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Analysis of Permaculture's Water Conservation and Crop Supporting Abilities

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ANALYSIS OF PERMACULTURE'S WATER CONSERVATION AND CROP SUPPORTING ABILITIES

A Capstone Project Presented in Partial Fulfillment

of the Requirements for the Degree Bachelor of Biology

with Honors College Graduate Distinction at

Western Kentucky University

By

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I dedicate this thesis to my parents, Curtis and Kay Chaney who always believed in me and my far-fetched dreams. Also the seven Great Pyrenees dogs that live across the street from Baker's Arboretum, thanks for barking at me when I needed it the most and keep up the good work.

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ABSTRACT

In the Middle East, virtually all agriculturally viable land is under high threat of desertification due to poor land and resource management and climate change. Mulching using straw flakes (straw mulch permaculture) is a method commonly used in successful dry land permaculture projects in the Middle East. We proposed that straw mulch permaculture would increase the amount of soil moisture during dry periods and that this method would not impact the growth and survival of the crop. In order to test this hypothesis, we took soil samples from plots with and without straw mulch permaculture in Bowling Green, KY and Essaouira, Morocco. We also measured the survival rate and total mass of plants grown in straw mulch-treated and control plots at the end of the growing season. Findings indicate that the presence of straw permaculture does increase the levels of soil moisture during dry periods, saving up to 33,000 L of water per hectare, and has no effect during wetter periods. The results also showed a significant difference between the mass of plants grown in plots treated with straw mulch permaculture and the control plots with plants grown in plots with straw permaculture having a slightly larger average. These results suggest that straw mulch permaculture has potential implications for small scale agriculture productivity in the Middle East.

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SECTION ONE: INTRODUCTION

The Earth's total population is growing at an unprecedented rate, reaching 7.5 billion people in 2017. The population is predicted to increase by 34% and reach 9.1 billion by the year 2050. To sustain this number of people, agricultural yields and water usage will also need to increase. The majority of this population growth will happen in developing countries where rapid urbanization is occurring at an accelerated rate (United Nations FAO, 2015).

The United Nations (UN) predicts that agricultural yields will have to increase by 70% by 2050 to meet demands. This increase will be mostly attributed to increasing cropping intensity, although agricultural expansion will still likely take place. Between 2005 and 2007, there were estimated to be 1592 million hectares of arable land that were used for agriculture, and it is estimated that there will need to be 1661 million hectares in use by the year 2050 (United Nations FAO, 2015). This increase will be mostly attributed to developing countries that are currently estimated to use less than 40% of their arable land for agriculture. Developed countries and land-scarce developing countries will likely stagnate in terms of agricultural expansion. Therefore, in order to keep up with the growing demand, cropping intensification will need to increase. Land use for cereal crops (rice, wheat) is predicted to increase by the largest margin, in order to keep up with growing demands caused by an increase in population and feed for the growing livestock industry. The overall increase in both total amount of agricultural land and intensity of cropping will require an increase in irrigation, furtherer straining water resources for drier countries.

Agriculture accounts for 70% of global water usage, and this rate is typically higher in developing countries (United Nations FAO, 2015). Currently, 80% of the world population lives in an area affected by some type of water stress (Vörösmarty et. al, 2010). Water stress is defined by the European Union as agricultural needs in developed countries are much higher than those in undeveloped countries because of increasingly industrialized diets. Two primary reasons for this are a more meat-rich diet and a higher dependency on biofuel. The production of meat and animal products requires substantially more water than crop production and globally constitutes 29% of an average consumer's water footprint (Hoekstra, A. Y., & Mekonnen, M. M, 2012). The predicted shift from fossil fuels to biofuels will also put an additional strain on freshwater and food resources (Gerbens-Leenes, W., Hoekstra, A. Y., & van der Meer, T. H., 2009). The World Bank reported that biofuels were likely responsible for the 75% increase in food prices between 2002-2008, and prices are going to continue to increase as the biofuel industry grows (Mitchel D, 2008).

This trend will inevitably cause higher food prices, more intensive and extensive agriculture, and increased utilization of water resources. If not managed properly, these issues will likely lead to extreme poverty and limited access to essential resources, as long as resources are not efficiently used and strategically distributed. Not having access to an adequate supply of food or water can lead to extreme poverty as well as political and economic instability that can result in total state failure and threaten global security (United Nations FAO, 2015).

Decrease in Arable Land

Desertification is the process by which land becomes increasingly arid and loses bodies of water, natural wildlife, and vegetation (Geist, H, 2017). Desertification can be a natural phenomenon but is often accelerated by climate change, deforestation, and improper agricultural practices. An increasing rate of desertification is decreasing arable land used for agriculture and decreasing the amount of available water on a global scale (United Nations, 2015). Studies in southern New Mexico indicate that long term grazing can lead to heterogeneity of soil resources like water and essential nutrients. These conditions promote desert shrubs, which then furtherer perpetuate soil, water, and nutrient heterogeneity by accumulating these resources under the shrub canopies while simultaneously making exposed soil lose fertility through erosion and evaporation. This positive feedback cycle leads to an accelerated desertification in the southwestern United States and the Sahel (Schlesinger, et al., 1990).

Topsoil is the most nutrient-filled layer of soil and is necessary for peak agricultural production. Elimination of topsoil in arid environments causes a shift in soil particle size and composition. One study in Mongolia indicated that during the transition of non-desertified cropland into severely degraded land, the proportion of sand in the plough layer increased from 68.8% to 92.5%, and organic levels of C and N decreased by 65% and 69%, respectively (Su, Y., & Zhao, H., 2004). Research evaluating 17 study sites from around the world determined that the most important indicators of degradation and desertification are rain seasonality, slope gradient, and water stress. The study found that areas with high rain seasonality have accelerated rates of soil erosion due to the high drainage density the area receives within the wet period of the year. Soil salinization is also found to be correlated with desertification in arid and semi-arid regions. It found that long term land use, overexploitation of the ground, and continuous water scarcity correlated with increased secondary soil salinization (Kairis, O., 2014).

Water Scarcity and the Middle East

In the Middle East, virtually all agriculturally viable land is under high threat of desertification. The Middle East region accounts for 4.4% of the world's population and 4.9% of the Earth's surface area but holds only 1.1% of the world's total renewable freshwater resources. In the Middle Eastern region, 84% of water withdrawals are used for agricultural irrigation (Frenken, K. 2009). Many countries in the Middle East and North Africa are considered land scarce with an estimated 28 ha of arable land, 19 of which are currently used for agriculture (Alexandratos, N., & Bruinsma, J., 2012).

The American Meteorology Association, among other sources, finds that the Middle Eastern region is likely to grow drier and hotter in the next century (Gleick, 2014). A study conducted by the University of New Wales predicted that the amount of precipitation in the Middle East region will decrease by 25% before the next century. According to the study, this will lead to significantly lower the soil moisture levels in the region and likely move the agricultural transition zone northward by approximately 75 km of where it is located today. This would result in a loss of 170,000 km2 of viable rain-fed agriculture in the next century spanning across Eastern Mediterranean, Turkey, Syria, and northern Iraq (Evans, 2009). This drying trend is especially destructive for countries where agriculture makes up a significant part of the labor force, such as Syria. Syria experienced one the worst droughts on record from 2006 to 2011 causing many farms to fail. Because of this, experts like Gleick have listed the drought as one of the leading causes of the Syrian Civil War (Gleick, 2014). The Middle East region is also subject to a degree of rain seasonality. As a whole, the region receives approximately 2cm of rainfall per month between November and May and less than .5cm per month between June and October (World Bank Group, 2016). These months are also the hottest, and are predicted to increase in temperature and cause more drought than already exists in the next century (Geist, 2017).

A vast majority of agriculture in the Middle East is possible through one of the two main types of irrigation: withdrawal irrigation and consumptive irrigation. Water consumptive irrigation is typically used in climates where there is enough precipitation to sustain crops at certain times of the year, but there are also periods of drought where there is little to no rainfall. In these cases, the consumptive water use is defined as the amount of water required to compensate for the net water loss through evapotranspiration. While rainfall and consumptive irrigation provide sufficient water for agriculture in a few regions of the Middle East including northern Morocco, Algeria, and Tunisia as well as Turkey (World Resources Institute, 2013), withdrawal irrigation is more prevalent.

Major withdrawal points in this region are significant river systems such as the Nile, Tigris and Euphrates, and Jordan River basins. Underground aquifers also act as a significant source of irrigated water. Worldwide, underground aquifers account for approximately 20% of irrigation sources, and this figure is estimated to be higher in arid and semi-arid countries. Many underground aquifers are considered to be non-renewable in drier regions because they were established at a time when the area had a wetter climate and now regenerate at a very slow or non-existent rate. It is projected that most Middle Eastern and North African aquifers are regenerating at a rate of 0-2 mm/year which is not enough to keep up with the demands of irrigation (Döll, 2009).

Non-renewable aquifers can also contain dangerously high levels of radiation. The world's largest freshwater aquifer, the aquifer located on the borders of Egypt, Libya, Sudan and Chad, has radium levels 20 times higher than international standards. This is not a problem unique to the Nubian Aquifer and has been documented in several other major aquifers across the Middle East. Radium is an element naturally formed from the uranium and thorium found in rocks, but is typically absorbed by minerals more readily available in surface waters and flow into the air (Patterson, 2005). Therefore, older aquifers naturally accumulate higher levels of radium than on the surface. According to the World Health Organization, the high levels of radiation caused by the radium have the potential to elevate cancer and cause other health related issues even if not consumed directly, as it also accumulates in irrigated crops and in livestock (Rogers, 2018).

Karst geologic conditions also play a major role in the distribution of water availability. The term karst describes a topography characterized by a rocky, barren landscape and subsurface caves and tunnels usually eroded from soluble rock substrate (Encyclopedia Britannica, 2019). Rocky desertification is when soil is eroded away to the point of exposed bedrock (Karst Water Institute, 2014). In an undisturbed karst system, water is kept near the ground's surface by topsoil. When this topsoil is eroded away, water's percolation through the aquifer into inaccessible depths is accelerated. Therefore, karst areas are more sensitive to human caused environmental damage such as deforestation (Baiping et al., 2006).

Permaculture and Related Research

Permaculture is a type of sustainable agriculture that attempts to mimic the natural ecosystem in order to grow crops as sustainably as possible. Bill Mollison and David Holmgren, who named these methods "permaculture," define it as carefully selecting plant and animal species to create a "cultivated ecology" that is self-perpetuating in local conditions (Mollison and Holmgren, 1981). Permaculture also integrates aspects of science through the unique selection of plant species that work together to create a healthier, regenerative ecosystem that is capable of supporting more than the landscape previously could.

There are a number of successful permaculture sites in dry regions, including Geoff Lawton's permaculture project in the Wadi Rum desert of Jordan, where he succeeded in growing a number of crops and fruit bearing trees using less than 50% the amount of water that is used by traditional agriculture methods in the region (Mackintosh, 2014). Cutting water usage to this degree has powerful implications for dry countries like Jordan, where over 85% of the renewable water budget is used for agriculture. This statistic suggest that, if permaculture projects like Geoff Lawton's were practiced on a large scale, Jordan could save between 460 and 532 million cubic meters of water annually (Greenwood, 2017). Lawton's project was also able to support fruit trees and legumes in desertified areas where these plants could no longer grow naturally. By establishing plant species that have deeper roots, these permaculture sites are also slowing soil erosion and promoting topsoil development (Footer, 2014.) Another significant example is a Neal Spackman's project in Saudi Arabia, located in a region that receives less than 10mm of rain per year. According to an interview with its creator, the site, which is less than 10 years old, is showing promising results such as fruit bearing trees and even fauna such as crickets and frogs, all of which are scarce in the dry region. (Footer, 2014).

Mulching is a common practice in permaculture and straw or hay is considered to be one of the most effective mulching options (Trought, 2018). Mulch in many drier systems is used to prevent excess water evaporation. This was done in Lawton's successful Greening the Desert experiment by using excess organic material (mostly straw) from surrounding fields. Although no scientific research has been published concerning the Greening the Desert project, there are studies that support the theory that straw mulch significantly increases moisture retention. One study from the American Agronomy Society found that straw mulch was able to increase soil water storage, especially in conditions with less precipitation. The study also reported a positive correlation between soil wetting depth and straw mulch (Ji, Unger, 2001). Despite this success, there have been no documented studies in the refereed journal that are focused on dry land permaculture. There are agricultural studies conducted that study methods similar to ones commonly used in permaculture; however, they do not explicitly mention permaculture, like projects mentioned previously.

An experiment was conducted in Morocco by the *Institut National de la Recherche Agronomique* that also supports that straw mulching can also improve soil conditions and protect plants from physiological stress. This experiment determined that soil aggregation and soil nutrient pools increased when the soil was not tilled and the system was straw mulched. Although the study did not find a correlation between soil moisture and the amount of straw mulch used, this is likely due to the periods of drought throughout the experiment and the type of drill used in planting and taking soil samples This experiment also found that plots with high amounts of straw mulch generally had higher crop yields. (Mrabet, 2002).The the *Institut National de la Recherche Agronomique* also noted that despite this success, excessive levels of crop residue could lead to phytotoxicity, plant disease, weed-control management problems, and difficulties in effective fertilizer placement. Based on these potential issues, the study determined that more research on the high crop residue rates was needed.

A study conducted near the Danjiangkou reservoir in Central China studied the effect of straw mulching on citrus production. It found that the straw mulch significantly increased the amount of soil water in the top 100 cm of soil and decreased the amount of runoff. This study used full straw mulch coverage like our study (6,000 kg/ha^2), although synthetic fertilizer was used. The study found that the results were only significant in the

dry portion of the year (January to March), but not during the wet season (July to September). The first year of the study, the straw mulch had no significant effect on the quantity of crops; however, in 2011 when this region experienced drier and cooler weather, the straw mulched citrus trees produced significantly more fruit than the control trees. The researchers theorized that the straw acted as an insulator during the cooler winter months that helped preserve the citrus trees, making them more fruitful later in the year. The results of this study indicate that full coverage of straw mulch can significantly improve soil water storage, reduce run off, and even increase crop quantity in cases of extreme weather (Liu et al., 2014). This experiment used a large amount of straw mulch (full ground coverage and several cm thick), and laid it in a manner comparable to the straw mulch permaculture technique used in our study.

A study was conducted at the University of Lithuania that measured the effect of different organic mulches on soil moisture, soil organic matter and key nutrients, and soil temperature. The study focused on wheat straw, peat, sawdust, and grass and layered the material down in 10 cm sheets. They found that straw, peat, and sawdust mulches significantly affected soil moisture level, with straw mulched areas retaining 21.98% more than unmulched areas. It was also noted that although this area of Lithuania receives enough rainfall to sustain crops, there are drier periods during the growing season. The study reported that straw mulch also stabilized moisture throughout the growing season and produced healthier crops during these drier periods compared to the unmulched crops. This study found a correlation between straw mulch and decreased soil temperature. The results of the experiment also showed a greatest temperature difference between the mulched plots and control plots with straw mulched plots being 0.7 to 1.6 C cooler than unmulched plots. This could be beneficial as many countries are experiencing warmer temperatures during growing seasons due to climate change (Sinkevičienė, A., Jodaugienė, D., Pupalienė, R., Urbonienė, M, 2009).

The success levels associated with dry-land permaculture are unprecedented which emphasizes the need for change in the way permaculture is studied (Footer, 2014). There is clear evidence of permaculture’s success; however, without experimental and quantifiable data, the benefits of this method will continue to be ignored. The goal of my research is to test straw mulch permaculture's ability to conserve water and its effect on overall crop growth by comparing soil moisture levels in straw mulch-treated and untreated plots in a garden situation. I am taking soil samples and assessing crop growth using non-destructive methods every three weeks in Bowling Green, Kentucky.

To further study the water conserving and crop growing properties of straw mulch permaculture we conducted the following study. We propose that straw permaculture will have a significant effect on soil moisture during drier periods and will not have an effect during wetter periods. We also predict that straw permaculture will not have an effect on crop quality and quantity. The null hypothesis for this study that straw-permaculture has no effect on soil moisture or crop quality and quantity, while the alternative states that there will be significant influence on soil moisture and crop quality or quantity.

SECTION TWO: METHODOLOGY

The Bowling Green site was located at Baker's Arboretum (36.987059N, 86.513427W). A field including 28 individual plots was established on May 21, 2018. The plots were randomly assigned one of four treatments that had seven replicates of each. The treatments included no straw flake and no crop, no straw flake and crop, with straw flake and no crop, and with straw flake and crop. A straw flake in this experiment is a meter by a meter unit of straw that is 3-4 cm thick and straw that is oriented parallel to the ground. The plots with no flake served as controls. The type of soil for these plots is Nolin silt loam (United States Department of Agriculture, 2019). The field was unplowed with shallow soil and located at a slight incline. The average soil depth for these plots was 30.213cm until bedrock was reached and the average soil depth for Nolin Silt Loam in this region is 152.4cm (Mitchell, 2000). The soil depth was measured by pushing a 45 cm rod into the ground, 5 times per plot and then averaging these results. No additional water was added to the crops aside from natural rainfall.

Soil sampling occurred roughly every three weeks from May 18, 2019 until October, 20, 2018 and then approximately one year from the start date on May 21, 2019. Soil is collected by a soil auger with a 1.5cm diameter at depths of 5-6cm or until bedrock was hit. After the soil samples were extracted, they were placed in paper soil bags. These samples were weighed using a Veritas M124A Analytical Balance within an hour of extraction. They were then dried in plastic cups with a lid for at least 4 days in an unheated greenhouse where temperatures were often above 40□C. After drying the samples, they were reweighed to determine the percent water in the soil. Additional drying measures were taken for some soil samples by putting them in a 100°C soil oven for at least 24 hours. The soil samples that were dried in an oven were from the weeks of May 22nd, 2018, September 22nd, 2018, October 19th, 2018, and May 21st, 2019 respectively.

In addition to soil sampling, data from soybeans planted at this location on May 18, 2018 was also collected. Roundup was sprayed on the field before and after planting. There was no additional weeding of the plots throughout the duration of the growing period. In each plot, there were five planting locations, four approximately 10cm from every corner and one in the center. Two seeds were planted in each location to increase the probability that a plant sprouted from each location. If two plants sprouted from a location, the smaller one was weeded out to eliminate effects from competition. If the center plant died, then data was taken from the plant with the next highest level of competition. On October 20, 2018, the plants were removed from the plots and weighed later that day. The pods and leaves were also collected, as well as the dry weight by drying the plants in a soil oven at between 54°C and 60°C for 20 minutes. All data collection days contained soybean data, with the exception of May 18th, 2018, and May, 21st, 2019. These dates both fell outside the soybean growing period in Kentucky, which is June - October.

The Moroccan site was located near Essaouira, Morocco at (31.37175N, 9.4016W). A field with two plots was established on July 6’ 2018, one a control with crop and the other being treated with straw mulch permaculture. This site was tilled to depths not exceeding 13 cm and was watered 20L/m2 once a week. Soil was extracted by a 2.5 cm diameter auger 6 days after watering. The soil was weighed immediately with a

Carolina 200g Compact Balance after removal and then weighed again after being dried outside for at least 24 hours. Sampling for this site was limited to once a week for two weeks after July 6; after this point, there was a water shortage and the plots were not able to be watered at the previous 20L/m2 rate.

The sampling for this experiment took place at two locations, one in Bowling Green, KY and one in Essaouira, Morocco. Each site contained an untreated control plot and a straw culture treated plot. Treated plots consisted of laying flakes on the plot. Soil samples were taken randomly from each plot but at least 3 cm away from the border of the field to eliminate outside influence.

The driest week was the focus of the statistical analysis testing due to the discrepancy between the precipitation rates in Bowling Green, the primary research location, and the areas of interest, the Middle East and Morocco. The average annual precipitation rate for Bowling Green, KY is 126.2cm whereas in Morocco it is 34.6cm and 15.5cm in the Middle East region (US Climate Data, 2019)(World Bank Group, 2016). Although there is a major discrepancy between precipitation rates, the data from the driest week test the straw flake's ability to hold onto water during drier periods. We want to recreate these conditions in order to test whether straw mulch permaculture can increase soil moisture in areas that experience rain seasonality such as the Middle East (World Bank Group, 2016).

We used the IBM Statistical Package for the Social Sciences (SPSS) Package to determine the significance of the straw and bean components on soil moisture. To do this, we used a two-way Univariate Generalized Linear Model ANOVA to compare the means of plots with straw treatment to those without. We tested the driest and wettest weeks of the sampling period that were oven-dried at the Bowling Green site. We also performed a two- way Univariate Generalized Model ANOVA to determine the level of significance that the presence of the straw treatment had on the total mass of the plants at the Bowling Green site.

SECTION THREE: RESULTS

Throughout the experiment, the soil of the permaculture-treated plots typically held significantly more water than the untreated plots during dry periods and about the same amounts during wetter periods at the Bowling Green site (Figure 1). Two significant factors that affected soil moisture were rainfall and the presence of straw permaculture (Figure 2). The amount of soil moisture fluctuated with the amount of rainfall received the week prior to data collection. Plots treated with straw mulch permaculture generally had a higher percentage of soil moisture than untreated plots.

A Two way General Linear Model Univariate Analysis showed that we could reject the null hypothesis that straw permaculture has no impact on soil moisture levels and accept the proposed hypothesis that it significantly affects soil moisture levels in drier conditions (Table 3). Weekly rainfall rates varied throughout the study. The wettest week of the study duration was the week of October 19th, 2018 when Bowling Green received 8.86cm of rain. The driest week of the study was May 21st, 2019 when Bowling Green received 0.504cm of rain. During this week, the average control soil moisture content was 9.8 % while the treated average was 16.4%. The only week during which the average soil moisture of the control was similar to the treated was the wettest week (the week of October 19th, 2018) at 19.5% and 19.8%. A Two way General Linear Model Univariate ANOVA on the wettest week's data showed that the difference between the mean soil moisture values from plots treated with straw permaculture and untreated plots was not significant (Table 4). A Two way General Linear Model Univariate ANOVA was also performed on data from May 21st, 2019, the driest week that was oven-dried. This test showed that the difference between average soil moisture values from treated and untreated plots was highly significant (Table 5). This test also shows the influence of the soybeans was not significant. (Table 5)

The average mass of the soybean plants at the end of the study was 144.7g, and the survival rate was 67%. A Two-way General Linear Model Univariate Analysis shows that soybean plants were significantly larger in treated plots than those in control (Table 5).

Table 1

Includes general information from each plot in the Bowling Green location such as the treatment type (1: Control, 2: straw and no soybean, 3: soybean and no straw, 4: straw and soybean), the average soil depth for the plot, the average percent soil moisture after the implementation of the straw flakes on May 21st, 2018, and if applicable, the average plant mass at the end of the experiment and survival rate of the soybean plants.

Plot Number	Treatment Type	Soil Depth (cm)	Average Percent H20/Mass, After Treatment	Soybean Plant Mass (g)	Soybean Survival Rate
1	2	17.76	12.21994	--	--
2	2	15.66	15.23416	--	--
3	4	34.18	22.99687	146.375	0.8
4	3	38.45	16.15502	136.25	0.8
5	4	37	17.23832	133.56	1
6	1	30.41	20.2062	--	--
7	3	25.14	19.66541	64.9	0.4
8	2	26.22	20.64909	--	--
9	3	37.66	16.98832	131.8	0.8
10	2	34.96	22.02123	--	--
11	4	37.64	19.47285	180.85	0.4
12	4	31.02	17.18978	223.825	0.8
13	1	14.22	14.57315	--	--
14	1	25.66	12.99093	--	--
15	1	36.72	14.65307	--	--
16	4	37.12	21.05006	163.3667	0.6

17	4	25.04	22.24234	134.7	0.2
18	1	30.54	17.44616	--	--
19	2	39.42	20.68983	--	--
20	4	30.02	16.60812	324.7333	0.6
21	3	23.36	11.95046	92.71333	0.6
22	3	35.56	14.87766	75.1	0.8
23	3	33.1	16.55243	101.825	0.8
24	2	38.32	18.30421	--	--
25	2	24.8	15.52265	--	--
26	3	33.4	13.0754	115.175	0.8
27	1	26.3	14.73415	--	--
28	1	29.08	16.98405	--	--

Table 2

Includes general information from each plot in the Essaouira, Morocco location such as the treatment type (1: soybean and no straw, 2: straw and soybean), the average soil depth for the plot, the average percent soil moisture after the implementation of the straw flakes on July 6th, 2018.

Plot Number	Treatment Type	Soil Depth (cm)	Average Percent H20/Mass, After Treatment
1	1	33.6	8.297101
2	2	33.6	13.50004

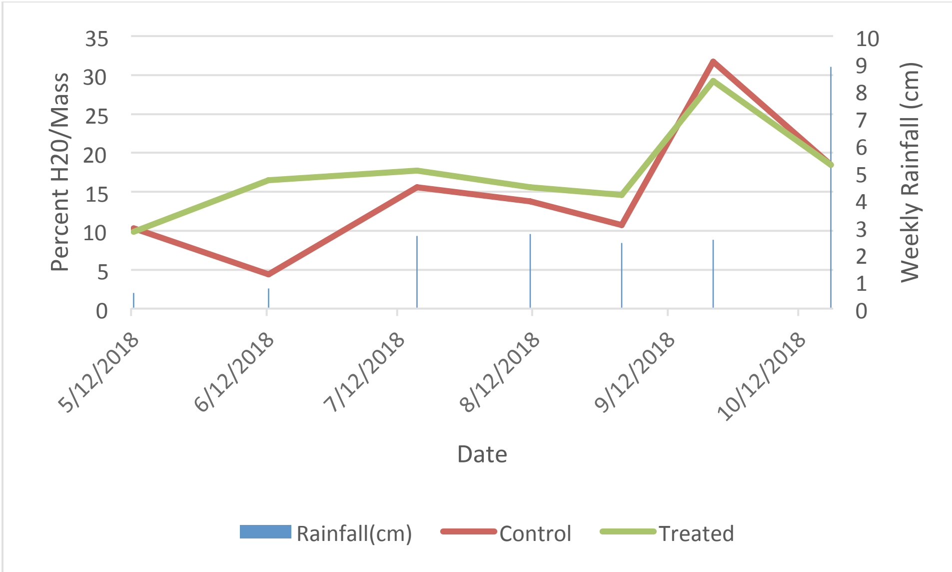

Figure 1 Measures the percent water of the soil mass from May to October in the control and treatment plots. Note that the yellow line indicates the implementation of the straw permaculture on May 21, 2018. The amount of rainfall during data collection is also included as bars along the X-axis of the graph.

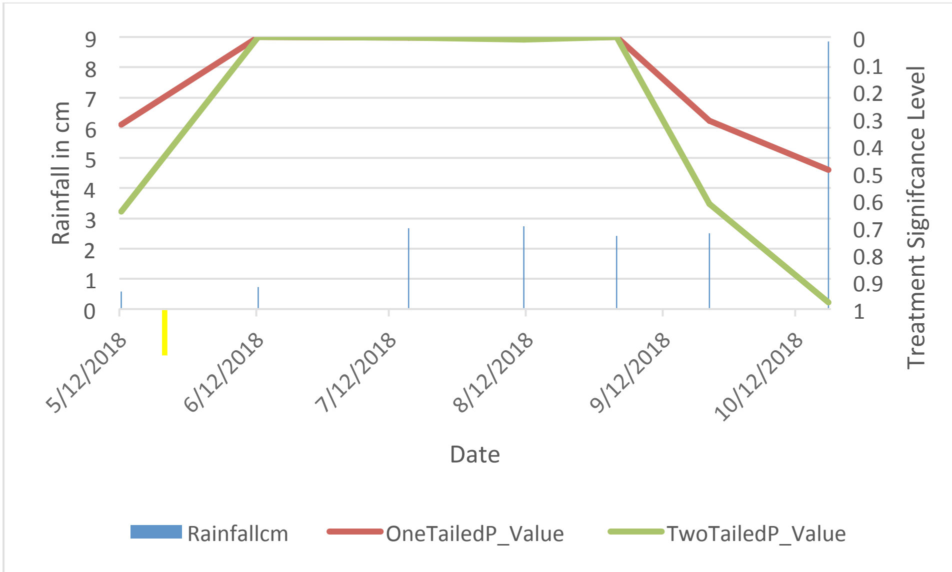

Figure 2 Measures significance level of permaculture treatment May-October. Note the yellow line which indicates when permaculture was implemented. This figure indicates that straw had a very significant influence on soil moisture during drier periods and during wetter periods straw flake's effect on soil moisture was not significant. P-values gathered from Two Sample T-tests for Independent Samples.

Table 3

This two way Univariate General Linear Model Analysis compared the soil moisture levels of the presence of straw and the presence of beans on soil moisture levels during the week of May 21, 2019. This was the driest sampling period that was oven-dried at the Bowling Green site with .508cm of rain. The test showed that plots with straw permaculture treatment and plots without treatment had highly significant difference in soil moisture levels (sig=0.000). The ANOVA also showed that the soybean plants did not have an effect on soil moisture (sig=.991).

Tests of Between-Subjects Effects

Dependent Variable: Per_Water

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	4692.392[a]	3	1564.131	8.317	.001
Intercept	170659.584	1	170659.584	907.495	.000
straw	4344.907	1	4344.907	23.104	.000
bean	.023	1	.023	.000	.991
straw * bean	347.462	1	347.462	1.848	.187
Error	4513.334	24	188.056		
Total	179865.310	28			
Corrected Total	9205.726	27			

a. R Squared = .510 (Adjusted R Squared = .448)

Table 4
This two way Univariate General Linear Model Analysis compared the soil moisture levels of the presence of straw and the presence of beans on soil moisture levels during the week of Oct 19th, 2018. This was wettest sampling period at the Bowling Green site with 8.86 cm of rain. The test showed that plots with straw permaculture treatment and plots without treatment had an insignificantly difference in soil moisture levels (sig=0.971). The test also showed that plots with soybean plants and plots without soybean plants had an insignificant soil moisture difference (sig=0.981).

Tests of Between-Subjects Effects

Dependent Variable: SOILMOISTUREDEC

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	5.712E-5[a]	3	1.904E-5	.045	.987
Intercept	.953	1	.953	2262.893	.000
STRAW	5.717E-7	1	5.717E-7	.001	.971
BEAN	2.476E-7	1	2.476E-7	.001	.981
STRAW * BEAN	5.630E-5	1	5.630E-5	.134	.718
Error	.010	24	.000		
Total	.964	28			
Corrected Total	.010	27			

a. R Squared = .006 (Adjusted R Squared = -.119)

Table 5
Two way General Linear Model Univariate Analysis comparing the average mass of soybean plants on plots with straw permaculture treatment and plots with no treatment at the Bowling Green site. The result was soybean survival was a significant difference between plots with straw permaculture and plots with no treatment (sig=0.011).

Tests of Between-Subjects Effects

Dependent Variable: Plant Mass

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	24834.514[a]	1	24834.514	9.146	.011
Intercept	292951.931	1	292951.931	107.891	.000
straw	24834.514	1	24834.514	9.146	.011
Error	32583.014	12	2715.251		
Total	350369.459	14			
Corrected Total	57417.528	13			

a. R Squared = .433 (Adjusted R Squared = .385)

SECTION FOUR: DISCUSSION

The results of this research support the alternate hypothesis that straw mulch permaculture increases soil moisture during dry periods and has a negligible effect during wetter periods (Figures 1 and 2). The plots that were treated with permaculture had an average moisture rate averaging 2.4 % higher than the surrounding soils throughout the experiment and up to 12.1% higher during drier periods. This equates to one hectare field containing $33m^3$ (or 33,000L) more water in the top 5 cm of soil during dry conditions if it is treated with straw mulch permaculture. This disparity is likely because the straw flakes lessen evaporation directly from the ground and absorb water during wetter periods that is then slowly distributed into the soil when conditions are drier. The soil moisture value is similar during wet periods because the ground is at near saturation point. Due to the water shortage at the Essaouira, Morocco location only two samples were collected at each site. This was not enough data to produce a statistically significant analyze.

The results of the Bowling Green site suggest that straw permaculture would be beneficial in climates with high rain seasonality. The method of laying straw in flakes is simple and easily done. The only major issue with this tactic is finding enough straw to lay it in flakes 3-4 cm thick. This can be difficult to accomplish in drier areas of the region where growing grasses can be challenging. However, there are ways to acquire straw in parts of the region. In Geoff Lawton's Greening the Desert project, they were able to use organic material such as straw from farms that had no use for the organic matter after their harvest (Greenwood, 2017). In Mrabet's experiment they were also able to utilize the wheat residue left over from the previous years' crops in several hectare fields (Mrabet, 2002). Therefore, utilizing organic matter could make straw mulch permaculture practical on a large scale in some areas. Based on the results of this experiment, this approach would be best utilized on a smaller scale because of the large amount of straw that was required to conserve soil moisture. This experiment used $0.04m^3$ per plot and if this was uniformly applied to one hectare, $400m^3$ would be required to achieve the same results.

In a garden-sized setting, this method could be easily utilized in the Middle East. In countries such as Jordan, gardens are fairly common, often lining yards of homes even in urban centers such as Amman, Jordan. Gardens are present throughout lower and upper class homes in the Middle East and often serve to provide a household with vegetables and fruits such as lemons, olives, grapes, and tomatoes, and because most of the Middle East does not receive enough rainfall to support these plants they are often watered. Gardens in this region range from a few square meters in urban settings up to a couple hundred square meters in suburban and rural settings.

Implementing straw permaculture practices in gardens could potentially lower the amount of water used in households. Due to gardens smaller size, straw permaculture would be more practical in these settings because significantly less straw would be needed than in a large agricultural operation. Implementing straw permaculture in gardens could conserve a significant amount of water given the abundance of gardens in the Middle East. Household gardens contribute to domestic water use which is one of the fastest growing water using sectors in the Middle East and currently accounts for 42% of water usage in Jordan. (Fanack Water, 2015). If straw permaculture were applied in this way, water could be conserved in urban areas where it is arguably needed the most. Straw permaculture is also a method that, once applied, can increase soil moisture for an extended period of time, so one treatment could potentially last several years before more straw is needed.

The significance of the soil moisture levels in response to the presence of straw permaculture during dry periods supports the alternate hypothesis that straw mulch influences soil moisture. Based on previous studies, this is the result that was expected. The American Agronomy Society conducted a study which showed that moderate levels of straw mulching significantly increased soil moisture, as did the *Institut National de la Recherche Agronomique* in a semi-arid region of Morocco (Ji, Unger, 2001),(Mrabet, 2002). These findings, as well as the results of our study, support the qualitatively successful results of Geoff Lawton's and Neal Spackman's permaculture projects in the Middle East (Mackintosh, 2014), (Footer, 2014). They also help explain how projects such as Lawton's can save 50% more water than surrounding projects (Mackintosh, 2014).

Despite the significance of this result, there are some variables in this study that may have impacted the final results. The greenhouse drying was the method used for majority of the study. This drying system did not account for the level of humidity that could contribute to the 'dry' soil weight, especially in cooler temperatures. This led to some negative values for soil moisture ratios, which should not be possible.

An additional sample was taken on May 21st, 2019. Straw flakes were still present at that time and the results showed that the presence of the straw flakes significantly increased soil moisture. There were no soybeans present at this time because they had been harvested six months prior on October 22nd, 2018 and planting season in Kentucky does not start until early June. The absence of soybeans at this date explains why soybeans were insignificant factor for this sample. The results may have been influenced by the late timing of this sample as well as the absence of soybeans. Due to the use of a drying oven as opposed to the greenhouse, the results of this data set are believed to more accurately reflect the dry mass of the soil. In future research projects concerning soil moisture, I highly recommend using a drying oven and keeping the soil samples in a humidity-free environment.

The significance of the crop data in this study leaves the null hypothesis in question. The null hypothesis stated that straw permaculture has no impact on soybean plants. While there was no significant impact of straw permaculture on the survival rate of the soybean plants, there was a significant influence of straw permaculture and the final mass of soybean plants. . The influence of straw permaculture on soybean growth in our study reflects findings of the study conducted by the University of Lithuania and the Chinese Academy of Sciences China. These studies also found that straw mulching supports healthier crops in times of drought (Sinkevičienė, A., Jodaugienė, D., Pupalienė, R., Urbonienė, M, 2009), (Liu et al., 2014).

Although the effect of straw permaculture on final soybean mass was found to be significant, there were many external factors that could have influenced this result. Throughout the duration of the experiment, there was significant damage inflicted by deer and other pests. One of the worst incidences occurred the week before final data collection, so this damage more than likely influenced the final results. Another factor that may have influenced the results was the lack of weeding throughout the experiment. I was able to lightly weed during data collection points (roughly every three weeks);

however, by the end of August, taller grass species were beginning to overshadow the soybean plants. This disproportionately affected the plots without straw flakes and was, likely, why the plants in areas treated with straw permaculture grew larger. This finding also supports that straw mulch permaculture allows more plant growth by suppressing weed competition; however, the level of weeding in this experiment was generally much lower than at a typical permaculture project. Therefore, more research conducted focusing on crop health is needed before a correlation between the health of crops and straw permaculture can be confirmed.

The results of this study indicate a strong correlation between straw permaculture and soil moisture, and a possible correlation with increased plant mass. This study and previous works support the notion that permaculture has the potential to significantly lessen agriculture resource consumption and serve to restore degraded land (Laffoon, 2016). Despite this, permaculture still needs to be researched on a larger scale if it is to be considered as an effective form of sustainable agriculture. More research needs to be conducted that evaluate permaculture's effect on a variety of crops, organic matter and soil restoration. There is also a need for permaculture research in different climates, particularly drier ones such as in the Middle East. This study attempted to research this topic at the Essaouira, Morocco site at a permaculture farm in North Africa. There were significant issues that prevented adequate data collection at this location, such as an unexpected water shortage and unreliable communication.

In conclusion, this experiment showed that straw mulch permaculture had a highly significant effect on soil moisture and the final mass of the soybean plants. These findings have major implications for arid and semi-arid regions, including the Middle

East. As previously stated, the Middle East is a region that is expected to experience higher temperatures and frequency of droughts over the next century, due to climate change (Geist, 2017). This study's findings support the argument that straw mulch permaculture could decrease water usage in the agricultural and domestic sectors, as well as promote healthier crops during times of drought.

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