AMERICAN UNIVERSITY OF BEIRUT

WATER PRODUCTIVITY OF *ORIGANUM SYRIACUM* UNDER DIFFERENT IRRIGATION AND NITROGEN TREATMENTS

by
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AN ABSTRACT OF THE THESIS OF

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Title: Water Productivity of *Origanum Syriacum* under Different Irrigation and Nitrogen Treatments

Origanum syriacum is a perennial herb from the Lamiaceae family in Lebanon. *Origanum* species are important culinary herbs with high commercial and medicinal potential. *Origanum* is native to Middle East and performs well in average dry soil, however, little is known about the species' water requirements. The present work presents the results of a field experiment at the American University of Beirut's (AUB) Agricultural Research and Educational Center (AREC) in addition to a greenhouse pot experiment performed to study the effects of various irrigation and nitrogen (N) treatments on the growth of *Origanum* which provides information on yield quantity, growth parameters and soil water use of *Origanum syriacum*. The field experiment included four irrigation treatments calculated to be equal to 60, 80, 100 and 120% of Hargreaves ET) automatically set and calculated via a commercial irrigation controller and a weather station and four N treatments (0, 75, 150, 225 kg/ha). Flow meters were installed on all four irrigation treatments to measure irrigation volumes. Additionally, the greenhouse experiment also consisted of four irrigation treatments based on available water (70, 50, 30 and 10% of managed allowable depletion) and four nitrogen treatments (0, 75, 150, 225 kg/ha). Irrigation scheduling in the greenhouse was automatically set based on soil moisture determination using soil moisture sensing devices. Two cuts were cultivated and analyzed from both the field experiment and the greenhouse experiment. *Origanum* water productivity, shoot height and number, fresh and dry weight, and dry leaf yield were assessed. Significant reductions were observed in above ground fresh and dry biomass and dry leaf yield with increasing water deficit. The lowest irrigation treatment in both field and greenhouse experiment was significantly different from all other treatments. Only the highest N had significant, pronounced effects on *Origanum*, and only during the second cut from the AREC experiment. Considering the various irrigation and N treatments, no significant effects were observed on *Origanum* shoot number. Significant increase in shoot height was observed at later stages through the growing season relative to the various irrigation treatments. Increasing water stress increased water productivity. Finally, results showed that the highest yields could be obtained when satisfying the crop's water requirement (120% ET). Furthermore, in case of water shortage managed deficit irrigation higher than 50% of field capacity or at 60% ET, increased water productivity, sustained yield and saved water.

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ABREVIATIONS

°C	Degree Celsius
3G	Third Generation
AC	Alternating Current
AREC	Agricultural Research and Education Center
AUB	American University of Beirut
C	Clay Soil
$CaCO_3$	Calcium Carbonates
cm	centimeter
CPE	Class A Evaporation Pan
CWP	Crop water Productivity
DAT	Day after Planting
DI	Deficit Irrigation
DLY	Dry Leaf Yield
DTC	Drought Tolerant Crops
DY	Dry Yield
EC	Electrical Conductivity
et al.	*Et allii* (and others)
ET	Evapotranspiration rate
ET_0	Reference Evapotranspiration rate
FAO	Food and Agricultural Organization
FC	Field Capacity
FY	Fresh Yield
g	gram
g/pot	grams per pot
ha	Hectare
I#	Irrigation Treatment
ID	Internal Diameter
K	Potassium
K_2O	Potassium Oxide
kg	kilogram
kg/ha	Kilogram per hectare
kg/m^3	Kilogram per cubic meter
L	Liter
L/sec	Liters per second
LAI	Leaf Area Index
LPH	Litters per hour
m	meters
m^3	cubic meters
m^3/ha	cubic meters per hectare
mg/pot	milligram per pot

mm	millimeter
mm/day	millimeters per day
mS/cm	milliSiemen per centimeter
N	Nitrogen
N#	Nitrogen Treatment
NH^{+}_{4}	Ammonium
NO^{-}_{3}	Nitrate
O. syriacum	*Origanum Syriacum*
OM	Organic Matter
P#	Pump Number
P_2O_5	Di-Phosphorus Pent-oxide
ppm	parts per million
R_a	Extra-terrestrial Radiation
RDI	Regulated Deficit Irrigation
RH	Relative Humidity
S#	Station number
S_e	Spacing between emitters
SH	Shoot Height
SIM	Subscriber Identity Module
SL	Sandy Loam
S_L	Spacing between driplines
SN	Shoot Number
SV	Solenoid Valve
t	ton
T_{avg}	Average Temperature
TDT	Time Domain Transometer
TDY	Total Dry leaf yield
TDYL	Total Dry leaf Yield
TFY	Total Fresh Yield
T_{max}	Maximum Temperature
T_{maxAVG}	Monthly maximum Temperature
T_{min}	Minimum Temperature
T_{minAVG}	Monthly minimum Temperature
UN	United Nations
V	volts
WP	Water Productivity
WUE	Water use efficiency
Y_a	Average yield

CHAPTER I

INTRODUCTION

The world has become increasingly aware of water and its scarcity over the past hundred years. Simithies (2011) mentions that the two most important factors for water scarcity are: (1) a boom in the population growth rate, as well as (2) an increase in economic growth and living standards. Water is becoming increasingly scarce in areas with abundant rainfall as well as arid and semi-arid regions (Pereira et al., 2002).

The United Nations (UN) predicts that water scarcity will be a major issue that would plague the 21st century (UN-water, 2007). The Food and Agriculture Organization's (FAO) Natural Resource and Environment Department stipulates that 1.8 billion people will be living in regions with absolute water scarcity by 2025.

Irrigation in arid and semi-arid regions would consume 70-80% of the world's diverted water supply (Fereres and Soriano, 2006). Given the fact that the environment in arid and semi-arid regions, where potential evapotranspiration is high and precipitation rate is low, irrigation is a necessity for better agricultural yields that satisfy the demand.

Throughout recent decades, extensive research has been invested into studying the limiting factors in production systems, mainly the availability of water and land (Greets and Raes, 2009). Deficit irrigation, a strategy where a reduction in the amount of water applied in periods of the growing season in which the yield is not significantly affected is one example of a more efficient growing system. Another would be the use of crops with high water productivity, which would improve the economic return per unit of water applied. Other options may include the use of mulches, crop rotations, efficient water delivery systems, drought tolerant crops (DTC), and plant breeding (Fereres and Soriano, 2006).

Irrigation has a direct effect on crop yield, as crops show different yield responses to irrigation. This has been and will continue to be studied thoroughly for various crop systems under different conditions. Previous research confirmed that water supply is the most limiting factor of herbal crop production and yield (Azizi et al. 2009). *Origanum syriacum* (*O. syriacum*) is an aromatic plant from the family Lamiaceae with a growing market interest over the past few years (Marques et al., 2009).

The objectives of this research were:

- Determining the yield response of *Origanum Syriacum* under four different irrigation treatments.
- Determining the yield response of *Origanum Syriacum* under four different nitrogen treatments.
- Determining the water productivity of *Origanum Syriacum* under different irrigation and nitrogen regimes.
- Determining the optimum combination of water and nitrogen requirements on yield and the economics of *Origanum Syriacum*.

CHAPTER II

LITERATURE REVIEW

In this chapter botanical classification description, economic importance and growth of the market interest of *Origanum syriacum* will be thoroughly discussed. This will be preceded with an explanation of the concept and goals of deficit irrigation, its effect on increasing crop water productivity (WP) and irrigation efficiency. The different Method used in irrigation scheduling and deficit irrigation management will be debated. Finally, this review will provide an overview of recent studies on the effect of hydric stress (deficit Irrigation) and N rates on oregano's economic yield under different agricultural practices.

A. Origamnum syriacum

1. Botanical Classification

The *Origanum* genus belongs to the Lamiacea family (in the subfamily *Nepetoidae*), in the Trobe *Mentheae*. Linneus (1974) initially described this genus in the year 1754. Iestwaart revised the taxonomy in 1980 according to variations in morphology. This revision gave rise to 10 different sections made up of 42 species, or 49 taxa. *Amaracus, Brevifilamentun, Anatolicon, Longitibus, Chilocalyx, Majorana, Campanulaticalyx, Origanum, Prolaticorolla*, and *Elongatispica* are all part of the genus *Origanum*.

Of the 49 taxa, 46 are distributed in the Mediterranean region and are locally spread: Three are in Morocco and the South of Spain; three are in Libya; two are in

Tunisia and Algeria; nine are in Greece, the South Balkans, and Asia Minor; 21 are in Jordan, the Sinai Peninsula, and Occupied Palestine (Kokkini, 1997).

The three most common *Origanum* species in lebanon are: *O. syriacum*, *O. libanoticum and O. ehrengergii represent Origanum* with the last two being an endemic in the country (Post and Dinsmore, 1933; Mouterde, 1983). *O. syriacum* has three different varieties. The first, *O. syriacum* var. *syriacum* is found in Syria, Jordan, and Occupied Palestine. *O. syriacum* var. *bevanii*, the second variety, grows in Syria, Cyprus, Turkey and Lebanon. The third variety grows in the Sinai Peninsula, and is called *O. syriacum* var. *sinaicum*.

2. Botanical Description

As one of the most successful and common plant in Lebanon's flora, *O. syriacum* is ubiquitous on the coast and on the west side of Mount Lebanon. Even though it is less common in the oriental mountains of Lebanon, *O. syriacum* is one of the most common species among the Lebanese flora (Mouterde, 1935).

O. syriacum can reach a height ranging from 0.5m to 1m. It has stiff branches and has a shrubby base. The leaves are petiolated/sessile, alternate, and ovate to ovate-oblong, obtuse, thick and entire. The limb being obviated to elliptic is 1cm to 3cm long and is usually obtuse with an entire margin with well-marked nerves (Post and Dinsmore 1933; Mouterde, 1983). Because the botanical identity of the plant is confused, many shrubs have been classified into "oregano" despite belonging to different genera or families. According to Labiatae L.H. Bailey Hortorium of Cornell University, the term "oregano" refers to a species of plants that is commonly Mediterranean termed "Origanum vulgare" (Olivierk, 1997). Nonetheless, Calpouzos

(1954) would argue, “the condiment name oregano should be understood to refer, not to any species but to a particular spice flavor furnished by plants of several genera in different parts of the world.”

Conpositae, Schrophulariaceae, Rubicaceae, Umbelliferae and Verbenaceae are all families that consist of plants known as “oregano”. Origanum vulgare L subsp. Viride (syn. O. Heiraclroticum) (Kokkni 1997, Skoula and Kamenopoulos 1997), Greek organo is an example of a species that has achieved economic significance. Furthermore, the chemovarieties that have been distigniuished based on oil composition and flavor profiles are: Marjoram, thyme, and oregano (Kokkini, 1997).

3. Economic Importance of the Genus Origanum

The genus *Origanum* encompasses the species of plants that are used for their aromatic, culinary, medicinal, and ornamental properties (Ietswaart, 1980). “Oregano” is the name given to *Origanum* plants used globally. The oil extracted from these types of plants has been found to possess antimicrobial, antioxidant and cytotoxic properties (Kokkini, 1997). However, in Lebanon *Origanum* is grown and marketed as dried leaves, fresh leaves, and essential oils.

In some instances, the same *Origanum* field is harvested several times throughout the growing season. Fall and spring cuts are marketed as dried leaves while summer cuts are used for the production of essential oil (Reuveni, 1997).

4. Cultivation

Biologically, domestic oregano can last for decades (Chiapporo, 1997). Economically, however, the life span is considered to be from the start of crop production until variable costs and gross costs become equal (a much shorter lifespan) (Kitiki, 1997).

The lifespan of oregano plants is affected by frost, disease and pests, how and how many times they are cut. Favorable conditions would give the crop an economic lifespan of 3 to 4 years in Italy (Marzi, 1997), and 5 to 6 years in Hungary (Bernath, 1997).

5. Propagation and Plantation

Oregano is a perennial crop and that exhibits asexual or sexual prorogation. If seeds were used, then propagation would commence in October. However, in May, rows would be prepared with an inter-distance of 25cm and seedling transplant (into the rows) would occur when the seedlings are at a height of 10-12cm. The spacing between each crop within the row must be 50-60cm (Bernath, 1997; Marzi, 1997). According to Kitiki (1997), 45 cm was the best spacing distance between crops

On the other hand, asexual propagation would be done in January either via stem cuttings (Chiapparo, 1997) or by clump splitting (Pasquier, 1997).

6. Harvesting and Yield

Determining when to harvest *Origanum* is dictated by what the end product is going to be. For herb production, *Origanum* plants are best harvested at bloom initiation; however for essential oil production harvesting should be carried out at full bloom (Marzi, 1997).

Chiapporo (1997) produced a ‘fresh’ yield of 10.2 tons per hectare that had a density of 17,000 plants per hectare with a total of two cuts per year. Another study that was conducted in the same region involved the monitoring of yield over time. With a density of 20,000 plants per hectare, and with 2 cuts per year, dry yield was increased from 2 tons per hectare during the first year, to 8.5 tons per hectare the following year. However, the third year showed a reduction in dry yield (5.8 tons per hectare) (Leto and Salamone, 1997). With a plant density of 63,500 plants per hectare in Slovenia, dry yield was 9.6 tons per hectare in the third year, with two cuts per year.

7. Recent studies on O. syriacum

Knowledge of a crop's performance under different agriculture practices is a must for successful cultivation and better yields. Recently, the market has been exhibiting an increasing interest in aromatic plants and herbs especially those coming from oregano (Marques *et al.*, 2009). This interest spawned different studies to be carried out on oregano. The main studies concentrated on studying the effects of hydric stress, different irrigation and nitrogen regimens on the crop's growth, yield, and quality and quantity of extracted oil (Attallah *et al.*, 2011; Hadid *et al.*, 2004; Scheffer, 1992; Silva *et al.*, 2002).

B. Evapotranspiration (ET)

ET is a term that describes a combined process where water is removed from an evaporative surface (evaporation), and from the leaf of a plant (transpiration). Considering that both ET and transpiration occur together, it is difficult to differentiate between them.

At early stages of the plant's life cycle, most of the water lost to the atmosphere (in the field) is due to evaporation. Throughout the growing season, and as plants grow, evaporation decreases while transpiration increases. The trend of an increase in transpiration coupled with an increase in evaporation will continue until the plant reaches its full maturity with a full soil coverage (at this stage, evaporation is almost zero) (Irmak *et al.* 2009). At field level ET rates are usually expressed as a unit of depth of water per unit time.

ET rate is influenced by the climatic conditions (solar radiation, relative humidity (RH), ambient temperature, humidity, speed of wind) and the characteristics of the mentioned crop (variety, type, development stage) (Irmak *et al.* 2009). ET rates are directly affected by the net solar radiation reaching the field and the ambient temperature on the field. Solar radiation increases the net kinetic energy, which increases water loss.

Wind has a direct relationship with ET rates as well; as the area around the crop becomes saturated with water, drier air will replace the surroundings, and consequently, ET will increase. On the other hand, RH has an indirect relationship with ET: As ET occurs, the surrounding air will become saturated with humidity, and ET rates of the plant will slow down and even stop. Wind speed also has a direct relationship with ET: ET increases as wind surrounding the crop increases (Allen *et al.*, 2011; FAO 56).

C. Irrigation Scheduling:

In the past, and with the absence of large populations, there wasn’t much of a competition for irrigation water (Burt *et al*., 1997). However, with the human population on the rise, water needs will increase beyond current supply in the near future (Fereres and Soriano, 2006).

The presence of large populations and the problems of climate change, industries and recreations, will all compete with irrigation water especially in arid and semi-arid climates where water is a scarce commodity. One approach of water saving can be achieved through increasing the irrigation efficiency. The ideal solution to alleviate the scarcity of water does not lie in increasing its supply, but rather in improving the effectiveness and efficiency of the irrigation methods used (Jensen, 2007).

Irrigation scheduling aims to achieve the optimal level of water supply for crop productivity (Jones, 2004); Water in the soil is kept at field capacity. Furthermore, irrigation scheduling involves calculating when the next irrigation events will occur, and the amount of water that will be applied during each event (Howell, Meron, 2007). Modern irrigation scheduling programs aim to set irrigation programs based on the water deficits of the plant itself, as opposed to basing calculations on the soil's moisture status (Jones, 2004).

Worldwide shortage in water is forcing the development of new methods that would maximize water efficiency. Although, trickle irrigation and such precision irrigation techniques have been efficient in reducing water loss of agricultural and horticultural crops, they have highlighted the need to develop more accurate irrigation schedules (Jones, 2004).

Irrigation scheduling is ideal for maximizing the effectiveness of irrigation water. The same benefit of conventional irrigation systems will be achieved, but with a far less amount of water supply and maximum crop yield (Jury and Vaux 2007). This method functions on a set of criterion and a prescribed strategy as to how much water to apply according to a particular time and situation (Sammis *et al.*, 2012).

1. Advantages of Irrigation Scheduling:

Irrigation scheduling offers various advantages, furthermore it gives them the ability to maintain a flexible and more accurate irrigation system whereby a more efficient and productive water delivery system will ensure proper and adequate water rotation, and minimize crop water stress simultaneously (Howel and Meron, 2007).

In addition to ensuring a more flexible irrigation system, the fact that water supply will be delivered according to the crops' proper need for irrigation –with no excess water- automatically means less drainage of costly water, and saving on the use of excess fertilizer by avoiding deep percolation (leaching) (Howel and Meron, 2007). This overall strategy of irrigation would ensure a lower economic burden upon the farmer.

2. Irrigation Scheduling Methods:

Proper and accurate irrigation scheduling could be carried out via a number of different methods of implementation. Which method will be used is based on the level of soil moisture. For maximum yield, soil moisture content has a threshold below, which it must not go; if or when it does, irrigation should be triggered (Jones, 2004; Howel and Meron, 2007).

Different methods are used as indicators of when irrigation should be triggered. These methods can be categorized as soil moisture based or ET based. Soil moisture content can be determined using many methods such as the feel method, gravimetric method, and with soil moisture sensors (Jones, 2004). On the other hand, ET based methods are the ones that replenish moisture lost by measuring the amount of water lost due to ET over a certain period of time and applying the same amount of water to the field.

ET can be determined through accurate measurements of physical and weather parameters or by the use of specific devices. ET measurements can be computed directly or indirectly. Lysimeters provide direct ET measurements whilst indirect methods include measured climatic data and calibrated equations. Other equipment such as calibrated atmometers and FAO Class-A evaporation pan are also used (Allen *et al.*, 1997; Allen *et al.*, 2011).

3. Evapotranspiration –based Controllers:

Evapotranspiration-based controllers are those that use ET data for irrigation scheduling. Studies have shown that, in comparison to regular time-based controllers, ET-based controllers have the ability to save about 40% of water (Davis and Dukes, 2010).

Standalone, signal based and historical based controllers are the three main types of ET-based controllers (Riley, 2005). Standalone controllers are connected to sensors installed in the field that measure the crop's cumulative ET and schedule the irrigation timing accordingly. Sensor types are many and may include: ET gauge, temperature, solar radiation or even fully equipped weather stations (Riley, 2005). Oother types of ET-based controllers are those that wirelessly receive information on ET_0 rates from the manufacturers (signal based controller). These ET_0 rates can be from an average of nearby weather stations or from only one weather station (Riley, 2005). Lastly, the historical type controllers are having the historical ET_0 data already logged into the controller. The data is adjusted based on the history of the site in question for better irrigation scheduling (Riley, 2005). Inputs into the ET-base controllers are a must from both the manufacturer and the user for more efficient irrigation.

4. Irrigation Scheduling on Oregano

Hadid et al. (2009) states that climate is only one of the factors that would determine ET. Furthermore, proper Irrigation scheduling may result in a significant increase in crop production. In a recent study carried on by Marques et al (2009) studying the effect of irrigation scheduling using Class A evaporation pan at different irrigation rates showed significant results with a total of 161.8 grams of fresh weight per plant, as opposed to 62.5g from treatments using 0%CPE (Class A Evaporation Pan).

D. Deficit irrigation

Deficit irrigation (DI) is the application of water at a rate below the crop's ET. The reduced amount of water applied is based on the crop's maximum ET (Fereres and Soriano, 2006). Another definition of DI would be: "an agricultural water management system in which less than 100% of the potential evapotranspiration can be provided by combination of stored soil water, rainfall and irrigation, during the growing season" (Upchurch *et al.*, 2015).

1. Goals and Benefits of DI

The benefits of DI are varied. According to Chalmers *et al*. (1981), maintaining a slight water deficit in a plant would enhance partitioning carbohydrate assimilates into reproductive structures. This observation gave rise to the term: "Regulated Deficit Irrigation" (RDI) (Chalmers *et al*., 1986).

One drawback of RDI is that it provides a very narrow tolerance of water imbalance; Excessive application of water would cost more (in terms of water use). Conversely, insufficient water supply would cause a sever reduction in yield and yield quality (Jones, 2004).

If an insufficient amount of water is applied via DI a drop in yield could be exhibited, with an increase in crop water productivity (WP) (Greets and Raes, 2009). DI may maximize the yield per one unit of applied water thus improving water use efficiency by reducing vegetative growth whilst maintaining yield (Pereira et al., 2002; Geerts *et al*., 2008). In fact, in areas where water is scarce, maximizing WP through DI practices is often much more profitable than maximizing the crop yield (Greets and Raes, 2009).

Other Benefits of DI may include: the reduction of excessive and unnecessary vegetative growth, soil moisture maintenance (at an acceptable level), the reduction of diseases and pests emergent due to waterlogging in the crops' root zone as a result of excessive water application, and the maintenance of deficit throughout the irrigation schedule. All the aforementioned benefits translate into overall improved water use (Pereira *et al*., 2002; Steduto *et al*., 2007; Geerts *et al*., 2008; Fereres and Soriano, 2007).

2. Deficit Irrigation and Irrigation Scheduling:

The kind of irrigation scheduling applied is decreed by the farmer's aims and the available irrigation systems. More sophisticated systems are required for more precise irrigation scheduling and scheduling techniques (Jones, 2004). It should be noted that even flood irrigation, and other less precise irrigation practices benefit from irrigation scheduling. DI aims to irrigate ‘less but more often’ based on soil moisture and plant moisture readings (Jones, 2004).

DI necessitates the use of precision in irrigation controls, and the maintenance of soil moisture statuses within very narrow ranges so as to achieve the desired crop management system (Jones, 2004). Trickle irrigation and similar precise irrigation techniques are needed here due to their ability to supply the desired amount of water precisely and at required intervals (Jones, 2004). Manual monitoring programs are out of the question due to the requirement of monitoring water levels either in real time or at regular intervals throughout the day.

3. The Economic justification of DI

DI is an essential economic resource in increasing crop yield in regions where the insufficient or poorly distributed of rainfall negatively affects the farm’s income. Non the less, the economic viability is an indispensable factor for it being adopted by farmers (Silva *et al*., 2003; Mousinho *et al*., 2006). DI could increase net farm income by decreasing farming input (Dudley *et al*., 1971; Stewart et al., 1974; Howell et al., 1975; Gulati and Murty, 1979; Kumar and Khepar, 1980; Martin *et al*., 1989; English, 1990). The reason a farm’s income may increase could be considered as follows: If the irrigation efficiency is increased, irrigation costs decrease, and so would the opportunity cost of water. (English *et al*., 1990). Here, the costs of energy and water should be considered.

Still, other factors must be taken into consideration, for example the cost of energy, and the price of water (Vera *et al*., 2013). Some texts explicitly stipulate that the system should deliver enough water to meet total crop water demands. Studies describing different irrigation systems stressed on the system that allows for maximum allowable soil water depletion. This maximum can be determined or set by the designer but the depletion levels recommended in the design texts all imply full irrigation (James, 1988; Keller and Bleisner, 1990).

Wang and Nair (2013) mentioned that maximum economic return could be achieved, as the price of the last irrigation unit applied is equal to the revenue of the product produced from this unit of irrigation. There are several factors that affect the maximum economic return and these are: the soil application uniformity and the ratio of commodity prices to production costs (Wang and Nair 2013; Vera *et al*., 2013; Stern and Bresler, 1983; Stegman *et al*., 1980; Miller and Aarstad, 1976). Production cost is directly affected by the head/level of total pumping, and by the seasonal distribution of applied water and associated crop yield. Maximum economic level can be determined through the application of crop production functions (Greets and Raes, 2009).

4. Deficit Irrigation management:

There is a threshold for the level of transpiration reduction below which the plant suffers crucial yield reductions (English, 2002). DI aims to increase irrigation efficiency by avoiding the application of excess water that doesn’t impact crop yield. DI will reduce crop yield, but allow unused water to be available for the irrigation of more crops (Kirda, 2004).

Knowing how a crop would respond to water under different growth stages is crucial in DI (Kirda and Kanber, 2002) because DI is a method in which water consumption is optimized by applying water to the crop at specific drought-sensitive growth stages (Greets and Raes, 2009). So determining the ideal timing for irrigation is a must throughout the drought sensitive stages of the crop cycle (Hsiao, 1973). Studies analyzing crop responses to DI have concluded that different crops responded in a different manner to DI. This confirms that no one DI strategy can be applied to all types of crops (Zwart and Bastiaanssen, 2004).

Given the advances in irrigation techniques and management, DI practices can be applied much easier by both farmers and researchers. Farm irrigation systems such as drip irrigation have proven their success with DI. Drip irrigation allows the delivery of small volumes of water over a longer period of time (with the use of low flow rates) and directly to the plants' root zone, maintaining the soil moisture (Karaa and Karam, 2004). When properly operated and maintained, drip irrigation systems are capable of increasing irrigation efficiency (Wolf *et al*., 1995; Jensen, 2007). Advanced equipment tailored for irrigation scheduling is of great importance when practicing DI. Soil moisture sensors, ET monitoring where reference ET is being measured using weather stations, calibrated equations, atmometers and ET-based controllers are all used in DI. This equipment and monitoring methods prompt irrigation efficiency in the sense that only the water consumed is replenished upon each irrigation interval, with the minimum amount of water wasted.

Irrigation scheduling and DI practices would cause more water to be available to irrigate more land. On the other hand, however, the net return will be negatively affected by the decrease in yield, higher capital cost of irrigation equipment and the need for more expertise (Wang and Nair, 2013).

5. Effect of deficit Irrigation on O. syriacum

Water supply is the most limiting factor for the production and yield of *Origanum* and in most cases, *Origanum* plants should be irrigated if better yields are to be obtained According to Hadid *et al*. (2004), oregano grown using supplemental irrigation provided "24 times more payback than wheat cultivated in arid regions of Syria." Supplemental irrigation is justified by a need to increase crop yield (and consequently farmer income) in regions that suffer from inadequate water supplies.

Silva et al. (2002) studied the effect of hydric stress on *Melaleuca alternifoli* and showed that crops grown under water stress resulted in less growth of both fresh and dry yield (Silva *et al*., 2002). This same drop in growth, yield and production of fresh and dry yield from oregano grown under water deficit conditions was observed in a similar study by Marques et al. (2009) in Brazil. A positive linear relationship was observed between water depth replacement and oregano shoot and root fresh weight and similarly for dry weight. This study concluded that water deficiency throughout the cropping cycle has a cumulative effect: It would interrupt the crop's growth process, favoring catabolism in the plant. When irrigation depths were at 216.82mm (100% ET_0), maximum shoot fresh weight was at 161.8g/plant. However at 0% ET_0, shoot fresh weight was 0%. The shoot dry weight, showed a drop in 64.5% between 100% ET and 0% ET (Kudrev, 1994; Marques *et al.*, 2009).

DI also had effects that were directly visible in oregano root fresh and dry weight. Bergonci et al. (2000) stated that a reduction in the soil's water content would reduce hydraulic conductivity, and it would be harder for water to reach the roots. Marques et al. (2009) deduced that in 50% and 75% CPE (which are moderate deficiency situations); the root system of oregano was able to reach water sources in the soil that have not yet been depleted. Plants classified as perennial aromatics require a considerable amount of water throughout the entire growing season (7000-9000m^3/ha) if intensive biomass production is the goal (Putievsky et al., 1990; Dudai, 2005).

According to Azzizi et al. (2009), water deficiency would significantly decrease dry matter production in O. *creticum*, O. *heracleoticum*, and O. *samothrake*. Reductions in dry weight occurred when water deficiency was consistent, or when it occurred at a later stage in the growing season. With consistent deficiency, dry matter weight was reduced by 30%, whilst when water deficiency was induced at a later stages during the growing, no more than a loss of 10% in dry weight was exhibited. Water deficiency treatments by Bernstein, Chaimovitch, and Nativ Dudai (2009) on three different types of oregano showed a reduction in dry weight as well.

E. Water Productivity

Water productivity (WP), also known as water use efficiency (WUE) in its broadest sense can be defined as the amount of benefits obtained from a crop (in terms of higher yields, profit and ecological benefits) at a less social and environmental cost per unit of water applied (Molden et al., 2010). Water productivity is expressed as a unit of yield per unit of water applied or transpired.

Water productivity can be expressed in the following equation:

$$WP = \frac{\mathrm{Ya}}{\mathrm{ETa}} \quad (1)$$

Where Y is the average grain yield or biomass (kg ha−1) and ET is the evapotranspiration or water used (l/ha).

In terms of physical water productivity the numerator of this equation is the amount of yield obtained per unit of water, however in terms of economical water productivity the numerator is the value of profit derived from the mass of marketable yield per unit of water (Geerts and Raes, 2007; Molden et al, 2010). As for the denominator it is expressed either in terms of water supplied or depleted (Seckler, 1996; Molden et al., 2010). It should be noted that any water that evaporates from the soil with no productive function is not included.

Regions suffering water scarcity would be better off selecting crops that have higher WP. It must be understood that WP is not the only factor that should be taken into consideration when selecting crops for regions with water scarcity: High-energy crops could have a low WP with a high nutritional value. Nutritional value is a key factor to be considered when selecting crops for production in areas prone to drought (Steduto and Albrizio, 2005).

1. Advantages of increasing Water productivity

In areas where water is scarce, having an increasing WP is particularly effective. Increases in food demands from wealthier and more urban countries with an increasing population, a need to act against the pressures involved in diverting water from agriculture into cities whilst maintaining available water for environmental purposes, and a need to reduce poverty are all driving forces in research involved in improving WP. Increased WP could mean improved nutrition, income and employment for the poor. Cultivating crops with higher WP means a reduction in investment costs because the amount of water needed is reduced. Furthermore, increased WP would mean reduced environmental stress and less land and water is usage. For the aforementioned reasons, it is imperative to improve WP (Hengsdijk et al., 2006).

2. Water productivity on Origanum

Several studies were conducted on herbal plants to determine water productivity. WP was determined as the mass (kg) of yield per cubic meter of water applied (ET_c). WP increased with decreasing water applications. Native spearmint grown under water stress (54% ET) presented a higher WP with a value of 0.021 kg/m^3 of water compared to a value of 0.019 kg/m^3 for native spearmint grown under higher water application (80 and 100%) (Nakawuka et al 2014). Similar results were obtained in previous studies on Oregano showing that increasing irrigation resulted in an increased WP. This confirms increasing WP can be achieved via deficit irrigation practices (Marques et al. 2009).

F. Nitrogen

1. Role of Nitrogen in Plants

Nitrogen is one of the most dominant nutrients in plants. A healthy plant has 3-4% nitrogen in its above ground tissue. Nitrogen is absorbed from the soil in two forms: Ammonium (NH_4+) and nitrate (NO_3^-). Plants absorb NO_3^- faster than NH_4^+ ions because nitrate can move freely towards the roots. Inside the plant, nitrate would undergo a reduction to NH_2 which is the form used to assimilate more complex molecules. Plants require a large amount of nitrogen, and extensive root systems allow the plant to take up nitrogen without any restrictions, assuming that the nitrogen in the soil is not restricted to begin with (Singer, 1996).

Adequate nitrogen allows the plant to produce fuller foliage with large succulent leaves. When supplied adequately, nitrogen allows the plant to reach maturity without delays. Nitrogen deficiency causes the plant to turn pale green or yellowish (chlorosis), which also signals a lack of chlorophyll. Chlorosis occurs in lower (older) leaves because nitrogen would be displaced into younger leaves that would remain green.

2. Effect of Nitrogen on O. syriacum

In Nitrogen deficient soil, oregano plants responds significantly to nitrogen fertilization. In a recent study carried by Abdul AL-Kiyyam *et al*. (2008) in Jordan, *Origanum* produced the best yield at nitrogen rates as high as 150 kg/ha According to Bernstein, et al. (2009), nitrogen applied at high levels (at 1.5g/plot) increased dry weight but reduced essential oil content in Oregano. Omer (1999) showed that Nitrogen fertilization at 2g/pot significantly reduced essential oil content in Egyptian oregano. Another study conducted by Aziz et al. (2009) high nitrogen levels (1-1.5g/pot) caused oregano dry matter to increase 9% in the first year of the experiment (where only 1g of N was added per pot), to 26% in the second year of the experiment (where 1.5g of N were added per pot. This indicated a dependency of oregano dry weight on nitrogen dosage.

Successful nitrogen fertilization involves the application of enough nitrogen to maximize production, without wasting fertilization inputs. Over fertilization causes nutrient leaching and unnecessary financial losses. According to a study conducted by Omer (1999) on Egyptian oregano (Origanum syriacum L. var. aegyptiacum Tackh) , higher doses of nitrogen were successful in increasing the crop mass, but active substances in the herb reached their maximum level when moderate levels of nitrogen were applied. In fact nitrogen fertilization greatly increased the height of Egyptian oregano over three cuttings within the same season. When no nitrogen was applied, the average plant height was 20.8cm, and average yield was 23g/plot. However, when Nitrogen fertilization was increased to 4g/pot, plant average height increased to 32.7cm, whilst average yield was 33g/pot. It was concluded that increased nitrogen fertilization, and plant height were positively correlated until 4g N were added per pot. After 4g, plant height leveled off. The increase in plant fresh and dry weight was maintained throughout all the cuttings, during the two seasons the experiment was conducted. Also in biomass, oregano exhibited a linear response to the addition of nitrogen; but biomass development leveled off when application rates were higher than 4g/pot. Omer (1999) concluded that applying N levels between 4 and 8g/pot did not improve yield and that was probably due to the fact that the crop was adapted to living in the wild, and was able to overcome nitrogen deficiency. Oregano's metabolic ability to produce dry matter is limited by nitrogen, even at high fertilization rates (Omer, 1999). Levels of fertilization that higher or lower than the required amount could decrease in yield. Studies have shown that increasing fertilization rates could reduce essential oil content in the herb (Bernath et al., 1973; Boyle et al., 1991; Burt, 2004; Omer, 2008).

Sotiropoulou and Karamanos (2010) showed that nitrogen increased inflorescence especially when nitrogen rates were applied at 40Kg/ha. Furthermore, as plant age increased, so did leaf dry weight per unit leaf area. The 'nitrogen effect' tended to decrease as rates of application increased, especially at 80Kg/ha. This same study found that nitrogen rates were successful in increasing leaf area index (LAI), but it had an optimum effect at 120Kg/ha during the third period of the experiment. With regards to dry matter yield, the 'nitrogen effect' was most efficient at 80Kg/ha (which produced a dry yield of 2.5-2.6t/ha), but this result was significant only during the third cultivation (Sotiropoulou and Karamanos, 2010). The study also concluded that increasing nitrogen rates increased the growth of stems and leaves, instead of inflorescence.

A study by Said-Al Ahl (2009) found that nitrogen levels of 0.9g/pot did not improve fresh weight, whilst 0.6g/pot did. Irrigation at 80% available soil moisture, coupled with the addition of 1.2g of nitrogen for each plot, fresh weight was at its highest. This was applied for the two seasons that spanned the period of the experiment was undertaken (Said-Al Ahl, 2009). Agamy(2004) and Said-Al Ahl (2005) both reported similar results of increases in fresh herbage yield, with increasing nitrogen fertilization.

CHAPTER III

MATERIALS & METHODS

The two experiments in this thesis were designed to study the effect of various nitrogen (N) and irrigation treatments on oregano. The field experiment was conducted at the Agricultural Research and Educational Center (AREC) between May 2014 and November 2014, whilst the greenhouse pot experiment, was conducted at the American University of Beirut (AUB) between November 8, 2014 and June 11, 2015. This chapter will explain the procedures carried out in this study.

A. Methods of Soil Analysis

Soil analysis was carried out at AUB in the Faculty of Agriculture and Food Sciences (FAFS) agricultural research labs on the two types of soils used in this study. A composite soil sample 1 (SS1) was collected from 10 points at AREC's Plot D54 and another composite soil ample 2 (SS2) was sampled from the soil used for the greenhouse pot experiment. The physical and chemical properties of both soil samples were determined based on the procedures outlined by Bashour and Sayegh (2007). Results of the soil analysis are presented in Table 1 below.

Table 1: Soil analysis results of the two soils used in the study (AREC and Greenhouse).

Test	AREC Soil Sample	Greenhouse Experiment
% Sand	19	68
% Silt	36	29
% Clay	45	3
Texture (USDA)	Clay	Sandy Loam
Bulk Density	1.37	1.27
pH	7.89	8.02
EC (µS/m)	398	463
OM (%)	6.9	2.12
CaCO3 (%)	32.5	4.5
Available P (ppm)	19.9	9
Available K (ppm)	530	66
Available N (ppm)	30	35.5

1. Physical Analysis

The soil samples collected were spread out on two separate trays and left to air dry at room temperature for four days. The samples were then ground to break up big soil clods and produce a uniform particle size. Then the samples were sieved using a 2 mm-sieve. Finally the samples were placed in airtight clean plastic containers. Field capacity was determined for both soil samples using a pressure plate apparatus (Abbott, 1985; McIntyre, 1974).

a. <u>Soil Moisture Content</u>

Soil moisture content was determined using the gravimetric method. Air-dried soil was placed in tin cans for 24 hours in an oven at around 105°C. The moisture content in the soil sample was determined by subtracting the weight of the oven –dried samples from the air-dried samples. The results of the soil analysis are interpreted on an oven-dried basis.

b. Soil Texture

Soil texture of both soil samples was determined using the Bouyoucos hydrometer method (Bouyoucos, 1962). The textural class of the soil sample was obtained via the USDA textural triangle.

c. Bulk Density

Soil samples collected were transported in sealed plastic bags, The bulk density was determined using the cylinder method. This method consists of filling a known weight of the sampled air-dried soil (50 grams) into a cylinder, and compacting the soil by tapping the cylinder a few times. The volume of soil obtained was recorded.

2. Chemical Analysis

The chemical properties that were studied for each soil sample are: pH, Electrical Conductivity (EC), organic matter, nitrate analysis, total free calcium carbonates ($CaCO_3$%), available phosphorus and potassium. These tests were conducted according to Bashour and Sayegh (2007). Physical and chemical properties of both soil samples are summarized in table 6.

B. Field Experiment

1. Experimental Site

The field experiment was carried out at the (AREC), Bekaa (33°55' latitude and 36°04' longitude and 1000 m altitude) during the period between May 2014 and November 2014. The experiment took place in Plot D54 (Figure 1) from which clay (Calcaric Cambisols) soil was sampled. This experimental site is characterized by a semiarid climate with dry hot summers from May to September, and very cold winters throughout the rest of the year. Average rainfall is around 500 mm per year; with a maximum precipitation of 150mm during January. Precipitation was recorded during the second cut of the growing season during November.

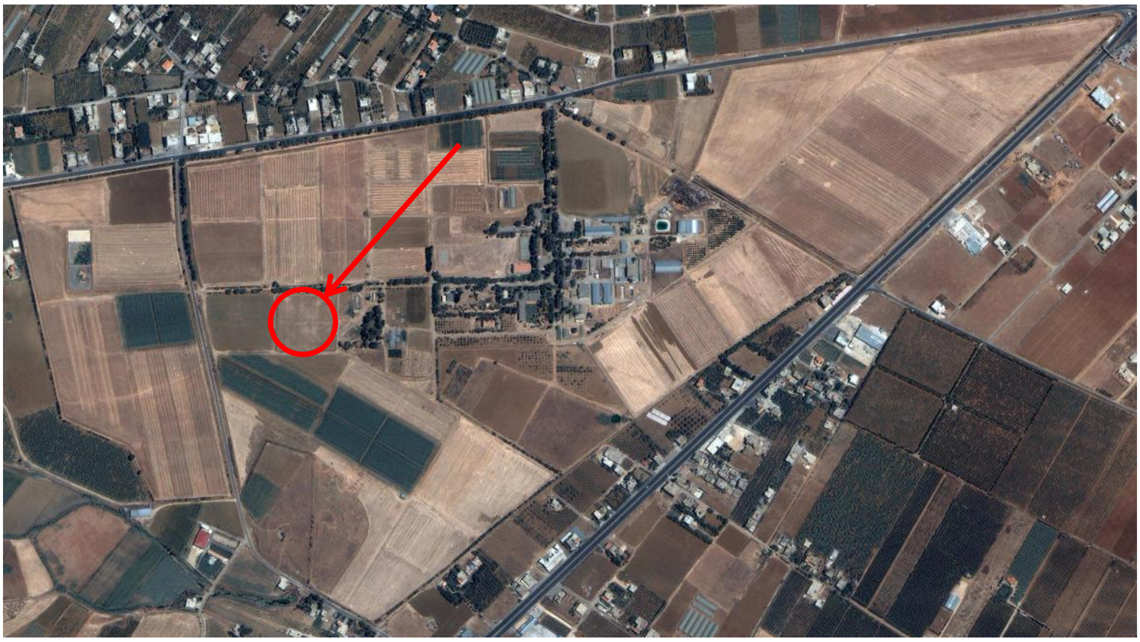

Figure 1: AREC map showing circled experimental plot (Plot D54)

2. Climatic Data

The climate of the experimental site is classified as semi-arid, with an annual pan evaporation of 2 meters, 70% of which occurs between April and September. Mean annual rainfall in the area is 528 mm. Monthly climatic data throughout the field experiment was collected from the weather station present at AREC. Monthly precipitation rates for the growing season at AREC are presented in Figure 1. Average monthly temperature (TAvg), monthly maximum temperature (TmaxAvg) and minimum temperature (TminAvg), in degree Celsius, and monthly relative humidity in percentage during the experiment period (May 2014 till November 2014) are presented in Figure 3. Daily ET data were calculated using the SLW5 weather station installed in the middle of the experimental field (ET-H). Daily ET was also calculated using net solar radiation measured on site. Figure 4 represents ET data measured throughout the growing season.

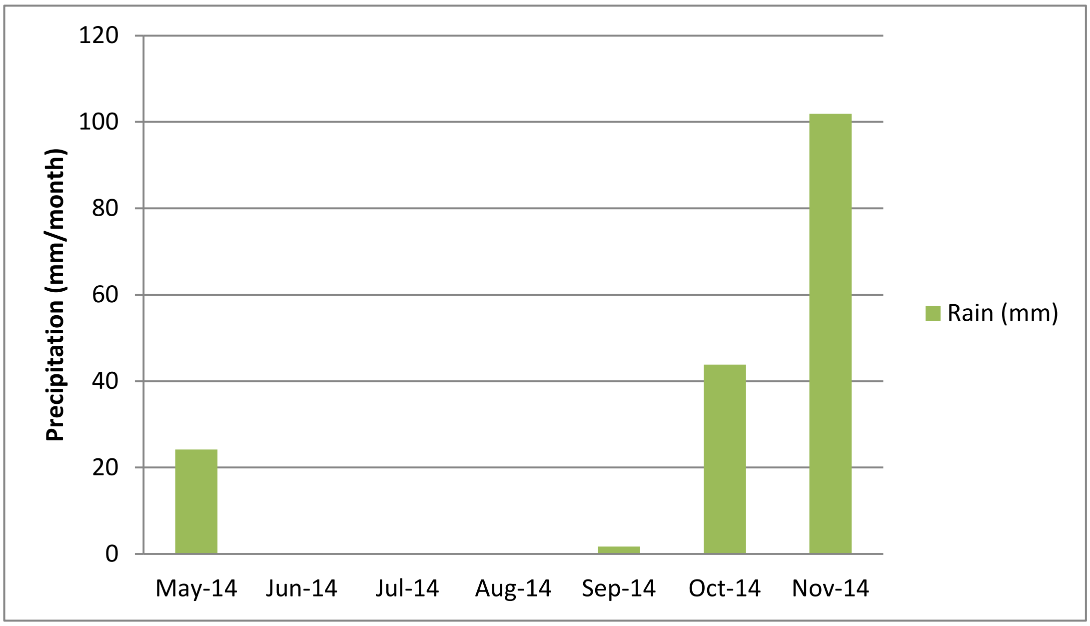

Figure 2: Monthly Precipitation Rate during the experimental Period

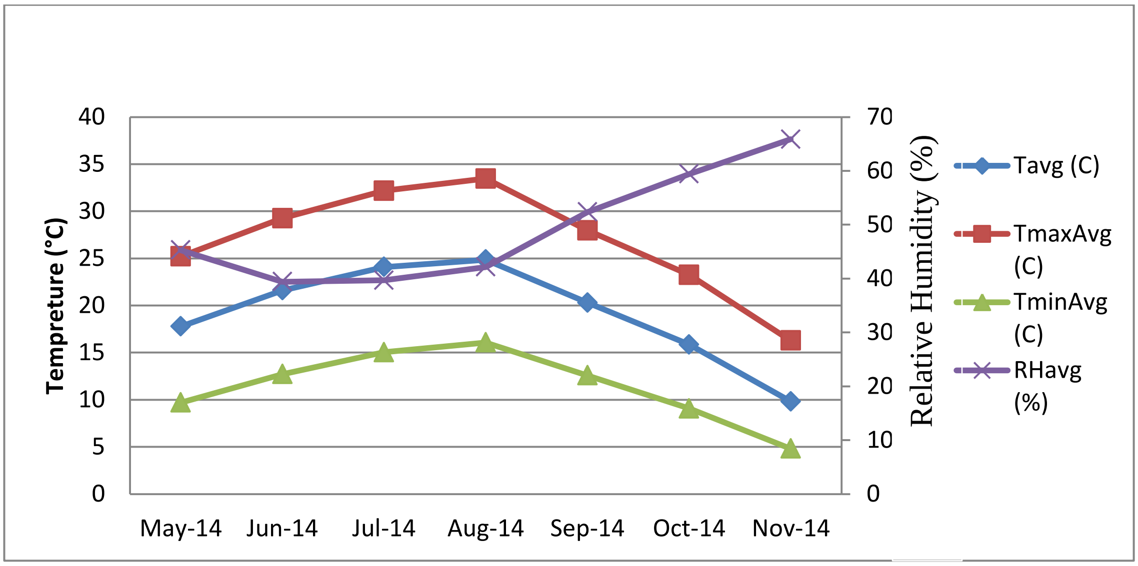

Figure 3: Monthly Average Temperature during the experimental Period and Relative humidity during periods of experimentation

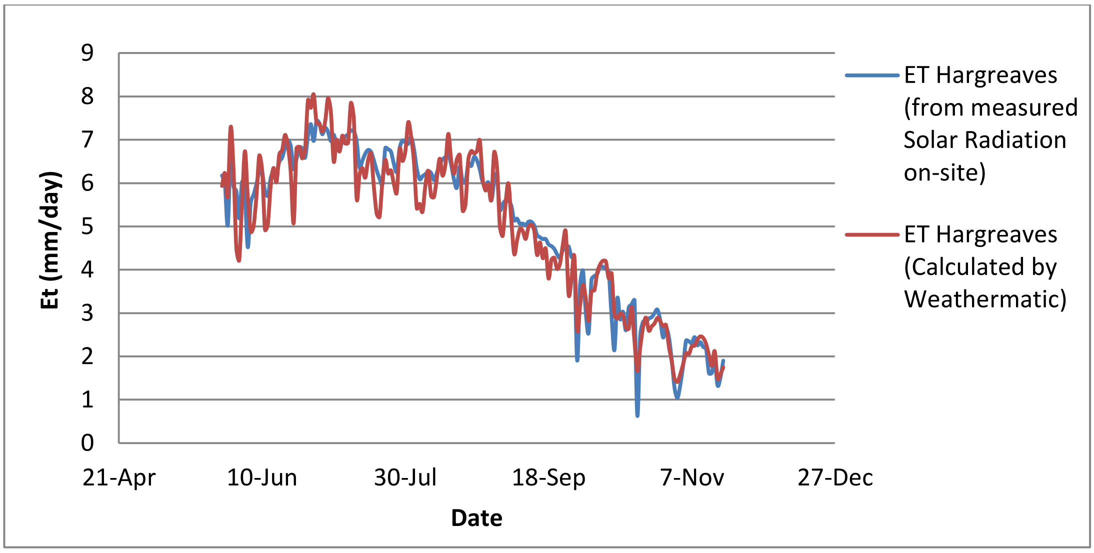

Figure 4: ET data throughout the growing season.

3. Experimental Design

The experiment was a randomized split-plot design. There were a total of 64 subplots, and for each combined irrigation/nitrogen treatment four replicates were assigned. This means that the experimental field was divided up into four equal blocks 8.5×7.5 m each, and each block was then divided into 4 equal whole plots. Irrigation treatments were randomly assigned at the whole plot level. Each whole plot had three lines of the crop spaced 0.4 m apart; a 1 meter barrier between each whole plot was applied. The plots were then divided into four subplots. These sub plots were 1.8×1 m each, and separated by 80 cm. Each subplot was had3 rows of plants, which made for a total of 12 plants per subplot. Four different Nitrogen treatments were randomly assigned for each plot (Figure 6).

4. Agricultural Practices

Agricultural practices were the same for all treatments. The practices are elaborated below:

a. <u>Seedbed preparation</u>

The experimental area was plowed once at a depth of20 cm on May 15, then disked and leveled for transplantation.

b. <u>Transplanting</u>

Two-months-old *O. syriacum* seedlings with an average height of 10 cm were obtained from a local nursery. Seedlings were givenfor two days adapt to the dry climate of the Bekaa area. Transplanting was carried out in the experimental plot on May 27, 2014. *Origanum* plants were planted at 0.4X0.4 spacing, three columns per subplot and 4 plants per column, (Figure 6). A total of 768 plants were transplanted.

c. Pruning

One week after transplantation, the seedlings were decapitated to induce apical dominance and shoot development. The tips of the plants were pruned by removing the top 3 cm of each plant.

5. Fertilizers Applied

One week after transplanting, mono-potassium phosphate (0-52-34) was applied via the irrigation system (fertigation) for all plants at a level of 45 kg P_2O_5/ha and 30 kg K_2O/ha. No additional potassium and phosphorus fertilizer was applied during the experiment.

6. Nitrogen Treatments

In order to determine the yield response of *O. syriacum* to N, four different N rates were applied (N1=0 kga/ha, N2= 75 kg/ha, N3=150 kg/ha and N4=225 kg/ha).

The source of nitrogen used was Urea, which contains 46% nitrogen by mass.

a. Methods of nitrogen application

N was applied in over a course of three doses. The first dose was applied on 18th of July (21 days after transplanting, DAT). The second N dose was applied on the 2nd of August (42 DAT). Third and final application was carried out on the 23rd of August (63 DAT). Details of fertilizer application rates and timing are all summarized in

Table 2.

Table 2: Amount of urea applied per subplot at different dates throughout the experimental period during the field experiment.

			N1	N2	N3	N4
Application	DAT	Date	g/subplot	g/subplot	g/subplot	g/subplot
1	21	18-Jul	0	13.5	27	40.5
2	42	2-Aug	0	13.5	27	40.5
3	63	23-Aug	0	27	54	81

For every N treatment, N was dissolved in a barrel containing 96 liters of water. 2 liters of the dissolved nitrogen solution is applied for every plant.

7. Irrigation System

The experimental site was fitted with a fully automated irrigation system consisting of a reservoir with two pumps, a main network, one controller, weather station, flow sensor, flow meters, four 25-mm solenoid valves (each corresponding to a different irrigation treatment). A secondary irrigation network downstream the solenoid valves were installed. Water was sourced from a well into the irrigation pond located in plot number D52 from which water was pumped into the irrigation reservoir located at the experimental site.

Two pumps were used: The first pump (P1) was installed at the irrigation pond and was controlled by an automatic floating valve installed inside the irrigation reservoir which keeps the reservoir full at all times. Water from the irrigation reservoir was pumped to the experimental site via a second pump (P2) installed downstream the irrigation tank. P2 was directly controlled by the irrigation controller and operates upon each irrigation interval.

The main irrigation distribution network that was previously installed consisted of a 63 mm PE pipe buried under-ground with irrigation risers distributed throughout the system. A tapping was taken from one of the risers to feed the secondary network. A drip irrigation system was installed; 32 mm manifolds were installed downstream the solenoid valves, each corresponding to a different irrigation treatment. PE drip-lines with 16 mm in diameter were connected to a specific manifold depending on the irrigation treatment to which each drip-line corresponded. Drip lines were placed at a 0.4 m distance (S_L) and inline emitters were spaced at a 0.4m distance (S_e). Drip emitters were rated at a discharge rate of 4.56 liters per hour at a pressure of 1.2 bars. Details about the irrigation network are presented in Figure 1.

8. Automated Irrigation Control System Components

The automated control system consisted of: Weathermatic SL1600 controller, 3G card, SLW5 wireless weather station, and a flow sensor.

a. Control System

The Weathermatic SL1600 controller located at the irrigation head house near the experimental site facilitated the control of the irrigation system. The controller is a 4-station base model which commands, by the mean of low-voltage wiring, the opening and closing of series of 24V AC solenoid valves.

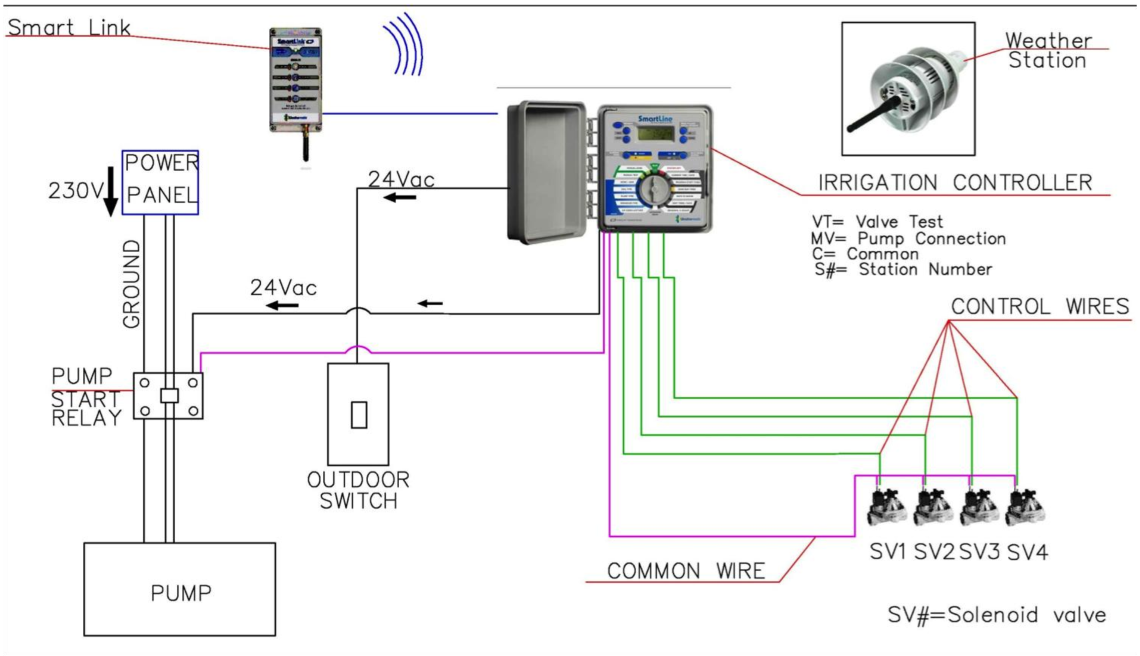

Figure 5: Wiring of solenoid valves pump and relay connections to the irrigation controller

b. Network Card

The Network card was installed with a 3G SIM (Subscriber Identification Module) card thus enabling the SL1600 controller to be connected to the smartlink^{tm} network (http://www.smartlinknetwork.com).

Details about the pump, solenoid valve, weather station and controller connections are presented in

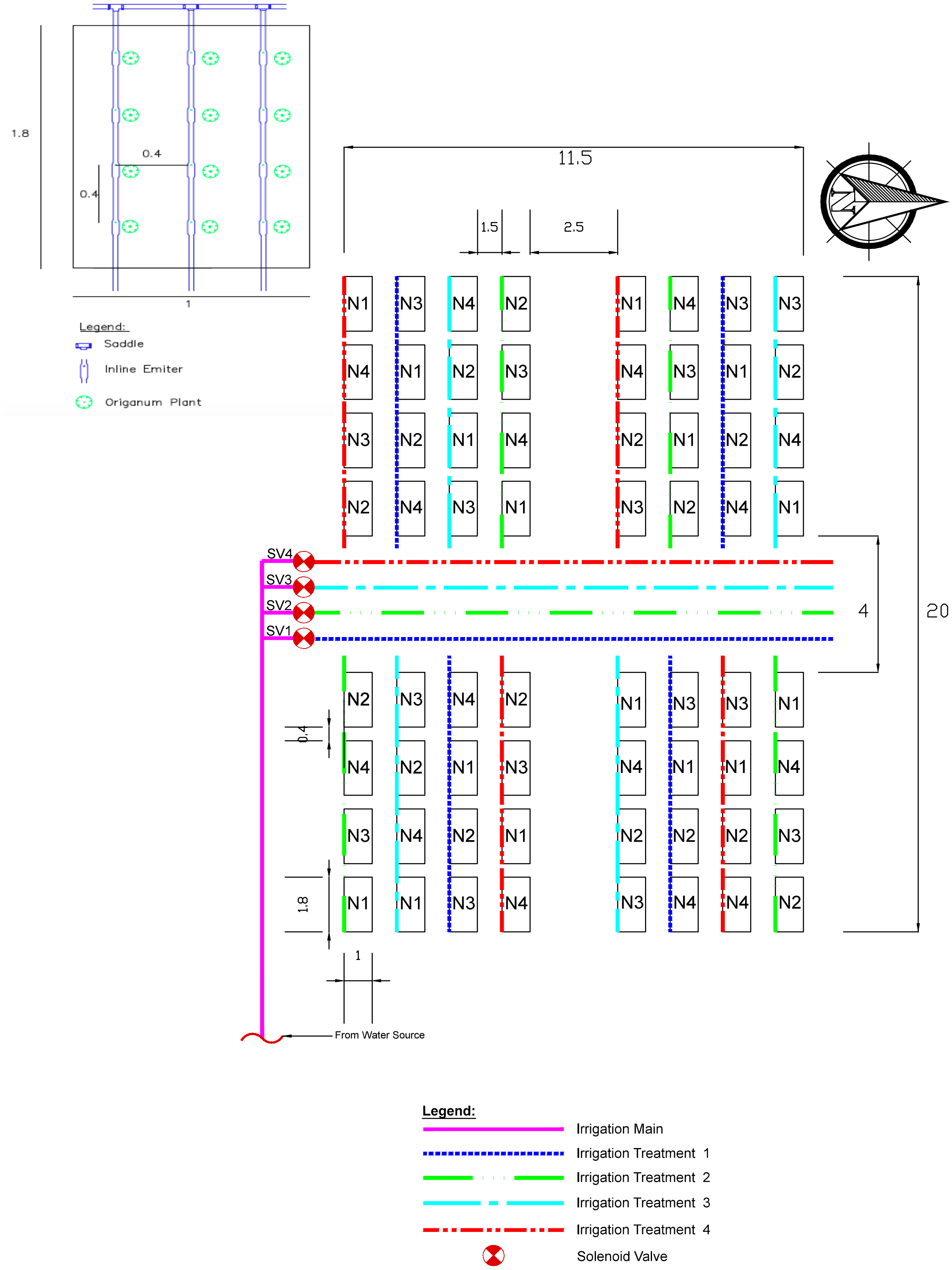

Figure 6: Open Field Experiment Layout. All units are in meters.

c. <u>Flowsensor</u>

The flow sensor was installed in a straight direction along the 63 mm diameter mainline, where a minimum of 0.63 m upstream flow (10*ID) and a minimum of 0.32 m downstream flow (5*ID) of a straight pipe section guaranteed no flow disturbance. The flow sensor was directly connected to the network card. Flow sensor connection details are presented in Figure 7.

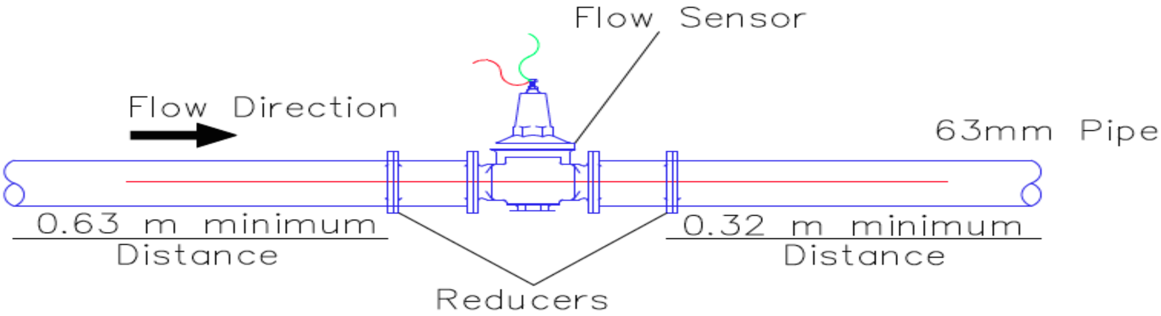

Figure 7: Flow sensor connection to mainline

d. <u>SLW5 Wireless Weather Station</u>

The SLW5 weather station was installed at the center of the experimental field and wirelessly connected to the SL1600. Average Daily high and low temperatures were monitored throughout the experimental period, turning the SL1600 controller into an ET-Based water management system.

e. <u>Solenoid Valves</u>

Four Solenoid valves were installed downstream from the mainline. The valves were labeled SV1, SV2, SV3 and SV4 corresponding to irrigation treatment 1, 2 3 and 4, respectively.

9. Other Irrigation components Installed

a. <u>Flow-meters</u>

Four flow meters were installed downstream of each solenoid valve. The volume of water applied for each treatment was recorded following r each irrigation interval.

10. Irrigation Treatments

To determine the yield response of *O. syriacum*, four different irrigation treatments were applied. The variable was the irrigation percentage fulfilling the reference of evapotranspiration (ET_0) rate calculated using Hargreaves equation. Irrigation treatments adopted are the following:

- Irrigation treatment I1: 60% of ET_0
- Irrigation treatment I2: 80% of ET_0
- Irrigation treatment I3: 100% of ET_0
- Irrigation treatment I4: 120% of ET_0

a. <u>Irrigation Scheduling</u>

The irrigation system is an ET based water management system. The weather station installed in the experimental field monitors the daily high and low temperatures. ET rates are calculated based on Hargreaves equation for reference evapotranspiration rate. The controller promotes the user to log the latitude in order to determine the extra-terrestrial radiation.

The Hargreaves equation for daily computation is given by:

$$ET_0 = 0.0023*(T_{mean}+17.8)*(T_{max}-T_{min})^{0.58*}R_a$$

Where,

ET_0 is the reference evapotranspiration rate

T_{max} (°C) is the maximum daily air temperature

T_{min} (°C) is the minimum daily air temperature

R_a (MJ $m^{-2}d^{-1}$) is the extra-terrestrial solar radiation

At each irrigation interval, P2 is activated by an order given by the controller. The irrigation system operated at a constant pressure of 1.2 bars with the emitter discharge rate was measured to be 4.56 liters per hour. During peak irrigation operating time, the ET_{gage} measured 10.3 mm/day. The irrigation system was assumed to be operating at 85% efficiency. The measured wetted width in one row was found to be 27 cm after 15 minutes of operating time.

b. Calculations for input into Controller:

- Assumption efficiency of the system = 85%
- Gross application depth= $\frac{ET_0}{efficiency} \times 100 = \frac{10.3}{85\%} \times 100 = 12.12\ mm/day$
- Discharge rate/emitter= 4.56 Lph
- Drip-line/subplot= 4×0.4=1.6 m
- Diameter of wetting pattern/emitter = 0.27 m
- Total volume applied per row= 4× 4.56 = 18.24 Lph = 0.01824 m^3
- Area= 0.27× 1.6 =0.432 m^2
- Depth applied= $\frac{0.01824}{0.432}$= 0.042 m =42 mm/hr

Irrigation treatment 1 (I1) was irrigated at 120% that of ET_0, and the total depth applied was:

12.12× 1.2=14.54 mm/day

- Total operating time $=\frac{14.54}{42} \times 60 = 21$ minutes

The total time needed at peak irrigation timing was 21 minutes for irrigation treatment I1. Similar calculations were carried out on the irrigation treatments I2, I3 and I4.

c. Flow meters

Flow meters were installed downstream of each treatment's solenoid valves. Regular readings were recorded from the flow meters right after each irrigation interval.

11. Parameters Measured

During the experimental period, the number of shoots and their heights were recorded every three weeks. Data was collected on July 18th, August 2nd and August 23rd, three weeks and six weeks after plantation, respectively. Following the first cut, the number of shoots and their respective heights were not recorded.

The first and second cuts were on September 13th, 2014 and November 17th, 2014, respectively. Fresh and dry leaf yield was measured.

Fresh yield was weighed right after harvest. The plants were then placed in an oven at a temperature of 60˚C for 72 hours so dry weight could be measured. This was followed by dry leaf weight measurements. Details about the timeline of the experiment are presented in figure 8.

12. Water productivity

Water productivity (WP) was determined for the fresh, dry above ground biomass and dry leaf yield per irrigation treatment, using the equation (1).

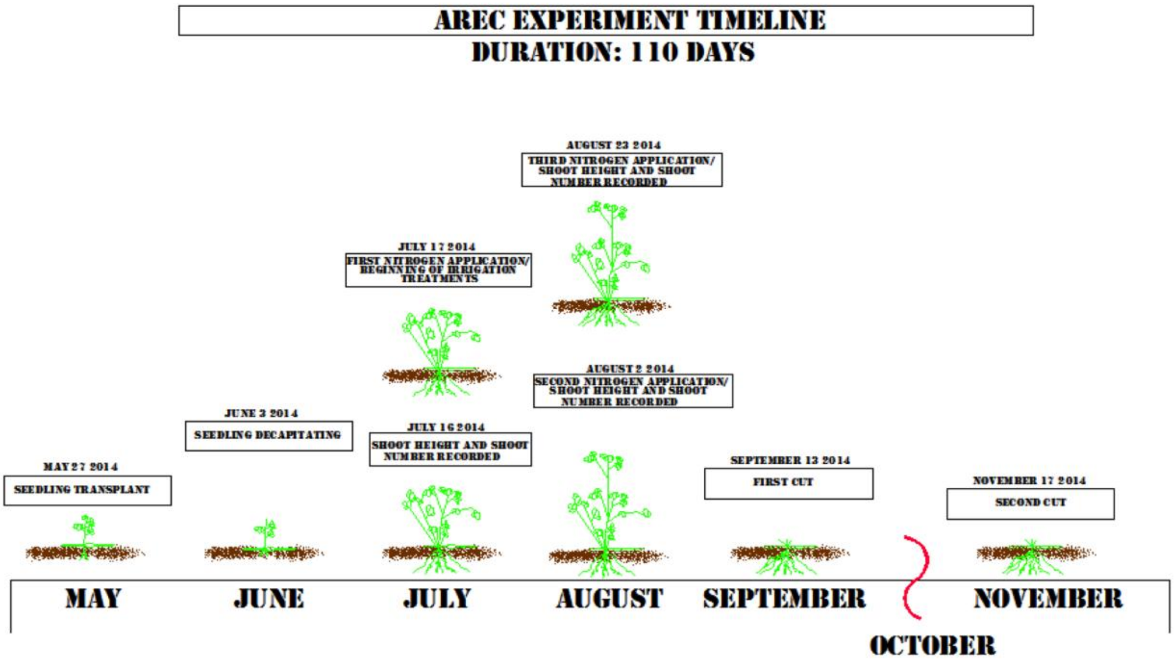

Figure 8: AREC field Experiment timeline

C. Greenhouse Experiment

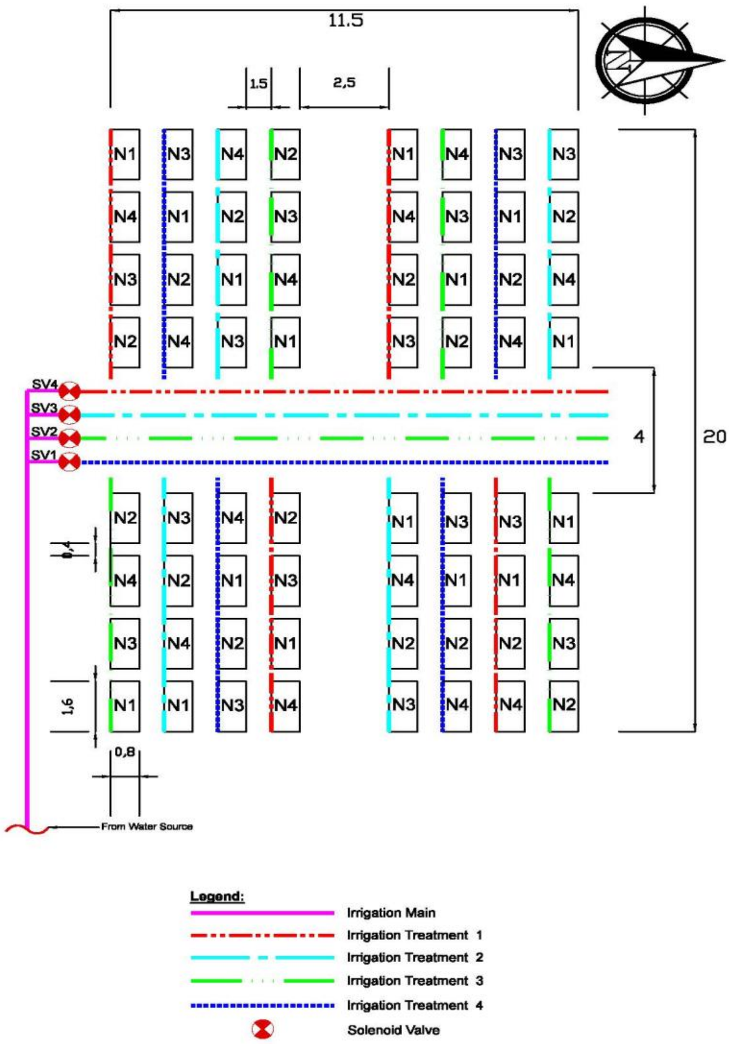

Figure 9: Greenhouse experimental layout plan.

1. Agricultural Practices

Two-month-old *O. syriacum* seedlings with an average height of 5 cm were obtained from a local nursery. Transplanting was carried out in the experimental plot on November 8, 2014. One *O. syriacum* plant was planted per pot, with a total of 128 pots (Figure 9). Seedlings were decapitated to a length of 10cm on January 23, 2015.A solution having a concentration of 60 grams of mono-potassium phosphate and 30 grams of potassium sulphate was prepared and every pot 100ml of fertilizer.

2. Experimental Design

The experiment was designed on a randomized split plot design. It consisted of four irrigation treatments (based on different percentages of soil moisture as measured by a tensiometer installed on one pot) and four N treatments. The greenhouse was divided into 4 blocks. Each block consisted of 4 lines, and each line consisted of 8 pots. Irrigation treatments were randomly assigned for each whole line, and N treatments were applied at the pot level. A total of 128 pots were used for the greenhouse experiment. Oregano plants were planted at a rate of one plant per pot. Details of the experimental design are presented in Figure 9.

3. Irrigation Treatments

Adjustments were needed on ET equations according to greenhouse conditions, a work beyond he scope of this thesis. Therefore irrigation scheduling was based on soil moisture via of soil sensing devices. As such, a soil water balance scheduling system was adopted based on soil moisture sensors measurement (Acclima® TDT sensors and a tensiometer), which provided an appropriate scheduling method. The system was programmed to maintain the soil water content in the pots at different percentages of Management Allowable Depletion MAD as shown hereafter:

- Irrigation treatment I1: 70% MAD
- Irrigation treatment I2: 50% MAD
- Irrigation treatment I3: 30% MAD
- Irrigation treatment I4: 10% MAD

4. Irrigation System

The greenhouse was installed with a fully automated irrigation, which consisted of an irrigation controller and data logger (GP2), a flow meter, tensiometer, two TDT sensors, two ML3 –Delta-t Theta Probe Soil Moisture Sensor and four 25 mm solenoid valves each corresponding to a different irrigation treatment. The source of water was the water reservoir present near the greenhouse area, whereby continuous water supply was available.

A secondary irrigation system downstream of the solenoid valves consisted of 25 mm laterals from which a ¼” distribution tubing (spaghetti tubing) was used to reach each pot. At the end of each distribution tube is a 2 lph emitter installed right next to the stem of each plant.

5. Nitrogen Treatments

Four nitrogen treatments were applied; the variable was varying the amount of nitrogen applied per hectare. Amount of nitrogen applied was 0, 75, 150, and 225 mg/pot for N1, N2, N3 and N4 respectively. The source of nitrogen used was Urea, which contains 46% pure nitrogen by mass. Therefore, the following was the amount of nitrogen applied per pot to satisfy the above mentioned nitrogen treatments.

- Amount Urea applied for N1: 0 mg/ pot
- Amount Urea applied for N2: 163 mg/pot
- Amount Urea applied for N3: 326 mg/pot
- Amount Urea applied for N4: 490 mg/pot

a. <u>Methods of Nitrogen application:</u>

N applications for each plot were relatively small; therefore the above-mentioned amounts were dissolved in distilled water and were applied to the plants at separate time intervals. Details about nitrogen application intervals are presented in Table 3 below.

Table 3: Nitrogen treatments applied during the greenhouse experimental period

			Nitrogen	Nitrogen	Nitrogen	Nitrogen
Application	DAT	Date	mg/pot	mg/pot	mg/pot	mg/pot
1	56	3-Jan	0	37.5	37.5	37.5
2	63	10-Jan	0	37.5	37.5	37.5
3	70	17-Jan	0	0	37.5	37.5
4	77	31-Jan	0	0	37.5	37.5
5	84	7-Feb	0	0	0	37.5
6	92	14-Feb	0	0	0	37.5

6. Parameters measured

During the experimental period, the number of shoots and their heights were recorded. Data was collected on the following dates (Table 4):

Table 4: Timeline of shoot number and shoot height measurements for the greenhouse experiment

Date	DAT	Shoot Height	Shoot Number
December 5, 2015	27	✓	✗
December 12, 2015	34	✓	✗
December 23, 2015	45	✓	✓
January 30, 2105	52	✓	✓
Feb 7 2015	60	✓	✓
February 21 2015	74	✓	✓
March 7, 2015	88	✓	✓
March 15, 2015	95	✓	✓
March 22, 2015	102	✓	✓

The first cut was carried out on March 28, 2015, followed by a second cut on June 11, 2015. Fresh and dry above ground biomass were recorded for each treatment. Plants were weighed right after harvesting for their fresh yield data, and then the plants were placed in an oven at 60°C for 72 hours followed by dry leaf weight measurements.

E. Statistical analysis

Statistical analyses to test the treatment effects were conducted using the JMP 10 – Copyright 2012 SAS Institute Inc. software Package was used. Least significant differences at an alpha of 0.05 were calculated using the all pairs student-t test. Treatment effects were analyzed at significant differences at p=0.05. The random effects,the effects of irrigation, Nitrogen, and Irrigation Nitrogen interactions were analyzed.

CHAPTER IV

RESULTS

This research focuses on the effect of different irrigation and nitrogen treatments on *Origanum syriacum* growth and yield. It also evaluates the water productivity function and the economic analysis if oregano relative to different irrigation treatments. In this chapter, results of soil analysis, field experiment and greenhouse pot experiments will be illustrated.

A. Results of soil analysis

The soil samples used in this study were collected from Block D54 at the Agricultural Research and Education Center (AREC) and from the soil used for the greenhouse pot experiment. Results of physical and chemical analysis are presented in Table 1.

Results indicate that:

Soil sample 1 (SS1) was a clay soil (C), highly calcareous, alkaline non saline and contains high quantity of organic matter. It had sufficient levels of nutrients to support good plant growth. Soil sample 2 (SS2) is Sandy loam (SL), it was coarser in texture than soil 1, was calcareous, alkaline, non-saline with a medium amount of organic matter. Its content in nutrients was little lower than soil 1 because it had a coarser texture.

In general, both soils were suitable for plant growth if provided with sufficient amounts of water.

B. Field Experiment

The following results were obtained from the field experiment at AREC between May 2014 and November 2014:

1. Effects on Crop Growth

Shoot height (SH) and shoot number (SN) were measured during the experimental period. The first data on the crop SH and SN growth was recorded on the 16th of July (50 DAT), followed by a second reading on the 2nd of August (67 DAT) and a final one on the 23rd of August (88 DAT). Shoot height of highest irrigation treatment was significantly higher that I1 (60% ET). Shoot height response to different irrigation treatments are presented in Figure 10 and Figure 11.

No significant difference was found within the alternate irrigation treatments, or nitrogen treatments. Similar results were obtained in a study carried by Sotiropoulou and Karamanos (2010) on Greek oregano. The number of secondary stems and main branches was no significantly affected with the application of N (Sotiropoulou and Karamanos 2010).

Shoot number was not affected by either irrigation or nitrogen treatments, with an average of 10 shoots per plant over the experimental period until the first cut.

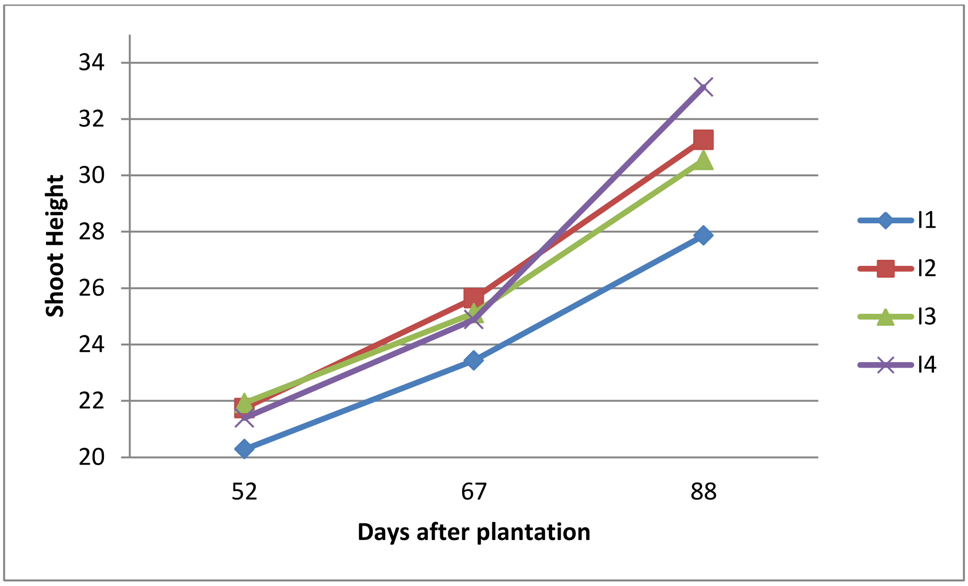

Figure 10: Shoot height recorded at different days of plantation (DAT)

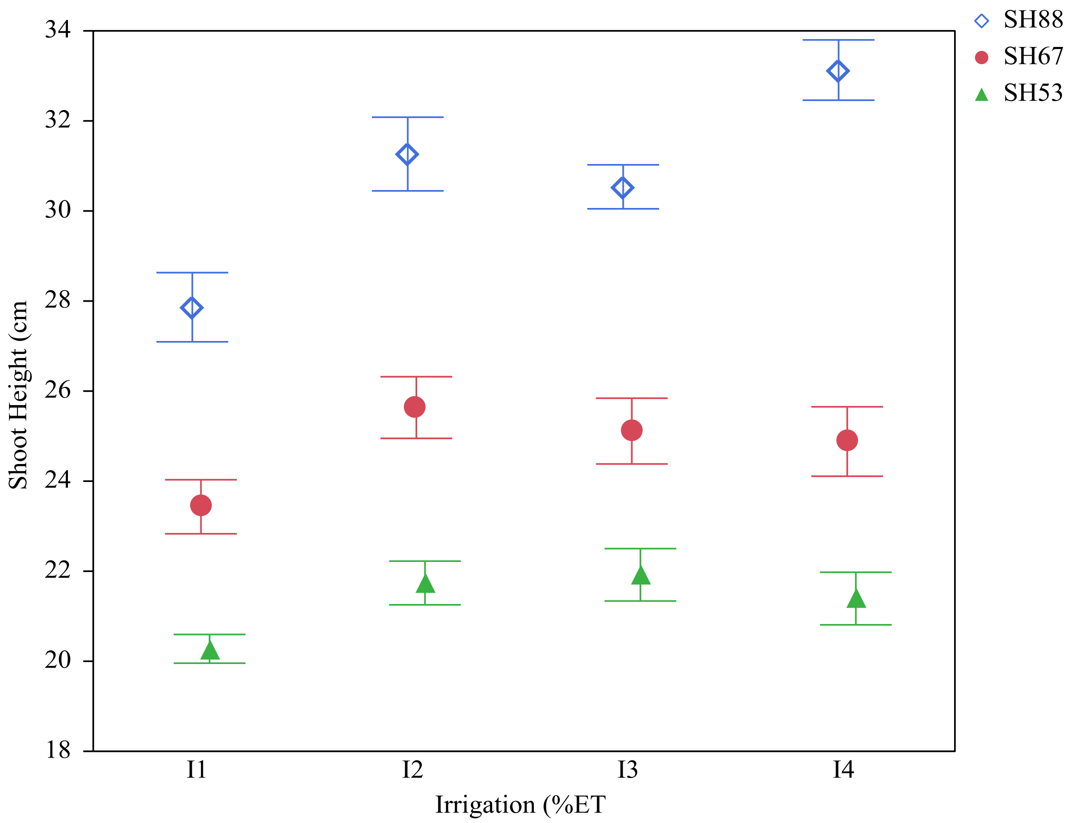

Figure 11: Changes in shoot height with respect to different irrigation treatments

2. Yield Response to Irrigation

The response of above ground biomass (fresh and dry) and dry leaf weight relative to the amount of water applied for both cuts was significant. As was expected, the lowest yields corresponded to the lowest amounts of water applied. At the first cut the highest irrigation treatment resulted in the highest yield (4.78 ton/ha) and was significantly different from all the other treatments. Upon comparing the 60% ET treatment with the 80% and 100% significant differences were obtained. No significant difference was observed between treatment 80% and 100%. Upon the second cut, no significant difference was observed between the 120% and the 100% ET treatments; both had the highest yield (7.14 and 7.31 ton/ha respectively). I1 and I2 treatments and 60% were significantly different from all the other treatments. The effect of different irrigation strategies on mean above ground biomass for the 1st and 2nd cut, fresh and dry weight, mean dry leaf weight, mean total above ground biomass and mean total dry leaf yield are presented in

Table 5 and Table 6.

Table 5: Mean above ground fresh and dry biomass yield and mean dry leaf yield relative to different irrigation treatment for the field experiment

	First cut			Second cut		
Irrigation Level (%ET)	**FY[1] (t/ha)**	**DY[2] (t/ha)**	**DLY[3] (t/ha)**	**FY (t/ha)**	**DY2 (t/ha)**	**DLY (t/ha)**
I1	2.28a[4]	1.21a	0.93a	4.73a	1.64a	1.44a
I2	3.19b	1.49ab	1.14ab	5.71a	1.83a	1.58ab
I3	3.54b	1.68bc	1.27b	7.31b	2.15c	1.8bc
I4	4.38c	1.98c	1.45c	7.13b	2.41d	1.99c

[1]FY= Fresh Yield.
[2]DY=Dry Yield.
[3]DLY= Dry Leaf Yield
[4]Means that share a letter down the column are not significantly different (0.05).

Table 6: Mean total above ground fresh and dry biomass yield and mean total dry leaf yield relative to different irrigation treatments for the field experiment

Irrigation Level (%ET)	TFY[1] (t/ha)	TDY[2] (t/ha)	TDLY[3] (t/ha)
I1	7.01a	2.84a	2.38a
I2	9.91b	3.33b	2.73ab
I3	10.86c	3.84c	3.07bc
I4	11.51c	4.39d	3.45c

[1]TFY= Total Fresh Yield.
[2]TDY=Total Dry Yield.
[3]TDYL= Total Dry Leaf Yield
[4]Means that share a letter down the column are not significantly different (0.05).

3. Yield Response to Nitrogen

Results showed that nitrogen had no significant effect on the above ground fresh and dry biomass weight or dry leaf weights with an average of 3.35, 1.59 and 0.94 ton/ha respectively upon the first cut. Fresh *Origanum* yield of the second cut for the above fresh yield during the second cut of the highest nitrogen treatment (N4) was significantly higher than that of the lowest nitrogen treatment (N1) where a 14 % increase in yield was noted. N application did not significantly affect above ground (fresh and dry) and dry leaf biomass relative to the nitrogen amounts applied (Table 7). Yield and N applications were directly proportional, but no significant results were noted. Results of the second cut relative to the different nitrogen treatments are summarized in Table 7 below.

Table 7: Mean above ground fresh and dry biomass yield and mean dry leaf yield relative to different nitrogen treatments for AREC field experiment.

Nitrogen Level (Kg/ha)	FY2 (t/ha)		DY2 (t/ha)		DLY2 (t/ha)	
N1	5.82	a[4]	1.95	a	1.70	a
N2	6.03	ab	1.92	a	1.64	a
N3	6.41	ab	2.00	a	1.67	a
N4	6.62	b	2.20	a	1.82	a

[1]FY= Mean fresh Yield.
[2]DY=Mean dry Yield.
[3]DLY=Mean dry leaf yield
[4]Means that share a letter down the column are not significantly different (0.05)

4. Yield Response to Irrigation and Nitrogen Interaction

Table 8 and Table 9 summarize the effect of irrigation and nitrogen treatments on total fresh, dry and total dry leaf yield for both cuts. As expected, results showed that the highest yield corresponded to the highest irrigation treatment. This indicates that the oregano plants mostly responds to the amount of water applied. Comparing the fresh yields I3N1 with I3N2, I3N3 and I3N4 showed that lower yield was related to lower N application. This suggests the importance of N in increasing yield.

There was no interaction between irrigation and N-rate treatments for the above ground fresh and dry biomass yield and the dry leaf yields. However, irrigation treatments had an important impact on yield (Table 8and Table 9). Response of *Origanum* to irrigation and nitrogen treatments on total above ground fresh and dry biomass yield and dry leaf yield are presented in Figure 12, Figure 13 and Figure 14, respectively.

Table 8: Mean above ground fresh and dry biomass yield and dry leaf yield with respect to different irrigation and nitrogen treatments upon first cut for AREC field experiment.

Irrigation (% MAD)	Nitrogen (kg/ha)	FY[1] First Cut (t/ha)	DY[2] First Cut (t/ha)	DLY[3] First Cut (t/ha)
60	0	7.6efg	3.02ef	2.46fg
	75	6.52fg	2.67f	2.37fg
	150	6.53g	2.61f	2.2g
	225	7.5efg	3.02ef	2.5fg
80	0	8.21efg	3.21def	2.79cdefg
	75	9.35bcde	3.53cde	2.87cdef
	150	8.63def	3.27def	2.61efg
	225	9.45bcde	3.29def	2.66defg
100	0	9.21cde	3.5cde	2.85cdef
	75	10.68bcde	3.74bcde	2.96bcdef
	150	11.93a	3.94abcd	3.17abcde
	225	11.6bcde	4.19abc	3.3abc
120	0	11.73a	4.55a	3.63a
	75	11.12abc	4.42ab	3.26abcd
	150	11.76a	4.42ab	3.4abc
	225	11.44ab	4.49a	3.49ab

[1]FY= Mean Fresh Yield.
[2]DY=Mean Dry Yield.
[3]DLY=Mean Dry leaf yield
[4]Means that share a letter down the column are not significantly different at a significance of 0.05.

Table 9: Mean above ground fresh and dry biomass yield and dry leaf yield with respect to different irrigation and nitrogen treatments upon second cut for AREC field experiment

Irrigation (% MAD)	Nitrogen (kg/ha)	FY[1] Second Cut (t/ha)	DY[2] Second Cut (t/ha)	DLY[3] Second Cut (t/ha)
60	**0**	5.19bcd	1.82abcd	1.54a
	75	4.07d	1.42d	1.37a
	150	4.42cd	1.52cd	1.32a
	225	5.27bcd	1.8abcd	1.56a
80	**0**	4.88cd	1.65bcd	1.56a
	75	6.28abcd	2.04abcd	1.72a
	150	5.45abcd	1.72abcd	1.54a
	225	6.24abcd	1.93abcd	1.65a
100	**0**	6.19abcd	1.92abcd	1.64a
	75	6.95abc	2.02abcd	1.63a
	150	8.02a	2.26abcd	1.96a
	225	8.1a	2.43abc	1.98a
120	**0**	7.06abc	2.4abc	2.07a
	75	6.84abc	2.19abcd	1.82a
	150	7.75ab	2.46ab	1.99a
	225	6.9abc	2.6a	2.09a

[1]FY= Mean Fresh Yield.
[2]DY=Mean Dry Yield.
[3]DLY=Mean Dry leaf yield
[4]Means that share a letter down the column are not significantly different at a significance of 0.05.

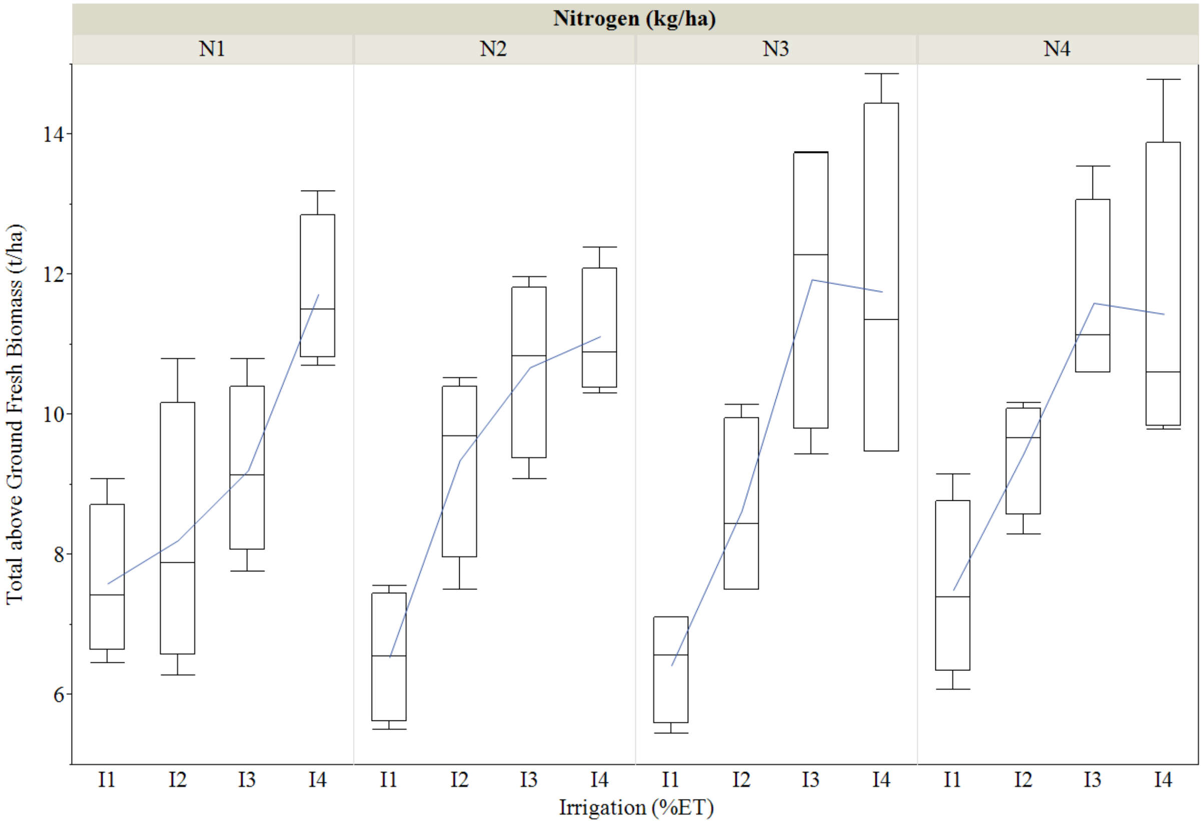

Figure 12: Effect of irrigation and nitrogen treatments on total above ground fresh yield

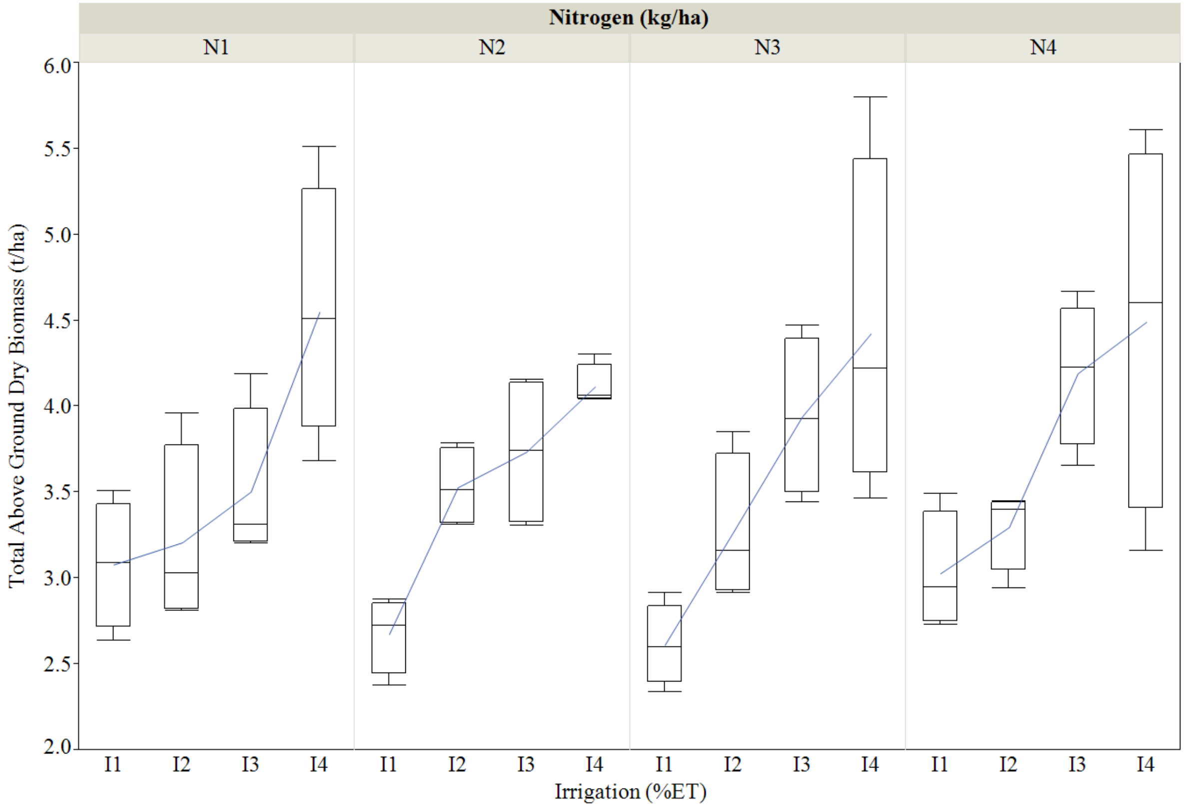

Figure 13: Effect of irrigation and nitrogen treatments on total above ground dry yield

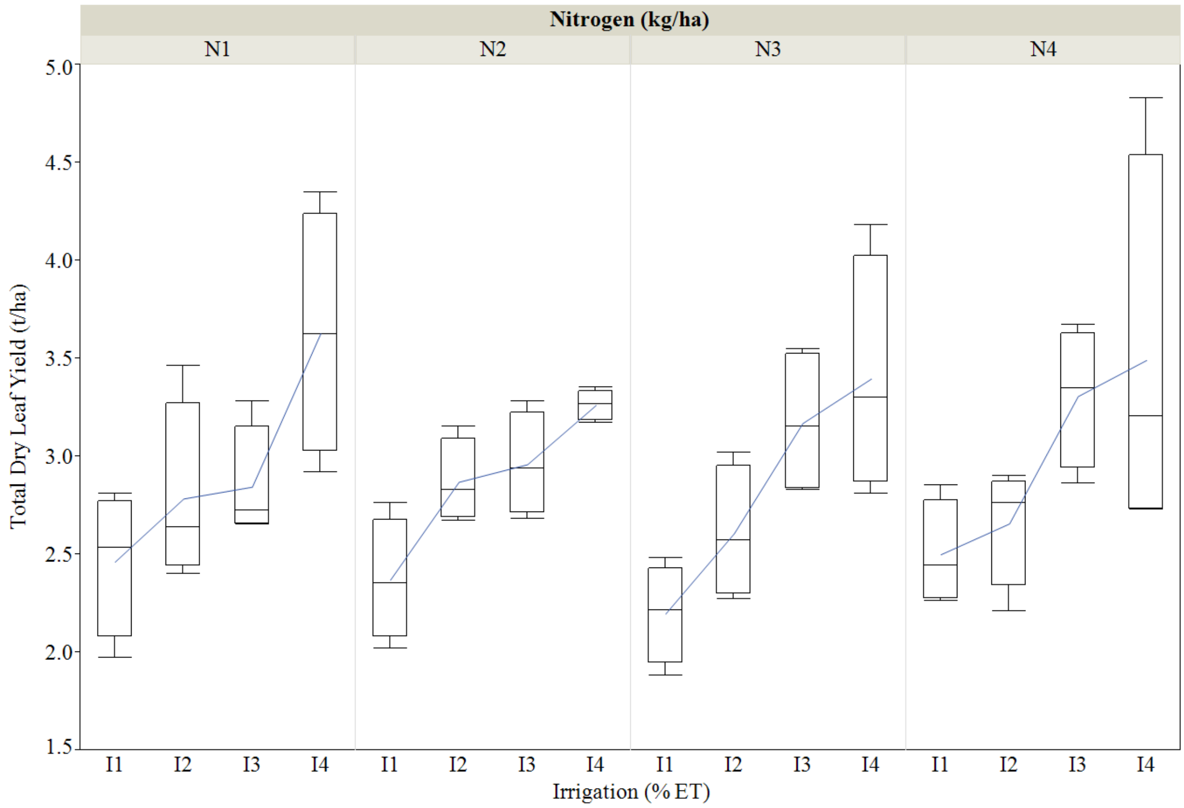

Figure 14: Effect of irrigation and nitrogen treatments on total dry leaf yield

5. Water Productivity

Water productivity was determined as the above ground fresh and dry biomass weight and dry leaf weight (kg) of oregano produced per cubic meter of water applied.

Table 10 shows that the maximum water productivity obtained under the lowest irrigation treatment. Water productivity increased with increasing water stress showing that irrigation treatments had an important impact on WP. The results are in agreement with previous research done on deficit irrigation on *Origanum vulgare* (Marques et al. 2009). Decreasing the amounts of irrigation water applied showed increasing values in water productivity, confirming that deficit irrigation can improve water productivity.

Table 10: Mean water productivity (kg/m^3) of oregano with respect to different irrigation treatments for both cuts for AREC field experiment

Irrigation (%ET)	WP[1] (TFY[2])		WP (TDY[3])		WP (TDLY[4])	
I1	2.59	a[5]	1.05	a	0.88	a
I2	2.45	ab	0.91	b	0.75	b
I3	2.54	a	0.90	bc	0.72	bc
I4	2.18	b	0.83	c	0.65	c

[1]WP=Water Productivity
[2]TFY= Mean Fresh Yield.
[3]TDY=Mean Dry Yield.
[4]TDLY=Mean Dry leaf yield
[5]Means that share a letter down the column are not significantly different at a significance of 0.05

C. Greenhouse Experiment

The following results were obtained from the greenhouse experiment between November 2014 and June 2014:

1. Effects on Crop Growth

The first data on the crop SH and SN growth was recorded on the 5th of December 2014 (50 DAT), followed by a series of readings with the last being on March 22, 2015. No significant difference was found within the alternate irrigation treatments, or among the nitrogen treatments. Similar results were obtained in a study carried by Sotiropoulou and Karamanos (2010) on Greek oregano. No significant results were detected upon applying different nitrogen rates on the number of secondary stems and main branches (Sotiropoulou and Karamanos 2010). Shoot number was not affected by either irrigation or nitrogen treatments, with an average of 10 shoots per plant over until the first cut. Shoot height response relative to different irrigation levels were recorded at different days after transplanting is summarized in Figure 15 below.

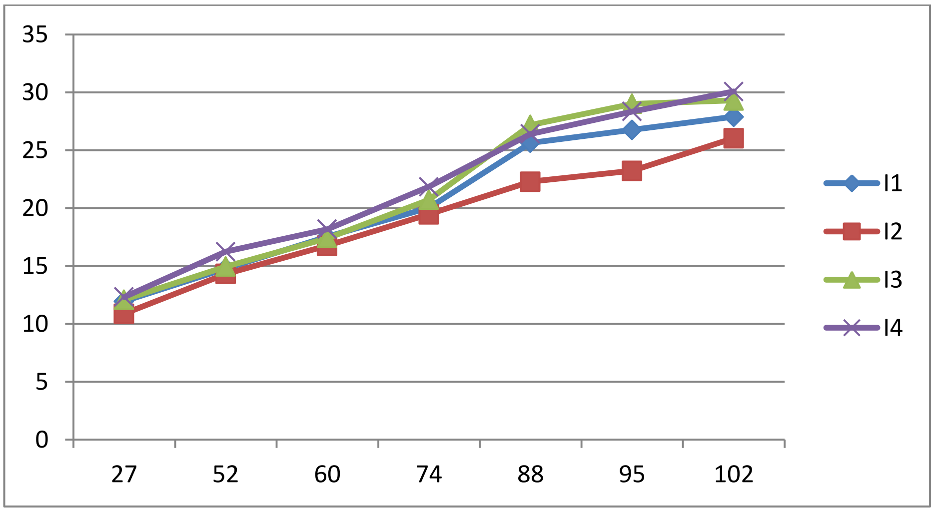

Figure 15: Changes in mean shoot height recorded at different days after transplanting

2. Yield Response to Irrigation

The response of above ground biomass (fresh and dry) and dry leaf weight relative to the amount of water applied for both cuts was significant (Table 11Table 11: Mean above ground fresh and dry biomass yield to different irrigation treatments for the greenhouse experiment.). As expected the lowest yields corresponded to the lowest amounts of water applied. The driest irrigation treatment (I1) was significantly different from all the other treatments and expressed the lowest yield among all treatments: 6.28 g/pot fresh yield and 5.25 g/pot for dry yield upon the first cut. Over time, the driest pots were observed to have significant stand thinning and very little growth. It is believed that *Origanum* plants in the driest pots were able to utilize the water stored in pot soil before irrigation treatments were started. Upon comparing the different irrigation treatments, I2 and I4 were significantly different for both fresh and dry weights; no significant results were obtained when comparing treatments I2 and I3 fresh yield but were significantly different when comparing the dry yield.

Upon the second cut, no significance was observed when comparing irrigation treatments I2, I3 and I4. However fresh and dry yield obtained from the driest pots was significant with respect to the higher irrigation treatments noting that after the first cut the severely water stressed exhibited a high mortality rate. These very unhealthy plants resulted in the lowest fresh and dry yields (5.52 and 5.25 g/pot respectively).

Table 11: Mean above ground fresh and dry biomass yield to different irrigation treatments for the greenhouse experiment.

Irrigation (% MAD)	FY1[1] (g/pot)	DY1[2] (g/pot)	FY2 (g/pot)	DY2 (g/pot)
I1	6.28a	5.25a	5.52a	5.25a
I2	8.27b	5.83b	9.39b	8.59b
I3	9.9bc	6.65c	9.72b	8.53b
I4	9.47c	6.43c	10.02b	8.91b

[1]FY=Fresh Yield
[2]DY=Dry Yield
[3]Means that share a letter down the column are not significantly different at a significance of 0.05.

3- Yield Response to Nitrogen

Upon the first cut, the highest N application (N4) resulted in the highest yield (6.57g/pot) showing significant results when compared to the dry yield of treatments N1, N2 and N3 (Table 13). No significant effects were noted on the above ground fresh yield for the first cut and above ground fresh and dry biomass yield leaf yield for the second relative to the nitrogen amounts applied. The response of mean fresh and dry above ground biomass yield is presented in table 13. An increase in yield was observed with the increase of nitrogen levels applied, however no significant effect was noted. This response may be due to the presence of sufficient nitrogen amounts in the soil prior to addition of the nitrogen amounts.

Table 12: Mean above ground fresh and dry biomass yield to different irrigation treatments for the greenhouse experiment.

Nitrogen (kg/ha)	First cut		Second cut	
	FY1[1] (g/pot)	DY1[2] (g/pot)	FY2 (g/pot)	DY2 (g/pot)
0	8.32a	5.87a	8.79a	8.01a
75	8.41a	5.75a	8.55a	7.83a
150	8.58a	5.96a	8.44a	7.51a
225	8.97a	6.57b	8.97a	8.03a

[1]FY=Fresh Yield
[2]DY=Dry Yield
[3]Means that share a letter down the column are not significantly different at a significance of 0.05.

4. Yield Response to Irrigation and Nitrogen Interaction

Table 13 summarizes the effect of irrigation and nitrogen treatments on total fresh, dry and total dry leaf yield for both cuts. As expected results showed that the highest yield corresponded to the highest Irrigation treatment indicating that *Origanum* plants mostly responds to the amount of water applied. There was no interaction between irrigation and N-rate treatments on *Origanum* yield. However, significant difference was obtained between I1N1 and I1N3 showing that high N rates applied under water stress may result in a significant decrease in biomass yields. This can be explained by the fact that with low water volumes and high N amounts applied will result in an increase in the soil's electric conductivity (EC). Higher EC values coupled with low water amounts applied will result in an increase in stress on the plant and as such lower yields. The response of *Origanum* yield to different irrigation and nitrogen treatments are presented in Figure 16 and Figure 17 below. Results showed an agreement with a similar study carried on native spearmint (Okwany et al., 2010), where spearmint plants grown under the driest conditions (50% of ET_c) showed the lowest yield and an extreme stress on the plants resulting in high mortality rates among the plants. Irrigation amounts applied at or below 10% MAD coupled with high nitrogen application rates will result in serious reduction in plant growth and population rendering such practice destructive for *Origanum* production. Therefore, under water stress conditions, fertilizer applications are not recommended.

Table 13: Mean above ground fresh and dry biomass yield relative to different irrigation and nitrogen treatments for the greenhouse experiment.

Irrigation (% MAD)	Nitrogen (kg/ha)	FY[1] First Cut (g/pot)	DY[2] First Cut (g/pot)	FY Second Cut (g/pot)	DY Second Cut (g/pot)
I1	**N1**	8.05cde	5.79cd	7.25bcd	7.03abc
	N2	6.26ef	5.69cd	6.14cde	5.91bc
	N3	4.56f	4.71d	5.11e	3.02d
	N4	6.22ef	4.79d	6.19de	5.33cd
I2	**N1**	7.78cde	5.64cd	9.66ab	8.85a
	N2	8.15bcde	5.56cd	9.21ab	8.6ab
	N3	9.32abcd	6.12bc	9.9ab	8.91a
	N4	7.83cde	5.99cd	8.81abc	8.02ab
I3	**N1**	7.75cde	5.57cd	8.59abc	7.56abc
	N2	8.71bcde	6.18bc	8.52abc	7.58abc
	N3	11.47a	7.48a	10.6a	9.29a
	N4	13.45a	7.38ab	11.2a	9.73a
I4	**N1**	9.71abcd	6.48abc	9.68a	8.61ab
	N2	10.55abc	6.49abc	10.34a	9.18aa
	N3	7.47de	5.52cd	9.74ab	8.81aa
	N4	10.14abc	7.24ab	10.3a	9.05aa

[1]FY= Mean Fresh Yield.
[2]DY=Mean Dry Yield.
[3]DLY=Mean Dry leaf yield
[4]Means that share a letter down the column are not significantly different at significance of 0.05.

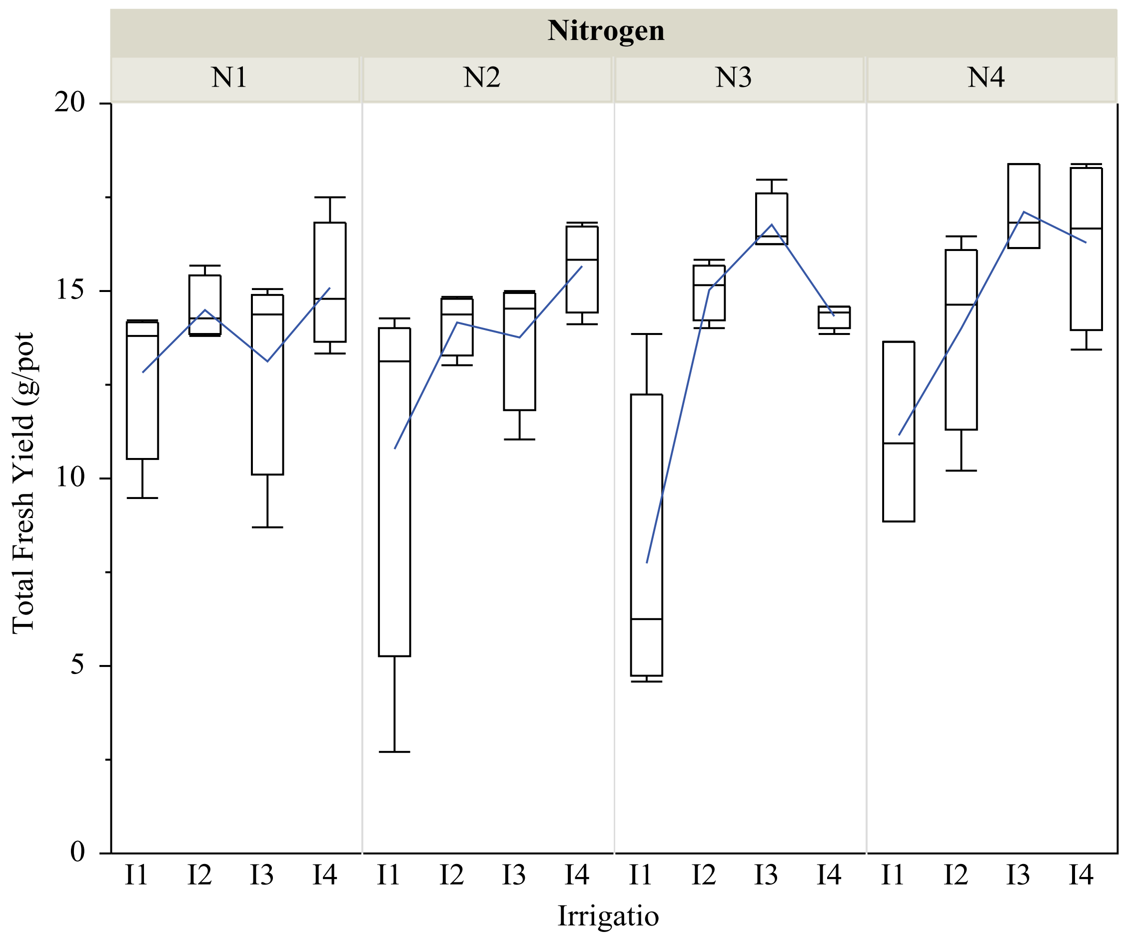

Figure 16: Changes in mean total fresh yield (g/pot) with respect to different irrigation and nitrogen treatments

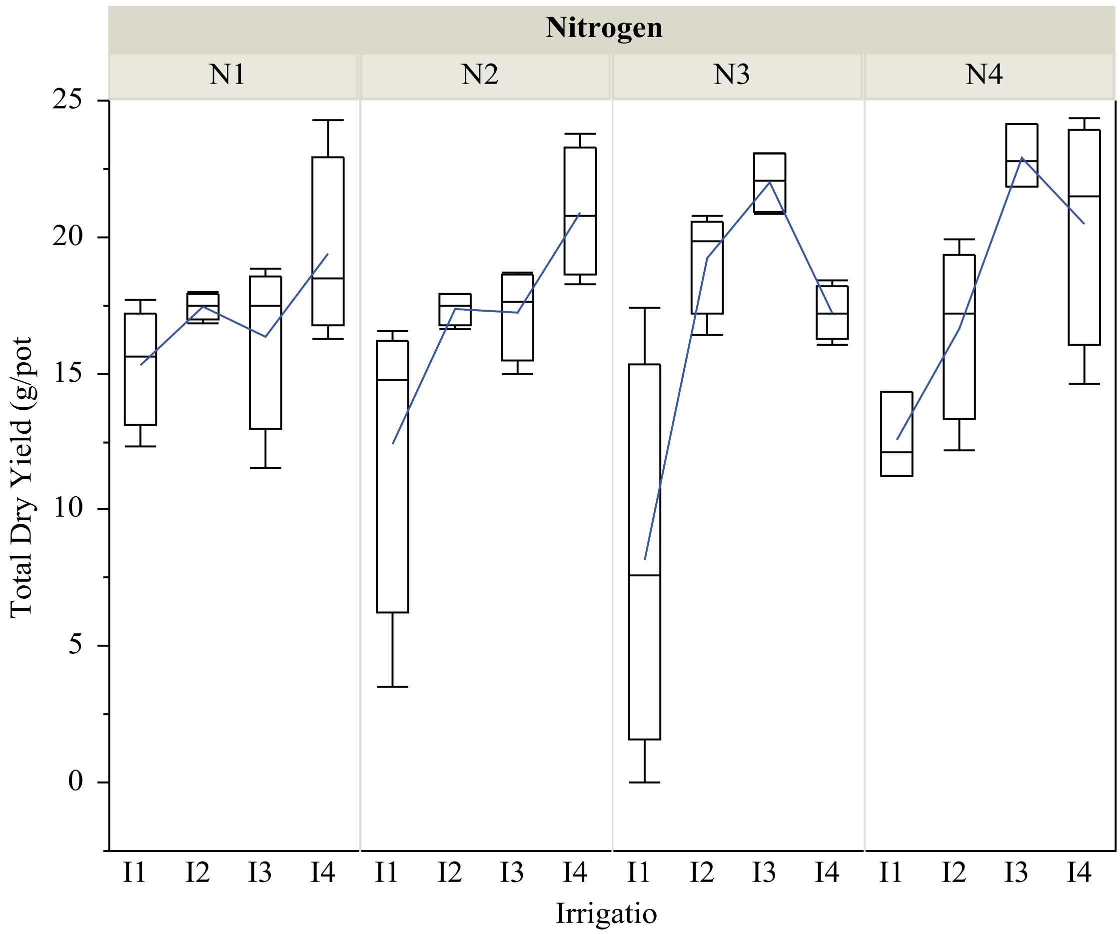

Figure 17: Changes in mean total dry yield with respect to different irrigation and nitrogen treatments

5. Water Productivity

Water productivity (WP) was determined by dividing dry yield (kg) over cubic meter of water applied.

Table 14 showed that maximum WP was obtained under the lowest irrigation treatment. WP increased with increasing water stress showing that irrigation treatments had an important impact on WP. These results are in agreement with previous research done on deficit irrigation on *Origanum vulgare* (Marques et al. 2009). Decreasing the amounts of irrigation water applied showed increasing values in WP, confirming that deficit irrigation can improve WP. N-rates had no effect on water productivity.

Table 14: Mean water productivity (kg/m^3) of oregano with respect to different irrigation treatments for both cuts of the greenhouse experiment.

Irrigation (%MAD)	**WP[1] (TFY[2])**	**WP(TDY[3])**
I1	0.14 a[4]	0.16 a
I2	0,08 b	0.10 b
I3	0.07 b	0.09 b
I4	0.06 b	0.08 b

[1]WP=Water Productivity
[2]TFY= Mean Fresh Yield
[3]TDY=Mean Dry Yield
[4]Means that share a letter down the column are not significantly different at significance of 0.05.

CHAPTER V

DISCUSSION

In this chapter, results field experiment and greenhouse pot experiments will be thoroughly discussed indicating the effect of the various irrigation and nitrogen treatments on crop growth, above ground fresh and dry yield and dry leaf yield and the effect of water stress on the crop's water productivity.

A. Irrigation effect

The differences in total fresh and dry yield and dry leaf yield at the various irrigation treatments were highly significant. As expected the highest yield recorded was obtained from the highest irrigation treatments for both cuts of the field and the greenhouse experiment. However, in the second harvest, the fresh yield of the field experiment almost doubled which can be explained to several environmental factors such as the Late- season rainfall is thought to have an effect on the yield of the deficit irrigation treatments. Temperature may be a factor causing yield differences between the first and second cut. The growing period after the first cut was cooler than the tempreture through the second cut (Figure 1). Cooler Temperature results in higher leaf weight ratio on *Origanum vulgare* (Clasikan et al. 2010). Results showed an agreement with earlier studies carried out on *Origanum vulgare* that showed a significant increase in yield with increased water stress (Hadid et al., 2004; Silva et al., 2009; Marques et al. 2009, Aziz et al., 2009). Effect of the various irrigation treatments on crop growth was assessed through measuring the crop height and the number of branches per crop. No significant results were observed within the alternate irrigation treatments on the number of shoots per plant. The crop's height was enhanced upon increasing the amount of irrigation water applied at later stages throughout the growing period and was significantly different upon the highest irrigation treatment to that of the lowest. It was concluded that the plant height is a better indicator for the yield than the number of branches (Attallah *et. al*, 2010).

B. Nitrogen Effect

No signicant effects were observed among the various nitorgen treatments on the crops height, number of branches per crop, above ground fresh and dry yield and the dry yield for both cuts of the field and greenhouse experiment. These results contradicts with previous finidings on *Origanum syriacum* where the plant biomass exhibted a linear increase with the amount of nitrogen applied (Al-Kiyyam *et. al.*, 2008). This could be due to the sufficient N content in the soil and the relatively high organic matter, which is also a good source of nitrogen. Another factor that might have reduced the effect of the added area (N source) is the tha fact that the same plot was planted with a leguminous crop earlier prior to the experiment.

C. Water productivity

Water productivity for both cuts of the field and greenhouse increased with increasing the water stress. Results showed an agreement with previous research done on defficit irrigation on *Origanum Vulgare* (Marques *et. al.,* 2010). Increasing the amounts of irrigation applied showed a decreasing value of the crop's water productivity confirming that deficit irrigation can improve the water productivity of *Origanum.*

CHAPTER VI

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

A. Summary

A field experiment and a greenhouse pot experiment were conducted to test the effect of different irrigation and nitrogen (N) treatment on growth and yield of *Origanum syriacum* plants.

The field experiment was conducted at Agricultural Research and Educational Center (AREC) of the American University of Beirut (AUB) in the Bekaa Valley from June 2014 to November 2014, in order to study of the effect of different amounts of irrigation water applied along with different N rates. *Origanum* plants were subject to four irrigation treatments I1, I2, I3 and I4 (60, 80, 100 and 120% of ET respectively) and four N application rates N1, N2, N3 and N4 (0, 75, 150 and 225 kg/ha respectively). The field experiment confirmed that water stress resulted in decreased biomass production. The impact of N had no significant effect on biomass yield but a response on fresh yield was observed upon the second cut where higher yields where obtained for crops treated with higher N rates. Deficit irrigation improved water productivity and was observed to be highest in the lowest irrigation treatment applied.

The greenhouse pot experiment was conducted to verify the results of the field experiment obtained at AREC. The methodology used in the greenhouse experiment was similar to those used at AREC. Separate *Origanum* crops were grown per pot (a total of 128 pots) and were subject to four irrigation treatments I1, I2, I3 and I4 (70%, 50, 30 and 10% of MAD) and four N application rates N1, N2, N3 and N4 (0, 75, 150 and 225 g/pot respectively). Similar results were obtained where the highest biomass yield was achieved in the treatments with the highest volume of water applied. None of the N treatments gave a significant effect in increasing yield. However effect of irrigation and N treatments combined gave significant results showing that an increase in amount N applied coupled with high irrigation volumes applied can result in better yields. On the other hand, high N rates applied under water stress may result in a significant decrease in biomass yields.

B. Conclusions

It can be concluded from this study that:

- Highest yields were obtained under full crop irrigation requirement and yield decreased significantly with decreasing water volumes applied.
- N fertilizer have a minor effect on yield and productivity of *O. syriacum*, however better yields can be achieved when coupled with high irrigation volumes applied.
- Higher yields were obtained in treatments with higher N rates applied upon later cuts, indicating that N fertilizer may have its significant effect in N deficient soils.
- Water productivity can be improved under water stress.
- Conducting experiments under automated Irrigation systems through the use of weather stations and soil moisture sensors due to the ease of use, precision and accuracy in delivering water.

C. Recommendations

It is recommended to:

- For achieving maximum yields, full crop irrigation requirements should be applied (120% of ET) one month after transplanting.
- N fertilizers should be applied upon later cuts after the crops have utilized the entire N stored in the soil.
- Framers with limited water resources can grow *Origanum* plants under water stress.
- Conduct more studies on:
    a. N Fertilizer uptake efficiency
    b. Effect of Irrigation interval
- Establish more field studies to develop the *Origanum* production function and economic analysis, which could be useful tools in forecasting the impact of water stress, N application and the cost of growing *Origanum* under real field conditions.

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