather factors during the growing season of corn and soybean as well as yearly in response to groundwater withdrawal. N=66

Factor	R^2 value	Pr > F
Growing season minimum temperature (°C)	-	0.1051
Yearly minimum temperature (°C)	-	0.1478
Growing season maximum temperature (°C)	-	0.1350
Yearly maximum temperature (°C)	-	0.2826
Growing season drought monitor index	-	0.2131
Yearly drought monitor index	-	0.0762
Growing season precipitation total (mm)	-	0.3750
Yearly precipitation total (mm)	-	0.5392
Growing season number of precipitation events	-	0.0772
Yearly number of precipitation events	-	0.3810
Combined model	0.2335	-

Table 9. Summary of linear regression for each individual edaphic factor in response to groundwater withdrawal. N=66

Factor edaphic	R^2 value	Pr > F
Organic matter	0.0351	0.0713
Infiltration class	0.0282	0.0941
Depth to limiting layer	-0.0144	0.7805
Water holding capacity	-0.0067	0.4551
Percent clay	-0.0156	0.9709

Table 10. Stepwise regression model shows three significant factors, total precipitation, soil organic matter, and minimum temperature. Significance value was set at 0.1.

Model	Intercept	Total precipitation (mm)	Soil organic matter (%)	Minimum temperature (°C)	R^2	Pr > F
1 parameter	64.87	-0.04	-	-	0.18	0.0003
2 parameter	44.96	-0.04	7.60	-	0.23	0.0002
3 parameter	-	-0.04	8.93	3.97	0.28	0.0001

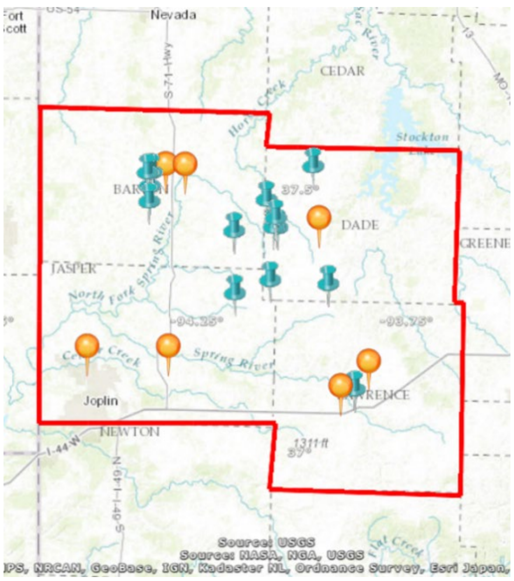

Figure 1. Map of the study area, blue pins represent well locations, orange pins represent weather station locations using ARC-GIS software (Esri, Redlands, CA).

CHAPTER 3 SOIL MICROBIAL RESPONSE TO IRRIGATION AND CROP RESIDUE

Introduction

Soil water is essential for plant growth. Irrigation is often used to supplement precipitation in sub-humid and humid regions in order to maintain optimal plant growth (Sincik et al. 2008). Soil water, including irrigation, is needed by more than just the crops, it helps keep the soil healthy (Fereres and Soriano 2007) and promotes a healthy microbial community in the soil (Paul 2015).

Soil water has a strong influence on soil microbial activity (Skopp et al. 1990). Soil microbes use water stored in the pore space to move within the soil profile (Brady and Weil 2004). Thirty to fifty percent water filled pore space is considered optimal range for aerobic soil microbial activity (Paul 2015).

Tillage can have a significant impact on soil microbial communities. Repeated tillage, like that found in a conventional system, can reduce the amount of crop residues and microbial biomass found in the upper 5 cm of a soil profile (Alvarez et al. 1995). In conservation tillage systems, increased organic matter on the soil surface results in cooler soil temperatures, increased soil moisture, and a denser profile (Young and Ritz 2000). Due to these factors, soil microbial biomass in conservation tillage systems is approximately double the biomass found in a field that is conventionally tilled (Alvarez et al. 1995; Young and Ritz 2000).

Tillage impacts the mineralization and dentification processes (Skopp et al. 1990). Break down of crop residue has shown a significant impact on soil microbial respiration. Nitrogen stored in crop residue is released during decomposition, feeding soil microbes, and increasing respiration rates (Bending et al. 2002).

The purpose of this study was to measure soil microbial respiration in response to soil water content and crop residues in a Barden silt loam soil.

Materials and Methods

This experiment examines the individual response as well as the interaction of percent water filled pore space and crop residue on soil microbial respiration. Treatments for this study included corn, soybean, and wheat residue, and no residue as a control. For each residue type, microbial respiration was determined in four samples at each 15, 30, 45, and 60 percent water filled pore space level. Crop residue treatments were included at 0.2g to represent conservation tillage at approximately 30 percent ground cover.

Soil and crop residue preparation Barden silt loam soil was collected near Golden City, Missouri (37.3931°N, 94.0938°W) in early July 2017 prior to soybean planting after winter wheat had been harvested. The soil had not been tilled as the producer used a conservation tillage system that included a corn, wheat, soybean rotation and only tilled after harvesting soybeans. The producer used no till after corn, drilling wheat into the corn stubble, and did the same with the wheat stubble with soybeans. Approximately 30 percent ground cover from the previous wheat harvest remained upon the collection of the soil used for this experiment.

The previous fall's corn and soybean residues were collected in August. Winter wheat residue from the summer harvest was also collected at the same time. These residues were air dried for two weeks and ground to 12.7 mm or smaller.

Soil was air dried for 24 hours and sieved through a 2 mm screen, and gravel and plant material were removed. Soil continued to air dry until it was used. Bulk density was calculated at 1.13 g/cm^3 after the soil been dried and sieved, this bulk density represents the soil used for this experiment not a natural soil bulk density. Particle density was assumed to be 2.65 g/cm^3 (Brady and Weil 2004). Percent pore space was calculated at 57.36 percent using the equation Percent pore space = 100% - ((Bulk Density/Particle Density) * 100).

The volume of water required to fill the pore space of a 20 g sample of soil sample was calculated at 12.96 ml. From this volume 15, 30, 45, and 60 percent water filled pore space was calculated at 1.94 ml, 3.89 ml, 5.83 ml, and 7.78 ml, respectively. Since 1 ml of water weighs 1 g, an ideal treatment weight was determined for each sample, based on 20g of soil, 0.2g of crop residue, and the weight of the water in the percent filled pore space.

Sample preparation Twenty grams of soil and 0.2 g of crop residue were added to each beaker and samples were brought to 15 percent water-filled pore space using 1.94 ml of distilled water. All samples had a preincubation weight of 22.14 g. Beakers containing the samples were placed in sealed 0.95 L jars with 10 ml 1 M KOH to capture released CO_2 and 10 mL water in the bottom of the jar to maintain humidity. Samples were preincubated for seven days at 25°C (Haney et al. 2004).

After preincubation, the samples were placed in a desiccator with a 50 ml beaker containing 10 ml chloroform and 15 boiling stones. A vacuum pump was used to evacuate the desiccator until the chloroform began to boil vigorously. The desiccator was sealed and incubated in the dark at 25°C for 24 hours (Jenkinson and Powlson 1976). After 24 hours, chloroform was removed, and desiccator was evacuated in 2-minute sessions until chloroform was no longer present in the samples (Jenkinson and Powlson 1976). Chloroform fumigation and incubation is a reasonable indicator of management induced changes without subtracting a control (Franzluebbers et al. 1999), for this reason a control was not subtracted from this study.

Since some water is expected to be lost from the soil, the samples were reweighed. This weight was subtracted from the sample's ideal treatment weight, water was added to bring samples up to their ideal treatment weight representing either 15, 30, 45, or 60 percent water filled pore space. Samples were placed back in their respective jars with a new 10 ml of KOH and 10 ml of DI water. Samples were then incubated at 25°C for another 10 days.

Titration After 10 days, samples were individually removed from the incubator and three drops of phenolphthalein indicator solution were added to the KOH trap. The KOH solution was titrated with HCl until the solution was neutralized. Amount of HCl used to obtain a neutral solution was recorded (Franzluebbers et al. 1996). This process was repeated at 1, 3, 7, 14, 21, and 28 days. Soil microbial respiration was calculated by converting ml HCL to mg of CO_2 released. The CO_2 output was then divided by an efficiency factor 0.41 (Voroney and Paul 1984).

Analysis of variance (ANOVA) was used to describe soil microbial biomass response to treatments (PROC GLM, SAS 9.4). Crop residue, water filled pore space, as well as the interaction of crop residue and percent water filled pore space were fixed factors.

Results and Discussion

No significant main effects and no significant interaction were found ($P<0.05$) in respect to soil microbial respiration (Table 11), for this reason no further replications were conducted. Neither crop residue type, percent water filled pore space, nor the interaction affected soil microbial respiration.

The greatest difference in soil respiration among residue types was between soybeans and the no cover control, however, it was not a significant difference (Table 12). The greatest difference in soil respiration among percent filled pore space was between 30 percent and 45 percent filled pore space but it was also not significant (Table 13). The interactions of crop cover and water filled pore space showed similar results with the greatest difference in soil respiration among the interactions being between corn at 15 percent water filled pore space and soybean at 15 percent water filled pore space, with no significant difference (Table 14).

No significant difference in microbial respiration in response to percent water filled pore space suggests that microbial respiration was not directly related to soil water. However, Torbert's study suggested that microbial activity is affected by water filled pore space and showed the highest significance at 60 percent water filled pore space. They conducted a regression analysis similar to what was used in this study, along with an analysis of variance. However, they used water filled pore space between 60 percent and 75 percent (Torbert and Wood 1992).

Microbial respiration also showed no significant difference in response to crop residue type. However, Bending et al. (2002) allowed crop residue mixed with soil to incubate for 28 and 112 days, and wheat showed the highest significance at 112 days. Based on this information, crop residue type should be reassessed on a longer-term scale. This study incorporated the crop residue directly before incubation only giving the residue 18 days total time in the soil. It is possible there was no reaction because the microbes did not have enough time to break down enough of the plant residue to show an accurate response.

References

Alvarez, R., D.A. Diaz, N. Barbero, O.J. Santanatoglia, and L. Boltta. 1995. Soil organic carbon, microbial biomass, and CO_2-C production from three tillage systems. Soil & Tillage Research 33:17-28.

Bending, G.D., M.K. Turner, and J.E. Jones. 2002. Interactions between crop residue and soil organic matter quality and the functional diversity of soil microbial communities. Soil Biology and Biochemistry 34:1073-1082.

Brady, C., and R.R. Weil. 2004. The Nature and Properties of Soils, 14th ed., 414-430. Upper Saddle River, NJ: Pearson Prentice Hall.

Fereres, E., and M.A. Soriano. 2007. Deficit irrigation for reducing agricultural water use. Journal of Experimental Botany 58(2):147-159.

Franzluebbers, A.J., F.M. Haney, F.M. Hons, and D.A. Zuberer. 1996. Determination of Microbial Biomass and Nitrogen Mineralization following Rewetting of Dried Soil. Soil Science Society of American Journal 60:1133-1139.

Franzluebbers, A.J., F.M. Haney, F.M. Hons, and D.A. Zuberer. 1999. Assessing biological soil quality with chloroform fumigations-incubation: Why subtract a control. Journal of Soil Science79:521-528.

Haney, R.L., A.J. Franzluebbers, E.B. Porter, F.M. Hons, and D.A. Zuberer. 2004. Soil carbon and nitrogen mineralization: Influence of drying temperature. Soil Science Society of America Journal 68:489-492.

Jenkinson, D.S., and D.S. Powlson. 1976. The effects of biocidal treatments on metabolism in soil-V: A method for measuring soil biomass. Soil Biology & Biochemistry 8(3):209-213.

Paul, E.A. 2015. Soil Microbiology, Ecology, and Biochemistry, 4th ed., 541-560. San Diego, CA: Academic Press, Elseveir.

Sincik, M., B.N. Candogan, H. Demirtas, S. Buyukcangaz, S. Yazgan, and A.T. Goksoy. 2008. Deficit irrigation of soya bean (Glycine max (L.) merr.) in a sub-humid climate. Journal of Agronomy and Crop Science 194:200-205.

Skopp, J., M.D. Jawson, and J.W. Doran. 1990. Steady-state aerobic microbial activity as a function of soil water content. Soil Science Society of America Journal 54:1619-1625.

Torbert, H.A., and C.W. Wood. 1992. Effects of soil compacting and water-filled pore space on soil microbial activity and N losses. Communications in Soil Science and Plant Analysis 23(11&12):1321-1331.

Voroney, R.P., and E.A. Paul. 1984. Determination of k and k in situ for calibration of the chloroform fumigation-incubation method. Soil Biology and Biochemistry 16:9-14.

Young, I.M., and K. Ritz. 2000. Tillage, habitat space and function of soil microbes. Soil & Tillage Research 53:201-213.

Table 11. Analysis of variance of soil microbial respiration in response to treatments.

Source	DF	Sum of squares (Type III SS)	Mean square	F value	Pr>F
Model	15	6907.89000	460.52600	0.71	0.7533
Error	32	20660.34667	645.63583	-	-
Corrected total	47	27568.23667	-	-	-
Crop type	3	(1733.930000)	577.976667	0.90	0.4543
Percent water filled pore space	3	(334.363333)	111.454444	0.17	0.9141
Crop type*percent water filled pore space	9	(4839.596667)	537.732963	0.83	0.515

Table 12. Means and standard error of microbial respiration in response to crop residue type. N=4

Residue	Mean	Standard error
Corn	123.38	7.3242
Soybean	130.49	7.5496
Wheat	119.72	7.3242
No residue	114.58	7.3242

Table 13. Means and standard error of microbial respiration in response to percent water filled pore space. N=4

Water filled pore space	Mean	Standard error
15%	121.50	7.0917
30%	119.90	7.3242
45%	126.68	7.3242
60%	120.08	7.7685

Table 14. Means and standard error of microbial respiration in response to the interaction of residue type and percent water filled pore space. N=16

Residue	Water filled pore space	Mean	Standard error
Corn	15%	95.333	14.6485
Corn	30%	132.00	14.6485
Corn	45%	130.53	14.6485
Corn	60%	135.67	14.6485
Soybean	15%	134.75	12.6859
Soybean	30%	123.20	14.6485
Soybean	45%	136.40	13.6485
Soybean	60%	127.60	17.9406
Wheat	15%	136.40	14.6485
Wheat	30%	115.13	14.6485
Wheat	45%	121.00	14.6485
Wheat	60%	106.33	14.6485
No residue	15%	119.53	14.6485
No residue	30%	109.27	14.6485
No residue	45%	118.80	14.6485
No residue	60%	110.73	14.6485

SUMMARY

While weather and edaphic factors do have some influence on water used for irrigation in Southwest Missouri, they are unable to fully explain the difference in this study. In order to better understand how to most efficiently use our natural resources, it must first be understood what factors drive their use. Further research into this topic would be beneficial for producers, consumers, and government officials as new policies are formed to conserve our natural resources.

The results of this study suggest soil microbes do not have a significant difference of response to water levels that would be expected in an irrigated agricultural field. However, other studies show that both crop residue and percent water filled pore space do have a significant influence on soil microbial respiration. It is possible that if time for crop residue decomposition was adjusted, or different percent water filled pore spaces were used, that not only would they have a significant influence on microbial respiration individually they may have an interactive effect as well.

This study suggests that the microbes respond similarly between 15 and 60 percent water filled pore space. If irrigation is used to maintain enough soil moisture for optimal crop growth, then soil moisture rates should be adequate for soil microbial respiration. Since soil microbes work to break down nutrients in the soil profile that are then taken in by the plant, it is important to keep soil moisture levels high enough to keep both microbes and plants healthy.