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EFFECT OF NO-TILL STRAW MULCHING SYSTEM ON WATER PRODUCTIVITY AND PERFORMANCE OF POTATO

by
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AN ABSTRACT OF THE THESIS OF

Ali Mohammad Msheik for Master of Science
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Title: Effect of No-Till Straw Mulching System on Water Productivity and Performance of Potato.

Field and green house experiments were conducted during the spring and fall semesters of 2014-2015 to evaluate the effects of different surface barley straw mulch (25, 50 and 75t/ha) on potato growth under a no-till system and to examine the response of potato to different irrigation regimes [120%, 100%, 80% and 60 % evapotranspiration (Eto)] with or without the surface mulch (till and no-till system). The results of the field experiment showed that the till potato (0t/ha mulch) under the four irrigation treatments significantly enhanced the shoot height and plant number, 35 days after planting potatoes (DAP). While, at 45 DAP, results showed that only plant number in till potato at 75/ha was significantly higher than that of no-till potato at all tested mulching rates (25, 50 and 75 t/ha) under 120%, 80% and 60% Eto. Also, results showed that no-till potato at 75t/ha at 60% Eto significantly reduced potato shoot number at 45 DAP compared to till (0t/ha). However, shoot number increased with time in no-till potato. For example, the shoot number in all no-till treatments at 80% and 100% were significantly not different from each other; the number remained at 75 DAP. Leaf number was high in till potato early in the growing season. However, it increased with time. Root and shoot dry weights were high in till potato (0t/ha mulch) at various irrigation regimes, compared to all no-till treatments at 35 DAP. However, both increased with time. The highest shoot dry weight was observed in no-till potato at 25t/ha at 80% and 120%. In regards to potato yields, results showed that all treatments had no negative effect on the total number of tubers except for the no-till potato at 75t/ha at 100% Eto. No-till potato at 25t/ha at 100% Eto gave the highest number of tubers. All no-till potato treatments at various irrigation rates significantly increased marketable yield in comparison to the till potato. Marketable yield was the highest with the no-till potato at 75 t/ha at 120% Eto. The highest total yield observed was with 50 t/ha at 120 % Eto and with 75 t/ha at 80% Eto. As for the crop water productivity, results showed that the maximum water productivity value (8.3Kg/m^3) was observed in no-till potato at 75t/ha at 80%Eto. Results of the greenhouse experiment showed that the highest shoot height was observed with till potato at 120% Eto. The leaf number was significantly low at 75 t/ha at 100 % Eto compared to 120 %, 80 % and 60 % Eto, 96 DAP except for no-till at 25t/ha at 120% Eto. All tested mulching rates at various irrigation treatments were similar. Shoot and root dry weight was significantly higher in till at 120% Eto than at 100%Eto, 80% Eto and 60 % Eto. The highest tuber collected was observed with no-till potato at 25 t/ha at 120% Eto. However, the tuber weight in till potato (0 t/ha) at 120% Eto gave the highest yield, in comparison to all various treatments. Root dry weight in no-till potato at 75t/ha at 120, 80 and 60% Eto was significantly lower than the till potato (0t/ha mulch) 117 DAP.

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ABBREVIATIONS

ASC	above ground shoot count
ASL	above sea level
AREC	Advancing Research, Enabling Communities
AUB	American University of Beirut
T_{avg}	Average Tempreture
CaCO3	Calcium Carbonate
Cm	Centimeter
C	Clayey Soil
CWP	Crop water Productivity
m^3	cubic meters
m^3/ha	cubic meters per hectare
DAP	Day after Plantation
DI	Deficit Irrigation
°C	Degree Celsius
EC	Electrical Conductivity
Em	Emulsifiable concentrate
et al.	*Et allii* (and others)
EP	Evaporation
ET	Evapotranspiration rate
FAFS	Faculty of Agricultural and Food Sciences
FC	Field Capacity
Fig	Figure
FAO	Food and Agricultural Organization
g	Gram
g/pot	grams per pot
Ha	Hectare
HCL	Hydrochloric acid
I#	Irrigation Treatment
Kg	Kilogram
Kg/m^3	Kilogram per cubic meter
Kg/ha	Kilogram per hectare

LSD	Least Significant Difference
L	Liter
L/sec	liters per second
LPH	litters per hour
T_{max}	Maximum Temperature
m	Meters
mm	Millimeter
mm/day	millimiters per day
T_{min}	Minimum Temperature
T_{maxAVG}	Monthly maximum Tempreture
T_{minAVG}	Monthly minimum Tempreture
NT	No till treatment
no/ha	number per hectare
OM	Organic Matter
ppm	Parts per million
P	Phosphorous
K	Potassium
ET_0	Reference Evapotranspiration rate
RH	Relative Humidity
SDW	shoot dry weight
SH	Shoot Height
SN	Shoot Number
NaOH	Sodium hydroxide
S_L	Spacing between driplines
S_e	Spacing between emitters
S#	Station number
SC	Suspension concentrate
t/ha	tons per hectare
WG	Water dispersible granules
WP	Water Productivity
WUE	water use efficiency

To My

Beloved Parents

CHAPTER I

INTRODUCTION

Today, the rapid increase in the world's population, climate change, and economic instability, are causing major challenges in the agricultural sector in regards to the sustainable satisfaction of the needs of millions of people. These challenges are further magnified as they are developing under present non-supportive and risky circumstances. Continuous soil degradation and increasing water scarcity are major threats to food production. Thus, there is a need for a clear strategy to promote sustainable agriculture. New techniques which aim to increase productivity and efficiency, and those which strive to avoid a consequential scarcity in agricultural resources, are imperative. Many researchers have realized and affirmed the complexity of this issue. As such, they have prioritized the objectives of their studies towards investigating sustainable agricultural techniques which may increase crop yields significantly without damaging the soil and the environment. Increased planting, irrigation, and labor cost, increased population and food demand, as well as diminishing agricultural land have created incentives for the promotion of sustainable techniques over intensive agricultural practices that are damaging to the soil and limited in their capacity to generate yields on a sustainable basis. Sustainable agricultural systems like no-till agriculture have become crucial for the prosperity of this indispensable sector (Campanhola 2013).

It has become evident that the no-till agricultural system is a solid technique. The prospects of achieving more sustainable agro-ecosystems with its implementation are high. It may thwart impending global challenges pertaining to soil degradation, water deficit, and climate change.

In 1999, the global no-tillage area amounted to forty five million ha. In 2003, the no tillage area amounted to 72 million ha, and in 2009, 111 million ha had comprised no-till areas (Derpsch *et al*. 2010). This may be attributed to the advancements of agricultural techniques and the expansion of planting areas. A significant expansion of no-till areas was observed in South Africa, however. There, permanent no-tillage systems form around 70% of the total planted area (Derpsch et al. 2010).

Water deficit is one of the key factors affecting crop production in Lebanon and the MENA region. The MENA is one of the most water scarce regions of the world as a consequence of climate change and population growth. With accelerated population growth, the need for food and thus agricultural water is increasing. Crop producers are facing challenges in providing sufficient outputs to meet the needs of the growing population, with limited accessibility to water for irrigation. Therefore, innovative methods of crop cultivation, suitable irrigation scheduling, and effective irrigation techniques are required for sustainable production and water conservation**.** Being a semi-arid region, the MENA also suffers from low humidity during the spring and summer seasons (cropping season). This leads to more evapotranspiration and an increase in the frequency of irrigations required for the crop. In comparison to no mulching or standard plantation, the no-till system can reduce surface evaporation of water, conserve soil moisture, and reduce the need of irrigation by using surface organic mulch.

Potato cultivation involves an intensive plowing arrangement, wherein the topsoil is loosened and pulverized into small aggregates during the seedbed preparation. In addition, hilling, inter-row cultivation, and mechanized harvesting entail intensive soil disturbance. These practices lead to increased soil erosion, and they may affect soil health. By adopting mulch planting techniques, no-till agriculture could reduce the risk of soil erosion, water loss from soil, and improve soil health. This can be done by placing the potato seeds (tubers) on the soil surface, and then covering that surface with organic mulch, such as wheat or barley straw.

The objectives of this research are to investigate the (1) appropriate mulch density for potato growth under no-till, (2) the economic water productivity of potatoes in no-till system, and (3) the feasibility of no-till system in potato production.

CHAPTER II

LITERATURE REVIEW

A. Potato General View

The potato (*SolanumTuberosum)* is an annual herbaceous plant that belongs to the family *Solanaceae.* They first originated in the Andean mountains, and they turned out to be one of the most important crops in the world. The potato is regarded as one of the most important crops in the East Mediterranean regions, and it is the fourth major world food crop after corn, rice, and wheat. In Lebanon, the Beq'aa and Akkar provinces are the main potato production areas, with about 68% and 19% of the total production, respectively (Abou-Jawdah *et al*. 2001). According to Dean (1994), potatoes satisfy the daily human nutritional requirements of protein, calories, iron, and vitamins B and C. In Lebanon, potatoes are considered to be the primary cash crop; their plantation covers 148,000 ha (Darwish *et al.* 2003). In addition, potatoes can be grown in an array of environments (FAO 2008). This is why the potato was selected for this study.

The potato is a "cool season crop," and its growth and tuber development are mainly mediated by temperature. The best yield could be obtained when the temperature ranges between 18-20^{0}C. Temperatures outside the range of 10^{0}C-30^{0}C would severely hinder tuber development (FAO 2008). The optimum temperature for best yield results is around 17°C, and the optimal water ratio for this is at about 60–80 % of soil-water holding capacity (Kolbe 2003). Accordingly, potatoes are planted at different times in the various climate conditions. For example, potatoes could be cultivated in early spring in temperate zones, in late winter in warmer conditions, and during the coolest winter months in tropical climates. Recommended planting time in the Beqaa plain in Lebanon is between March and June. If proper agricultural practices are followed, temperate climates could produce 40 t/ha of potato tubers.

With the exception of saline and alkaline soils, potatoes can be harvested in any kind of soil. Usually, soils that are naturally loose would provide the least resistance for tuber development. Loamy and sandy-loam soils are the type of soils that provide adequate drainage, aeration, organic matter, and an ideal pH of 5.2-6.4 for potato cultivation (FAO 2008). Good seedbed preparation is of principal importance to insure a high yield, namely, to ensure quick emergence, deep penetration of the roots, and well-drained loose soil. This can be accomplished by deep tillage of up to 25 cm followed by harrowing. Fertilizers and cultivar selection and agricultural practices determine the quality of the potato yield. Large amounts of nitrogen and potassium are needed (Dean 1994). While too much nitrogen can be detrimental to the crop, potassium and phosphorus are heavily used by potato plants during proliferation (Peet 2001).Various potato cultivars are planted in Lebanon. The most common one consumed in Lebanon is the variety “Spunta.” Agria is an industrial variety grown for the chips industry. Efforts to increase this variety are still underway, but the lack in a local seed production systems place many restraints on the potato industry in Lebanon (FAO 2007).

Common pests of potato include: bacterial soft rot, ring rot, black leg, black scurf, early blight, late blight, scab, seed piece rot, virus complex, nematodes, potato, tuber worm, aphids, leafhoppers (Cannon 2003; FAO 2008) and weeds. *Phelipanche aegyptaica*and *Cuscuta* spp. are among the dominant parasitic weeds infesting potatoes in Lebanon (Sabra and Haidar 2012). The former is considered to be one of the most dangerous and fast-spreading parasites in the potato-producing areas of Lebanon and its neighbouring countries (epidemic pest). Currently, there are neither pre-emergence (PRE) nor post-emergence (POST) herbicides registered for use against *Phelipanche*in potatoes (Haidar *et al*. 2005).

B. Soil Moisture

If high yields are desirable, the water requirement (ET_m) for a crop age of 120 to 150 days would be, according to the climate, 500 to 700mm (FAO, 2013). For this reason, the potato is usually an irrigated crop. However, if soil moisture fluctuates, tubers would develop unevenly and cracks would form. Furthermore, water losses due to evaporation should be minimized in high temperature areas by ensuring the canopy grows as quickly as possible. Thus, monitoring soil moisture is a basis for irrigation scheduling. It provides accurate information about the extraction of soil-water by the crop. There are various instruments for measuring soil moisture. Such instruments are most effective when used in combination with gathered data on evapotranspiration (ET) (ET is the amount of water that is lost due to evaporation from the soil, and plant transpiration). The instruments determine when to irrigate, and the ET data are used to calculate the volume of water loss since the last irrigation. From this information, we may calculate the volume of water that needs to be compensated for. Stieber and Shock (1995) concluded that soil moisture should be maintained between -50 and -60 centibar to achieve optimum potato yield. Studies carried out by Harris (1978) and Ekelöf (2015) found that potato yields were positively related to mean soil moisture.

C. Water Deficit

Adequate water and timing of irrigation affects the quantity and quality of potato tubers (Kleinkopf 1983). A high soil moisture level must be maintained. A requirement of 500-700mm of water is needed for a 120-150 day crop, if best yields are desired (FAO 2008). Water deficits are most deterministic during the bulking stage of the crop. It is known that a water deficit during that stage of development would negatively impact yields more than water deficits during any other stage. Studies have shown that water stress causes a reduction in leaf area, which would reduce photosynthesis, and ultimately reduce tuber yields (FAO 2008). Since the potatoes have shallow root systems, they respond well to frequent irrigation, especially when sprinkler irrigation systems are used to make up for evapotranspiration every one or two days. Sprinkler irrigation systems are commonly used in Lebanon due to cost-effectiveness and low maintenance requirements. Potato producers usually start effective potato irrigation in about 20 days after plantation, and they maintain intervals every 6-8 days till harvesting. A lot of water could be wasted in this process. To reduce water waste, few farmers are using drip irrigation. Sammis (1980) found that in comparison to sprinkler and furrow irrigation methods, drip irrigation delivered the highest potato yields by delivering uniform soil moisture in the root zone. Simonne *et al*. (2002) indicated that drip irrigation is economically feasible for potato production due to additional profits from costs and returns using drip irrigation.

D. Irrigation Scheduling

Proper irrigation scheduling is important to avoid under or over-irrigation. Potatoes are most commonly irrigated via furrow and sprinkler irrigation. Because the crop has a shallow root system, it responds well to frequent irrigation. For example, using a sprinkler irrigation system in potato production is beneficial because this type of irrigation system allows any water losses as a result of evapotranspiration to be compensated for as necessary. There are various ways to estimate how much water is required by crops and to assess which irrigation method is most effective. One of the most recommended methods is the use of weather data. A crop coefficient (Kc) assesses crop water use at a certain growth stage in relation to the amount of reference crop evapotranspiration (Eto) as calculated from weather data (Simonne *et al.* 2006). Water evaporates from soil and transpires from plant leaves. Together, these two processes in unison are referred to as evapotranspiration (Et).

Irrigation scheduling aims to increase water use efficacy by finding a balance between the water used by the crop and the water applied to the crop. In addition to conserving water, irrigation scheduling would also reduce the amount of energy used, and it would reduce ground water contamination by minimizing leaching. Water deficits should be avoided when potatoes are in the stages of stolonizaiton, tuber initiation, and yield formation. Water restrictions could be applied during the early vegetative growth and ripening stages. Furthermore, a higher depletion of soil-water could be allowed when ripening occurs. Such strategies could shorten the maturation phase (FAO 2013).

Water deficits during the beginning stages of yield development would increase spindle tuber formations. Tuber cracking and blackening could occur when water deficits are observed after that period. Dry matter content could exhibit proliferation when water supply is limited during the ripening stage. Furthermore, tuber malformation is reduced with frequent irrigation. When planting potatoes, it is recommended that pre-planting irrigation is implemented. This is because soil moisture prior to planting should be 70-80% of the field capacity, which is about a quarter of the allowable deficit. Pre-irrigation helps in clod-breakdown and in reducing clumps in the soil (FAO 2013).

During the early vegetative development (this stage starts at planting and continues up until sprouting), the first foot of the soil must be between 65%-80% of the field capacity. It is recommended that no irrigation occurs during this period of development; at this stage, the seed pieces have enough water in them to sustain their development until emergence occurs. If irrigation ensues during that period, the soil becomes favorable for pathogens such as soft rot and black leg, as well as stem and stolon canker. Furthermore, excessive moisture would place seed pieces under metabolic stress. Excessive moisture during this early vegetative period would cause an increase in *Verticilliumalbo-atrum*, which would cause death mid-season (FAO 2013).

Between the period of emergence and tuber initiation, which is the log phase of vine development, irrigation must be low (0.5"). It should increase however, by 0.5" every week as the canopy grows. When tubers initiate, the soil moisture must be between 70% and 80%. If the water content in the soil is below 65%, then the field would be considered to be in a water deficit. If water deficiency occurs at this stage of potato growth, then the canopy and root development would be stunted. Excessive water would stunt root branching, and it would increase the leaching of nitrogen (FAO 2013).

When considering determinate varieties, the end of vine growth is marked by full bloom. In indeterminate varieties, however, full bloom indicates a slowdown in vine development. At this stage, irrigation is of great importance, whilst water stress is considered less tolerable as the tubers begin to develop. During this phase, transpiration rates are at their highest, and soil moisture must be between 80%-90% of field capacity. In sandy type soils, irrigation must increase by 1.5-2.5' a week. Any deficits would increase tuber deformation and sugar end. In varieties that are susceptible to the common scab, it is preferable that soil moisture content be between 90-95% of the field capacity. During the stage of tuber development, an excess of water would cause tubers to develop a brown center, a hollow heart, and vines would die. Swampiness would cause late blight, and it may increase susceptibility to early blight. It should be noted that this stage of development is usually during the hottest time of the year. During the stage of tuber bulking, the tubers are in their log phase of development. It should be noted that tubers must obtain their water stores from the outside environment. During this period of development, irrigation should be between 2 to2.5 inches per week, and soil moisture should be between 80-90% field capacity. During this stage of tuber bulking, excessive water would increase the appearance of a hollow heart, swollen lenticels, black leg, late blight, and soft rot leak and pink rot. Water deficits would cause early dying, tuber malformation, early blight, brown spots, and common scabs (FAO 2013).

E. Evapotranspiration (Et)

Evaporation is the change of water from liquid to vapor form. This transformation requires energy. Light intensity and duration, air temperature, humidity, wind, crop species and plant size are the key factors that determine the Et rate. A crop's Et (Etc) is the amount of water that evaporates from the soil surface and transpires from the leaf surface to the atmosphere.

Crop water use (Etc) = Crop coefficient (Kc) * Evapotranspiration (Eto, a reference number)

Or, Etc = Kc * Eto

Et rates are high when the soil surface is covered by the crop canopy and leaf surface. Thus, as growth increases, Et reaches its maximum. Alva *et al*., (2002) found that potato yields were positively influenced with high Et rates than with lower Et growing conditions. According to Marutani and Cruz (1989), 3-5mm of water applied to a potato per day was enough to satisfy the crop's evapotranspiration requirements and keep soil water potential at its optimum growth in the tropics. While, the average Et requirement was 2.49mm in sub-tropics (Kashyap and Panda 2001; 2003) and 12-13 mm in hot and dry climatic regions (Ferreira and Carr 2002). Lynch and Tai (1989) were able to show that potato yield (marketable) decreased when the soil's water potential was reduced from -30 to -120 KPa.

F. Water Productivity

Water productivity (WP) is generally defined as the net return obtained from a unit of water used (Molden *et al*. 2010). Such returns include higher yields, ecological advantages, and increased profit. Water productivity aims to produce more food and income by applying less amounts of water. Physical water productivity is considered the agricultural output over the amount of water that has been used. Economic water productivity is the value obtained from the unit of water that has been used. Economic water productivity has been used to describe water use in other fields such as nutrition, jobs, welfare and the environment (Molden *et al*. 2010).

The following equation describes WP:

$$\mathrm{WP} = \frac{\mathrm{Ya}}{\mathrm{Eta}}$$

In terms of physical water productivity, Ya refers to the yield that is obtained per unit of water. However, considering economical water productivity, Ya would refer to the profit value that is derived from the mass of marketable yield per unit of water (Geerts and Raes 2007; Molden *et al*. 2010). Eta, the denominator, is the expressed as the amount of water applied or depleted (Seckler 1996; Molden *et al*. 2003).

G. Water Productivity on Potato

The water productivity of a crop is the mass of production or the economic value of this production over grow inflows, in inflow, depleted water, process depleted water, or available water. Usually, WP is expressed via mass of produce or its equivalent in monetary value per water unit (Rashid and Gholami 2008). The four levels of crop water productivity are (Molden 1997; Ahmad *et al*. 2004).

CWPY-2g= C Y/Ig

CWPY-lrr=C Y/I_{rr}

CWPY-Et(act)=C Y/Et(act)

CWPY-Ta= C Y/Ta

CWP is the crop's water productivity expressed in kg/m^3; Y is the yield actual expressed in Kg/ha; Ig is the difference of "gross inflow and storage in the water balance equation" given in mm (Rashid and Gholami 2008); I_{rr} stands for the irrigation requirements, and it is expressed in mm; Et(act) stands for actual evapotranspiration, and it is also expressed in1 mm; Ta stands for transpiration, which is represented in mm; and C stands for the conversion factor (0.10) (ha mm m^{-3}) (Molden 1997; Ahmad *et al*. 2004). When CWP is studied from a physical point of view, transpiration is only considered. However, considering the difficulty of separating transpiration from evapotranspiration, this is not practical. Furthermore, evaporation is tied to &influenced by tillage, crop growth, as well as to management practices (Rashid and Gholami 2008). Root water uptake, rainfall, irrigation and capillary rise are the basis for evapotranspiration. According to (Rashid and Gholami 2008) and by using the equation, CWPY-Et(act)=C Y/Et(act), potato CWP is between 1.92 and 5.25 kg/m^3. Potato WP is much higher during the winter (12.7Kg/m^3) season that in the summer (6.4/kg/m^3) (Bowen 2003). Similarly, Wright and Stark (1990) reported WP values of 4.4-1.2

kg/m^3.

H. Organic Mulch

Mulch is any dead material that is applied to the soil as a form of cover. Mulching has been practiced by farmers since ancient times. Its benefits include the control of soil erosions and an increase in the soils' organic matter (OM) content (Jacks *et al*. 1955; Rowe-Dutton 1957).

It has been found that soil moisture increases under straw mulching (Doring2005). Moisture increases in mulched soil because of increased infiltration (Ayanlaja and Sanwo 1991). This is a result of the mulch intercepting water drops which would reduce any compaction or sealing of soil pores. When evaporation is decreased, water is conserved (Ayanlaja and Sanwo 1991). It was further noted that shading partly contributes to water conservation. The higher the amount of mulch applied to the soil, the more water is conserved. It was observed that light and heavy applications of mulch are almost similar in their effect in water conservation (Russel 1940). Mulch has been observed to reduce weed germination, which also contributes to water conservation (reduced evapotranspiration). Mulch also leads to a reduction in the soil's surface temperature, and therefore it boosts dew formation (Jacks *et al.* 1955). It should be noted that the effect mulch has on moisture is observed only in the upper layer of the soil. However, mulch is not effective in conserving water from light rain falls as it intercepts it, hence; water evaporates before it reaches the soil (Russel 1940).

Mulch is able to stabilize the temperature in the soil (it increases temperature in the winter, and reduces average soil temperature in the summer)(Doring 2005). When it comes to soil temperature, the amount of mulch used is of great importance, with temperature regulations being more effective when the amount of mulch used is high

(Lal 1987). Doring (2005) observed that mulch hinders the process of soil erosion through reducing run off, velocity run off, drill formation, increased infiltration rates, and also in a reducing the impact of rain drops on the soil, which reduces soil breakup. Some studies suggested a reduction in soil-nitrogen content in mulched soils in comparison to un-mulched soils (Scott 1921); various studies have shown that straw mulch may affect the levels of nitrates in the soil throughout the cropping season. According to Jacks *et al*. (1955), Thurston (1997) and Cheshire *et al.* (1999), incorporating straw mulch into the soil would render nitrogen unavailable to the crop. Organic matter (OM) in the soil is shown to increase by 0-25% even after just one year of straw mulching (Doring 2005). In addition, mulching enhanced the beneficial soils' microbiota populations. Straw mulching increased earthworm populations (Thurston 1997) because mulch reduced desiccation and provided earthworms with a readily available source of food. It should be noted here that earthworms may reduce the amount of straw mulch because they would feed on it. Furthermore, in comparison to non-mulched soils, mulched soils exhibited a higher population of collemboles, diplopodes, and dipteran larvae. However, the reverse was observed for populations of mites and enchytraeids (Doring 2005).

I. Straw Mulch and Potato Growth

A two year experiment conducted by Dvořák *et al.* (2012) showed that applying cut grass mulching to potato increased the weight and number of tubers with a tuber fraction of 56-60mm and above, and it reduced the weight of tubers that were less than 40mm. According to Dvořák *et al.* (2012), the dry matter weight of tubers does not differ between potato grown in black textile mulching and chopped grass mulching at a rate of 25mm, and potatoes grown using conventional mechanical cultivation. Mulching with white polyethylene sheet, black polyethylene sheet, perforated black polyethylene sheet, and grasses had a positive effect on potato emergence over a three year trial (Mahmood *et al.* 2002).

Organic mulch had a positive effect on potato biomass and tuber structure. Singh and Ahmed (2008) reported an increase in plant height and stem number in potatoes grown under mulch verses those that were not. Amongst treatments with white mulching, black mulching, and no mulching, black polyethylene mulching reported the greatest in maximum average emergence and plant height. This could be attributed to the increase soil temperature exhibited with black polyethylene mulch. They also reported that for potatoes grown under black polyethylene, a higher number of tubers, in comparison to white polyethylene mulch or no mulch, was observed. Potatoes grown under black polyethylene mulch had a yield of 35.2t/ha. Under white ethylene mulch, potatoes had a yield of 31.5t/ha, and without any mulch, they had a yield of 26.6t/ha (Singh and Ahmed 2008).

Kar and Kumar (2007) reported that a great reduction in potato yield was obtained when irrigation numbers were reduced. Conversely, economic benefits from non-mulched potato were not reached when irrigation was reduced. The same study reported that rice straw mulch was able to increase potato yield by 24-42%. Mulching increased crop emergence by five days in comparison to non-mulched treatments. Combining mulching with pre-sprouted tubers proved to be the most efficient (Mahmood *et al*. 2002). Furthermore, a higher application of water to the potatoes rendered increased water consumption by the plant, without any significant increase in the yield. Mulched ridges were successful in increasing soil temperature and improving the soil's quality, which lead to earlier maturation of potato tubers and a higher yield. Mulching was successful in increasing yield from 14.3t/ha in non-mulched potato plots, to 16.7t/ha in mulched plots (Khalak and Kumaraswary 1993; Mahmood *et al.* 2002). According to Khkalak and Kumaraswary (1993), straw mulching was more beneficial than mulching with plastic, in terms of the incremental costs involved. Between different mulching types, no significant differences were observed in the yield. When analyzing incremental cost-benefit ratio, straw mulch was found to be of better value than plastic mulch (Mahmood *et al*. 2002). Bushnell *et al*. (1931) reported that straw mulching (8-10t/ha) doubled potato yield in comparison to till plots that exhibited mechanical cultivation. The same study reported an increase in yield of 50 bushels per acre from mulched potato plots, in comparison to potato yields from non-mulched (cultivated) plots. Bushnell *et al.* (1931) also reported that mulching and increased irrigation, improved potato yield. Zehnder and Hough-Goldstein (1990) reported that superior potato grown on mulched plots (wheat straw layered at 6-19cm deep) produced 21.6t/ha, whilst superior potato grown in non-mulched plots produced only 0.6t/ha. Jalil *et al*. (2007) stated that potatoes required the minimal time to reach emergence under black mulch, in comparison to non-mulched potato. The highest yield of potato tuber came from potato plots grown with black polyethylene (25.5t/ha) whilst the lowest yield came from potato grown in non-mulched plots (13.6t/ha).

J. Straw Mulch and Water

Farmers in dry lands use mulch as a way to reduce water loss via evaporation in dry land areas that suffer from water shortages and rainfall inconsistencies (Unger *et al*. 2002). Pabin *et al.* (2003) indicated that evaporative losses could be drastically reduced when the field is covered in plastic residues/sheets or straw mulch. Mulching reduces evaporation mainly by shading the soil surface from the sun. Unger and Parker (1976) reported that evaporation losses were higher in soils that were bare than soils that are covered in mulch during the first 15 days, but that the observations were reversed after that. In the field, Unger (1978) was able to report that average precipitation storage in soil that was covered with 12Mg/ha of wheat residues was more than double that of soil that was bare. This goes to show that the moisture content is highest in mulched soil, throughout the entire cropping season. A reduction in evaporative losses improved productivity of crops. Furthermore, mulching has been used as a method in improving the efficiency of fallowed land by increasing the level of water stored in the soil (Jones *et al*. 1994).

According to Li *et al*. (2013), wheat, straw, and plastic mulch were successful in reducing evaporative losses from the soil. In wheat straw mulched soil, water storage levels in the first 0-200cm of the soil was directly proportional to the amount of precipitation. Furthermore, wheat straw mulch was able to increase water storage levels in fallowed land by 106.9mm (fallow efficiency was increased by 35%) (Li *et al*. 2013). In contrast, non-mulched fallow had an efficiency of 10-15% (Li 1982; Li and Xiao 1992; Zhang and Wu 1994; Li and Li 2000). In conserving soil water, plastic sheet mulch was more efficient than straw mulch. When plastic mulch was used, no water losses due to infiltration were observed in the first 200cm of the soil; furthermore, fallow efficiency was at 46.1% (Li *et al*. 2013). Water losses due to evaporation were still exhibited. Wheat straw mulch exhibited a loss of water of 27% during the first two months of experimentation, and 73% during the last two months of experimentation, whilst plastic mulch exhibited a loss of 15-85% during the same time frame (Li *et al*. 2013).

Havlin *et al*. (1990) and Duiker and Lal (1999) have reported that the surface layer exhibited an increase in organic matter, an increase in water retention, and an increase in the stability of aggregates, when mulched. Maize stalk mulch added to sandy loam soils increased residual soil moisture (Sharma *et al*. 1990). It was also found that higher soil water capacity was associated with the use of crop residue mulch under conservation tillage systems which also resulted in an increase in OM and a change in pore size distribution (Bescansa *et al*. 2006). According to Jordán *et al*. (2010), soil moisture content in the filed increases as the mulching rate increases. Also, water field capacity increases from an average of 29.7% under no and low mulching rates, to an average of 36.3% for higher mulching rates (Jordán *et al*. 2010). This same study concluded that available water capacity would increase as mulching rates increased, but that was not exhibited in mulching rates above 5Mg/ha. Plots Mulched with wheat straw exhibited more available water for wheat cropping during dry spells in the growing season (Zhang *et al*. 2009) in comparison to plots that were conventionally sown and un-mulched. The same study revealed that soil water depletion was greatly reduced when soils were mulched with wheat straw in comparison to when they were left fallow or cultivated without mulching. This could be attributed to the reduced soil temperature in mulched plots which consequently reduces water evaporation. Ji and Unger (2001) reported that straw mulch was successful at increasing soil moisture storage. Crop residues on the soil act as vapor barriers by reducing water evaporation from the soil, slowing surface runoff and increasing infiltration (Rathore *et al*. 1998). Rathore *et al*. (1998) observed that more water was conserved in the soil profile during the early growth period with straw mulch than without it. Subsequent uptake of conserved soil moisture moderated plant water status, soil temperature and soil mechanical resistance, leading to better root growth and higher grain yields (Rathore *et al*. 1998).

K. Conservation Agriculture

Conservation Agriculture (CA) is a practice of sustainable land management, a concept that strives to ensure the security of livelihoods, and to achieve sustainable agricultural practices. The system is versatile when it comes to farm size and different agro-ecological systems. However, small shareholders are most in need of adopting CA, especially if labor shortages are one of the problems that the farms suffer from. The system provides a way of combining profitable agriculture with environmentally friendly practices that ensure sustainability (FAO 2015). Conservation Agriculture integrates the management of soil, water, and other biological factors, and it minimizes external factors, in an effort to better utilize agricultural resources (Shaxson and Barber, 2003). CA centers on maintaining permanent or semi-permanent soil covers, either through using mulch or live crops. This is done to protect the soil from abrasive physical factors such as wind, rain and sun, whilst feeding beneficial soil biota. Because CA follows a no-till farming system, labor costs could be reduced as a result of a minimized requirement for passing over farms. Still, farmers would require greater management skills. Special equipment is required to sow seeds into crop residues, but diesel costs are reduced by at least 30%. A no-till CA is not suitable for all crops. Because soil is perpetually covered, less soil erosion occurs, however, this lowers the seed's chance of reaching the soil as it is being sowed.. It also creates a greater demand for management skills to avoid that. A reduction in the rates of evaporation and runoff would allow the soil to retain more moisture. However, the risk for certain pests' infestations and diseases dissemination would increase. Sedimentation in water sources is reduced, but at the same time, crop destroying pests and rodent populations would thrive. Since CA would reduce the need for fertilizers and runoffs, less pollution of water sources and water ways would be observed. However, an increase in the weed population may cause increased competition with the crop, if management is not sufficiently meticulous. Unless the soil is fine textured and poorly drained, it takes at least five years for the benefits of CA to show. CA allows for double cropping, but also increases the chances of anaerobic soil condition developments, which would increase nitrification and ultimately make the nitrogen in the soil less available to the crop being produced. The fact that crop residues are not removed or ploughed under means that the soil is more nutritious. However, soil temperatures would be cooler during the spring season, and this may negatively affect the germination rates of crops (Shaxson and Barber, 2003).

L. Conservation Agriculture and Potato

Conventionally, potato cultivation requires intense soil tillage all throughout the cropping period. Such soil tillage practices encourage soil degradation, erosion, and the degradation of nitrates and other nutrients (FAO 2008). Preparing the 'seed bed' involves the loosening of the top soil and breaking up of soil aggregates. CA grants the opportunity to reduce the negative environmental impacts of intensive potato farming (FAO 2008). Instead of tillage prior to cultivation, green cover crops are cultivated the season prior to potato cultivation. Potatoes would then be sowed into a ground covered with dead cover crop, or in other words, with green manure (FAO 2008). The planters used in this process have special disks that would cut through the mulch, thus splitting potato beds. The function of the mulch is to provide protection during the first week post planting. The manure would be incorporated when the potato beds are reshaped. Another cover crop could be seeded as green manure, as the potato starts to dry off (FAO 2008). This second cover crop is used when drying up the potato crops. The drying up process contributes to a better crop yield, with minimum damage during the harvest. A mechanical potato harvester would separate the green manure crop from the potato tubers, and then it is left on the field as mulch cover (FAO 2008).

German and Swiss farmers use mulch planting for potato especially in areas where drinking water could be easily polluted by nitrates leached out from the soil through conventional tillage practices. It should be noted that mulch planting for potato still involves a significant amount of soil disturbance. Another practice in potato cultivation utilizes the basic concept of CA, no-till, and is called the 'no-till potato'. This practice involved pressing the potato tuber into the soil and covering it with a thick layer of mulch (FAO 2008). The mulch is usually straw, and it is preferred for its stability and resistance to rot. It is necessary that the mulch layer be thick to ensure that the tubers are not exposed to light as this leads to their greening and to the development of toxic glycoalkaloid levels. Farmers in dry areas would use the drip irrigation system along with black plastic mulch. The farmers would punch holes in the plastic mulch so enable the growth of the potato plantsout of them; the tubers would then develop under the mulch, but above the soil surface. This would allow the farmer to simply pull the mulch back and collect the tubers. It should be noted that "no-till potato" farming is practiced in small fields that utilize manual labor. Such fields are in Peru (under plastic covers) and the Democratic People's Republic of Korea (under rice straw) (FAO 2008). Although extensive agriculture uses less labor and capital, intensive farming produces a much higher crop yield than extensive farming would. Because of this, intensive farming requires less land (Britannica 2014). In practice however, intensive agriculture farmers work on very large scales. Farmers find it more profitable to shift away from intensive agriculture to extensive agriculture only when cost of machinery, chemicals, and storage is too high (Britannica 2014). The damage that intensive agriculture causes has resulted in a decline in productivity, considering the fact that the world needs to double its food production in an attempt to feed nine billion humans by 2050. Intensive farming has caused farmers to over plough, over fertilize, over irrigate and over apply pesticides (FAO 2015). Increased runoff could be dealt with using 'terrace seals' or 'contours. Protecting the soil from the impact of raindrops could be dealt with using separation and protection layers that would reduce the impact that rain has on the soil by absorbing the water's kinetic energy and then releasing the water into the soil in a slower manner (Eshel *et al*. 2015). Straw, wood–cheep, even cover crops could be used as protection layers (Unger and Agassi 1995). An experiment conducted in Canada showed that oat-straw mulching at 4t/ha just after potato sowing reduced soil loss by 50% and simultaneously increased water retention in the soil by 5% (Edwards *et al*. 2000; Eshel *et al*. 2015). Using a rain simulator, Döring *et al*. (2005) applied 2.5-5t/ha of straw 2-4 weeks after planting potato under summer (rainy) conditions). Döring *et al*. (2005) was able to report 97% reduction in soil losses, with a maintained potato tuber yield. Furthermore, applying straw at a rate of 3t/ha reduced the loss of phosphorus and soil by as much as 95%, in comparison to to non-mulched/bare soil (Griffin and Honeycutt 2009; Eshel *et al*. 2015). Potato yield increased due to an increase in the content of organic matter as well as water-holding capacity (Hester 1937, Eshel *et al*. 2015). Increases in OM and water holding capacity in the soil are all key improvements provided by CA. Eshel *et al*. (2015) demonstrated the feasibility of growing potato following soil and water conservation strategies.

CHAPTER III

MATERIALS AND METHODS

Field and greenhouse experiments were carried out at the American University of Beirut during the spring and fall semesters of 2014, respectively. The field experiment was carried out at the Advancing Research Enabling Communities Center (AREC) in the Beq'aa plain during the period between April and September 2014. As for the greenhouse experiment, it was carried out at the greenhouse area of the Faculty of Agricultural and Food Sciences (FAFS) in the Beirut coastal area during October 2014 and February 2015. In both experiments, a standard certified potato seed variety "Spunta" was used (Figure 1). The seed potato was obtained from the Netherlands through a certified local agent in Lebanon (stet holland: spunta, n.d).

Fig. 1. Certified potato bag

A. Field Experiment

1. General Information about AREC

AREC is located in the Central Beq'aa plain with an altitude of around 1000 m above sea level at 33° 55'latitude and 36° 04'longitude,995 m ASL. The experiment was performed during the spring growing season between April and September of 2014. The AREC area is hot and dry in summer, cold in winter, with most of the precipitation falling between November and April. It is a semi-arid region and characterized by 3 to 4 months of summer drought, with an average annual pan-evaporation of 2 meters, 70% of which occurs between April and September (Jaafar *et al*. 2015). The average monthly temperature (T_{avg}), monthly maximum temperature ($_{tmaxAvg}$),minimum temperature (t_{minAvg}), monthly relative humidity in percentage, and average precipitation rate in mm during the experiment period (May 2014 till September 2014) are all represented in Figures 2 and 3 respectively.

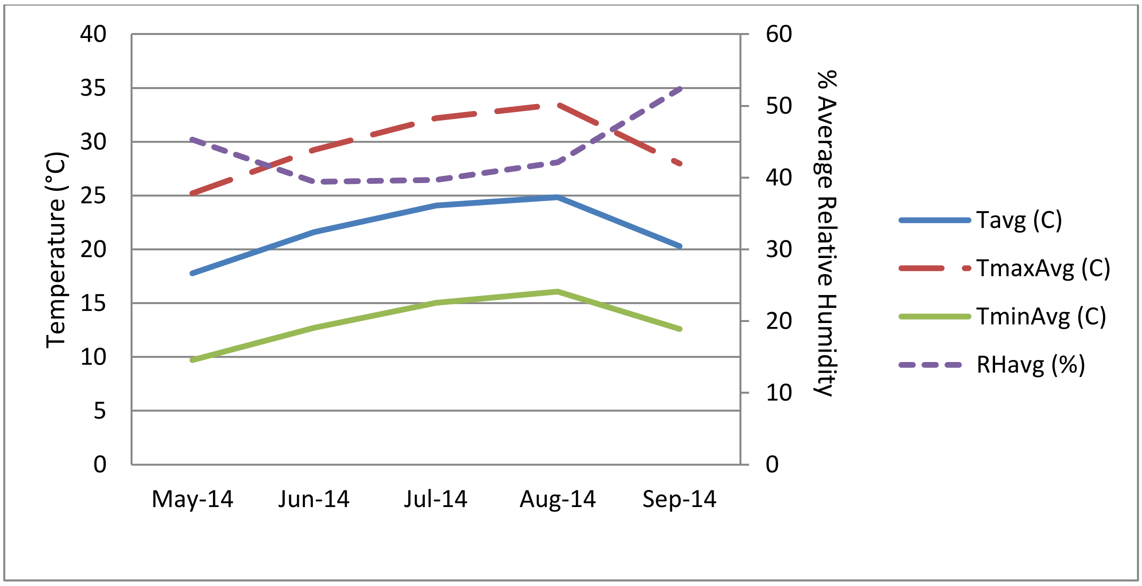

Fig. 2. Monthly average temperature and relative humidity during the planting season

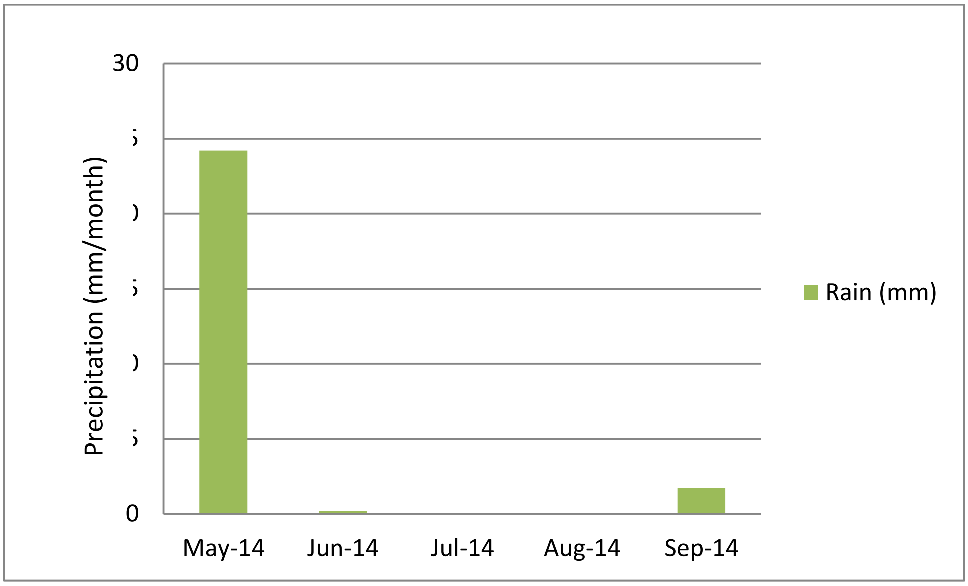

Fig. 3. Monthly precipitation rate during the experimental period

2. Methods of Soil Analysis

Soil samples were collected, before planting potatoes, from 10 randomly selected points at a depth of 0-30 cm. Soil samples were spread out on a tray in the lab to dry up. The air-dried soil was then grinded using a ceramic pestle and mortar, and it was sieved with a 2 mm sieve. Finally the soil was put in a clean and air-tight plastic container, labeled, and then analyzed for physical and chemical properties according to the procedures outlined by Bashour and Sayegh (2007).

a. <u>Physical Analysis</u>

- *Soil Moisture Content*

Soil moisture content was determined using the gravimetric method as described by (Bashour and Sayegh 2007). This method consists of oven-drying the samples at 105 to 110°C for 24 hours, and then estimating moisture level in the soil from the difference between the air-dry and oven dry weights.

- *Soil Texture*

Soil texture was analyzed according to Bouyoucos method (Bashour and Sayegh 2007). Briefly, 50 ml of 5 % Sodium Hexametaphosphate 1N (dispersing agent) were added to 50 g of soil with 300 ml of distilled water. Then the mixture was blended till all the aggregates were broken down. It was then was transferred into a 1L cylinder, filled with water till the mark, and shaken. Two measurements were taken while the mixture was settled using a hydrometer, first at 40 seconds and again after two hours. The temperature was recorded each time. Then the sand, silt, and clay fractions were calculated. The class of the soil was determined from the soil textural triangle.

- *Organic Matter*

Determination of the organic matter content was done using the dry combustion method according to Bashour and Sayegh (2007).

b. <u>Chemical Analysis</u>

- *Soil Reaction (pH) and Electrical Conductivity (EC)*

Soil acidity and alkalinity were measured in terms of pH values of the soil's aqueous solution or extract according to Bashour and Sayegh (2007).The pH and EC were obtained in a 1:2 ratio of soil: distilled water suspension that was shaken for 30 minutes on a mechanical shaker at 300 rpm. The solution was filtered with Whatman no. 40 filter papers. A pH-meter and an EC-meter were used to measure the pH and EC of the filtrate.

- *Sodium Bicarbonate Extractable Phosphorous or Available P (Olsen method)*

Available phosphorus was measured by colour as described by Olsen (1965) using five grams of the soil that were extracted by 100 ml of the extracting solution (0.5

M sodium bicarbonate, $NaHCO_3$).

- *Available Total Calcium Carbonate ($CaCO_3$)*

Soils of arid and semi-arid regions are characterized by their considerable calcium carbonate content, which is largely caused by low rainfall and limited leaching. The amount of a $CaCO_3$ present in the soil affects its physical and chemical properties by acting as a cementing agent and increasing the pH level (Bashour and Sayegh 2007). The acid neutralization method was used to measure the free $CaCO_3$. Five grams of each soil sample were boiled with excess amount (100 ml) of 1M Hydrochloric acid (HCl) for five minutes. The applied acid reacts with the carbonates and the excess acid not used in the process was estimated by back-titrated with 0.5M Sodium hydroxide (NaOH) solution using a few drops of the phenolphthalein indicator (Bashour and Sayegh 2007).

- *Available Potassium*

Potassium was extracted from soil according to Bashour and Sayegh (2007) by mixing 30 ml of ammonium acetate (1M) and 3 g of soil in a 50 ml tube. The mixture was put on a mechanical shaker for 30 minutes, and then it was filtered using a Whatman filter paper no. 40. Potassium was measured using the flame photometer (BWB technologies).

3. Field History and Seedbed Preparation

The field was fallow; it had not been planted for the last ten years. However, it was infested with various weeds (Figure 4). Accordingly, it was decided that the field be cultivated one week prior to planting with a mold board, before disking. Finally the process of seed bed preparation was ended by leveling the field to its best condition (Figure 5).

Fig. 4. Experimental site prior to the preparation of the seed bed

Fig. 5. Seed bed preparation

4. Site Description

The length of the planted area is 65 meters and the width is 19 meters (1,235 m^2). The site was divided into four blocks. Each block was divided into four large plots, and each plot was assigned a different irrigation treatment scheme (Figures 6 and 7). Each individual plot consisted of four sub plots (three mulching rates and till). These sub plot consisted of four rows (3.6 x 2.8m). Potato rows were 0.75 m apart androw spacing was around 0.25 m. The area of each sub plot is 10.08 m^2.

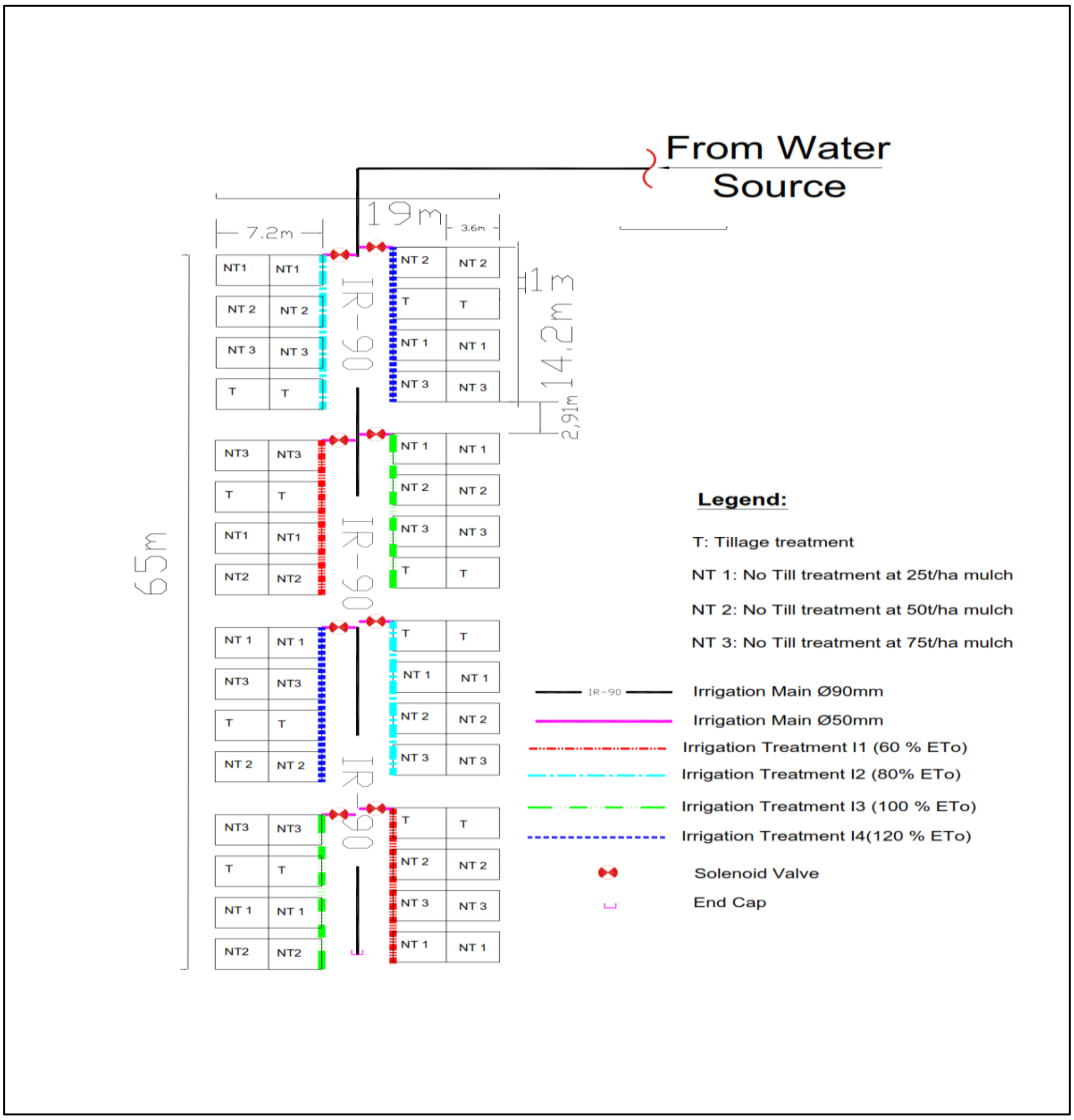

Fig. 6. Open field experiment layout

Fig. 7. Experimental site during the growing season

5. Experimental Design

A split plot design, with four replicates for irrigation as a whole plot factor and mulching as a subplot factor, was adopted. Four irrigation treatments based on different percentages of Eto were applied, and four mulch rates were tested. Statistical analysis was performed using JMP 10 – Copyright 2012 SAS Institute Inc. software Package. The effects of irrigation, mulch, and irrigation-mulch interactions were analyzed. Data was analyzed statistically using Tukey and Least Significant Difference (LSD) Test at p = 0.05 level of probability was used to determine significant differences between treatments means.

6. Mulching Rate and Sources

Four mulch rates were tested: 0t/ha (Till), 25 t/ha (NT1), 50t/ha (NT2), 75t/ha (NT3). Baled barley mulch (Figure 8) was obtained from a local farmer in the village of Budnayel, Beqaa plain at a cost of $250/ton.

7. Planting Method

In no-till treatments, potato seeds were placed on a soil surface on April 28, 2014 (Figure 9). Next, they were covered with a thick layer of dry barley straw mulch at 25, 50 and 75 tons/ha (Table 1). The barley straw was spread on the top of soil manually (Figure 10). The control treatment (tilled plots) was planted on the same day using a seed drill at a depth of 20 cm (Figure 11).

Fig. 8. Baled barley mulch

Fig. 9. Placing potato tubers on the soil surface in no-till treatments

Fig. 10. Spreading straw mulch in no-till treatments

Fig. 11. Planting potato in till treatments using seed drill

Table 1. Different mulching treatments

Treatment #	Amount of mulch used per subplot (Kg)
Till	0
No-till 25 t/ha	25.2 Kg
No-till 50 t/ha	50.4 Kg
No-till 75 t/ha	75.6 Kg

8. Irrigation

a. Installation of Main Pipes and Drip Irrigation System

For no-till treatments, drip lines were placed on the top of the soil before placing potato tubers on the soil surface. Drip lines were installed directly after planting in for-till treatments. The drip lines installed were 16 mm in diameter, and the inline emitter drip was 4lph/emitter, and it was spaced at 25 cm (Figure 12).

Fig. 12. Installation of drip lines in no-till treatments

b. Installation of Atmometers, Controller, Solenoid Valves and Filters

An atmometer (ETgauge) was installed in the field in order to measure evapotranspiration. The data was collected on daily basis at 10:00 am. The atmometer is supplied with a ceramic cover (No. 53) in order to estimate the Eto (alfalfa reference). In addition, a controller manufactured by Weathermatic company (SL1600) was installed on the site area to accurately control the timing for irrigation (Figure 13). This controller was connected directly to solenoid valves installed on each plot. In addition, filters were installed beside each solenoid valve (Figure 14).

Fig. 13. Controller to manage the irrigation timing

Fig. 14. Solenoid valves, filter connected to the controller

c. Irrigation Treatments

Irrigation treatments were based on the recorded percentage of Eto measurements using the atmometer (alfalfa reference). We designed an irrigation system based on four different evapotranspiration rates I1: 60% Eto, I2: 80 %Eto, I3: 100 %Eto, and I4: 120% Eto. Within each block, four different irrigation timings were applied to each plot separately based on the Eto rates.

d. Irrigation Scheduling

Irrigation scheduling was done depending on the amount of water that had evaporated from the ET gage. Growth stages were divided into three stages: vegetative growth (first stage), the beginning of tuber growth where the average root length was 32 cm (second stage), and the mature growth stage of tubers, where the average root length became 39 cm (third stage) (Table 2). To account for non-uniformity of emitters and lateral placement in the field, an irrigation efficiency of 85 % was assumed in first two growth stages. During the third stage and due to emitter clogging from algae and debris in water, the rate was reduced to 80%.

Table 2. Growth stages and the respective root length of potato

Growth stage	First stage (vegetative growth)	Second stage (beginning of tuber growth)	Third stage (tubers mature growth)
DAP	0	40	80
Root length (cm)	0	32	39

e. Irrigation Timing

Knowing that the irrigation depth is 40 mm (Table 3), irrigation timing was calculated depending on the Eto reading.

Table 3. Irrigation depth during one hour irrigation (mm)

Length of drip line/plot (m)	Flow per drip line/plot (m3)	Wetting pattern (m)	Area covered in each drip line (m2)	Irrigation depth (mm)
3.6	0.0576	0.4	1.44	40

- *Sample Calculation of irrigation timing during one irrigation period (fourteen days after planting)*

The net Eto during the planting season between two consecutive irrigations was 15 mm at 14 DAP; hence, irrigation timing for I4 irrigation treatments will be $=\left((\text{I4 (mm)} \div \text{waterdepth mm}) \times 60\text{minutes}\right) \div \text{Efficiency} \ =$ $\frac{(18 \text{ mm} \div 40\text{mm}) \times 60 \text{ minutes}}{0.85} = 32$ minutes.Similarly for I1, I2 and I3 (Table 4).

Table 4. Irrigation quantity (mm) and irrigation timing (minute) for one irrigation period at 14 DAP

Irrigation treatment	Irrigation quantity (mm)	Irrigation timing (mins)
I1 (60 % Eto)	9	16
I2 (80 % Eto)	12	21
I3 (100 % Eto)	15	26
I4 (120% Eto)	18	32

- *Sample Calculation of total irrigation flow of I4(120% Eto) treatment during the planting season (m^3/ha)*

The total flow of I4 (120% Eto) per hectare =($Flow\ of\ I4\ in\ all\ plots\ \times$

$10{,}000\ m2) \div Area\ of\ I4\ plots = (\ 132.1\ \times 10{,}000) \div 161 =\ 8{,}202.5m3\ /ha.$

Similarly for I1, I2, and I3 irrigation treatments (Table 5).

Table 5. Total irrigation quantity during the growing season

Irrigation treatment	**Total irrigation (mm)**	**Irrigation timing (hrs)/ irrigation treatment**	**Cumulative flow m^3/irrigation treatment**	**Total flow m^3 per ha**
I1 (60 % Eto)	438.6	24.7	90.9	5,646.8
I2 (80 % Eto)	584.8	28.4	104.6	6,498.70
I3 (100 % Eto)	731	32.1	118.3	7,350.60
I4 (120 % Eto)	877.2	35.8	132.1	8,202.50

During the growing season, and every two weeks, all plots were subjected to a two hour irrigation period together in order to return the water for the field capacity level. Cumulative ET (mm), reading are stated in Figure 15.

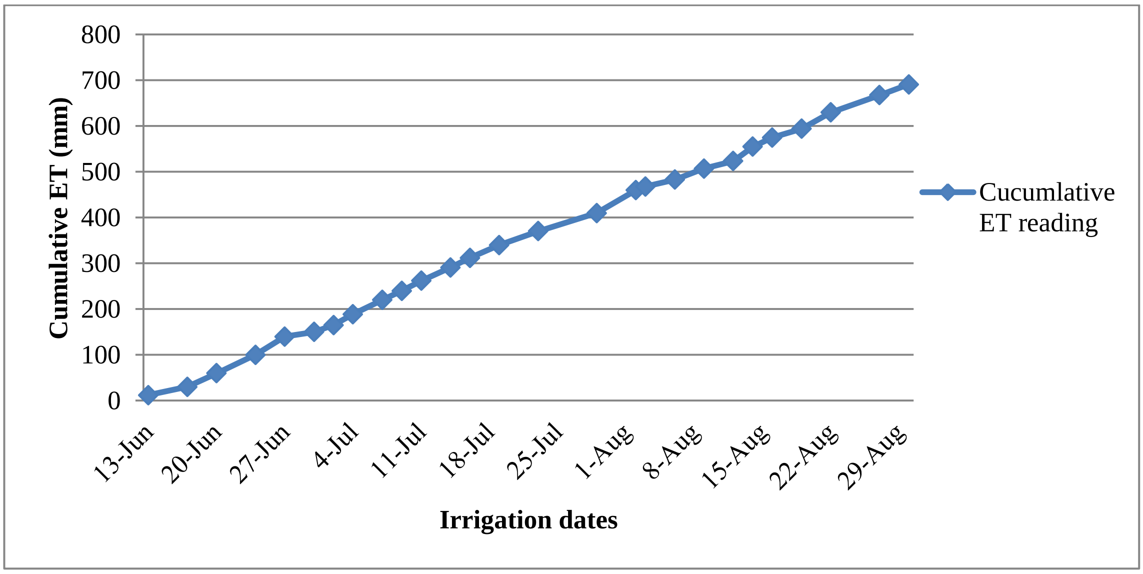

Fig. 15. Cumulative ET (mm) versus irrigation dates during the growing season

9. Placing Soil Thermometers

Four sensors were placed randomly in I4 (120% Eto) treatments. Three sensors were placed in three mulching treatments at the bottom of the mulch, and one sensor was placed at a 10 cm depth in the soil of till treatments. Readings were taken on daily basis at 1:00 pm.

10. Fertilizer and Pesticide Application

Granular fertilizer (15-15-15) was added to the soil surface, prior to planting at a rate of 500 Kg/ha using the band application method. Complimentary amounts of soluble fertilizers (20-20-20) were added in the drip irrigation systems every 15 days at a rate of 20 Kg/ha. Two weeks after planting, Metribuzin 0.75kg ai/ha (Metribuzin 70%) was sprayed in the early post emergence stage at a rate of 0.7kg ai/ha, and this was followed immediately by sprinkler irrigation at 0.5 bars for 1 hr. Metribuzin was applied with a CO_2-pressurized backpack sprayer that delivered 400 L/ha at 30psi through a Teejet 8002 flat fan sprays tips. Other pesticides were sprayed against various pests during the growing season as shown in Table 6.

Table 6. Pesticides sprayedby Knapsack sprayed after 50 days from planting

Trade name	**Active ingredient**	**Rate (g/20 liters)**	**Target**
Vertimec EC	Abamectin 1.8 %	10	Mites
Actara WG	Thiamethoxam 250 G	10	Aphids
Folio Gold SC	Mefenoxam 37,5 g Chlorothalonil 500 g	40	Downy mildew
Agral	Emulsifier & Surfactant Agent	5	Surfactant
Gold fert	Micronutrients	25	Nutrients

11. Harvesting Potato

In no-till plots, potatoes were harvested by hand, by removing the straw barley from the top of the soil (Figures16 and 17). While in the till plots, potato tubers were removed manually from the soil by using hoes (Figure18).

Fig. 16. Potato tubers in the straw

Fig. 17. Removing straw mulch from no-till treatments

Fig. 18. Harvesting potato in till plots

12. Data Collected

The data collected included the maximum and minimum recorded temperatures beneath the straw/soil (10 cm depth), the number of plants in the middle two rows (5.04 m^2), shoot height (six plants/subplot), shoot number (six plants/subplot), the number of leaves (six plants/subplot), root and shoot dry weight (two plants from the edge rows), and yield quantity and quality through counting and weighing the marketable and non-marketable tubers (Table 7). The potato yield was determined by harvesting the middle two rows in each plot (5.04 m^2). The yield quality was determined by separating harvested tubers into two classes: marketable (> 6 cm diameter) and non-marketable tubers (<6 cm in diameter) (Figure 19).

Table 7. Parameters evaluated in the different readings of open field experiemnt

Reading number	1st reading	2nd reading	3rd reading	4th reading	5th reading
DAP	35	45	75	117	142
Shoot height (six plants per subplot)	×	✓	✓	×	×
Number of plants in 5 m^2	✓	✓	✓	×	×
Crop shoot number (six plants per subplot)	×	✓	✓	×	×
Number of leaves (six plants/subplot)	×	✓	✓	×	×
Root dry weight(two plants from the edge rows)	×	✓	×	✓	×
Shoot dry weight (two plants from the edge rows)	×	✓	×	✓	×
Marketable yield in ha	×	×	×	×	✓
Non-marketable yield in ha	×	×	×	×	✓

Fig. 19. Data recording marketable versus non-marketable

B. Greenhouse Experiment

1. General Information

The same experiment was repeated in the greenhouse area of the Faculty of Agricultural Sciences in Beirut during September 2014. The greenhouse area was divided into four blocks where each block was subdivided into four plots each with a different irrigation treatment. Each plot consisted of four netted plastic boxes (30 x 40 x 30 cm). Within the four boxes in the plot we have different mulching rates (till or 0 t/ha, 25t/ ha, 50 t/ha, 75 t/ha). The rate of straw/box is shown in Table 8.

2. Planting Potato

Potato tubers were first placed in a plastic jar, covered with aluminum foil and kept in dark cold room for two weeks to enhance sprouting. Two tubers were planted in each box. For no-till potato, all boxes were one third filled with soil, and then tubers were placed on the soil surface and covered with various rates of barley straw (Table 8). While for till system, potato tubers were placed at a depth of 20 cm in pure soil. The soil source was collected in the south of Lebanon.

Table 8. Quantity of Mulch used in each box

Treatment #	**Amount of mulch(kg) used per subplot**
Till	0
No-till 25 t/ha	0.3
No-till 50 t/ha	0.6
No-till 75 t/ha	0.9

3. Irrigation

a. Treatments

In order to estimate the amount of water needed for sufficiently irrigating potatoes, we designed the same irrigation system used at AREC which is based on four different evapotranspiration treatments. Each block was divided into four plots of different irrigation timings: I1: 60% Eto, I2: 80% Eto, I3: 100% Eto, and I4: 120% Eto.

b. Installation of Main Pipes and Drip Lines

For no-till treatments, drip lines were installed on the soil surface before planting potato. Drip lines were installed after planting using for till treatments. Drippers of 4lph flow were used to irrigate the potato plants in the greenhouse (Figure 20).

Fig. 20. Potato planted in boxes inside the greenhouse

c. Installation of ET Gage and Valves

An ET Gage was installed in the greenhouse in order to read the evapotranspiration values on a daily basis in order to irrigate in accordance to irrigation timings. In addition, ball valves were installed for each plot in order to control the irrigation timings.

d. Irrigation Scheduling

Irrigation was employed only twice during the planting season (winter) due to the very low evapotranspiration. For I1 (60% Eto), 1.2 liters were applied for each box in this treatment, I2 (80% Eto) 1.6 liters, I3 (100% Eto) 2 liters, I4 (120% Eto) 2.4 liters.

4. Experimental Measurements and Statistical Analyses

Data collected included height/2 plants/box, crop shoot number (box), number of leaves/box, shoot and root dry weight and yield quantity (Table 9). Potato yield was determined by harvesting the whole box. Statistical Analysis was performed using JMP 10 – Copyright 2012 SAS Institute Inc. software Package. The effects of irrigation, mulch, and irrigation mulch interactions were analyzed. Data were analyzed statistically using Tukey and Least Significant Difference (LSD) Test at p = 0.05 level of probability was used to determine significant differences between treatments means.

Table 9. Parameters measured in greenhouse experiment

Reading number	**1st reading**	**2nd reading**
DAP	95	123
Shoot height (two plants/box)	✓	✓
Number of plants/box	✓	✓
Crop shoot number/box	✓	
Number of leaves/box	✓	✓
Shoot and root dry weight/box		✓
Tuber number in ha		✓
Tuber weight in ha		✓

CHAPTER IV

RESULTS AND DISCUSSION

In this chapter, the results of all parameters in the field and green house experiments are illustrated and discussed below.

A. Field Experiment

1. Soil Analysis

The results of soil analysis show the following textural composition: Clay: 50.4 %, sand: 12.11 % and silt: 37.47 %. Hence, the soil is classified as clayey, with a moisture content of 8.01 %, & an organic matter content of 6.26 %. Also, the electrical conductivity was 294µS/m, and the PH level was at 7.92. In addition, the soil analysis showed that there is 11ppm phosphorous (P), 514ppm potassium (K) and 22.5% calcium carbonate ($CaCO_3$).

2. Effect on Potato Growth

Results show that the till potato (0t/ha mulch) under the four irrigation treatments significantly enhanced the shoot height, compared to the no-till potato at all tested rates (25t/ha, 50t/ha and 75t/ha), 45 DAP. Shoot height in the no-till potato at 75t for 120% and 60% Eto was significantly lower than the rest of the treatments (Table 10). The same results were obtained regarding plant number. The highest plant number was for for-till potato under various irrigation rates in comparison to the no-till potato (25t/ha, 50t/ha and 75t/ha) after 35DAP. Plant number in no-till potato at 75t/ha was significantly lower than till 0t/ha under all irrigation rates after 35 DAP. While, at 45

DAP, results showed that plant number in no-till potato at 75/ha was lower than that of till potato under all irrigation treatments (Table 10). Plant number increased with time in no-till potato under all irrigation treatments.

Table 10. Effect of different irrigation rates and mulch treatments on shoot height and number of plants per 5 m^2. (Summer 2014)

Irrigation Treatments	**Mulch rates (ton/ ha)**	**Shoot height DAP**				**Plant number DAP**					
		45		75		35		45		75	
I1 (60 % Eto)	T (0)	53	a	66	bcd	30	a	24	abcd	28	ab
	NT1 (25)	30	bcd	71	abcd	24	ab	23	abcd	25	abcd
	NT2 (50)	29	bcd	76	abcd	12	bcd	20	abcd	25	abcd
	NT3 (75)	22	d	74	abcd	8	cd	17	cd	27	abcd
I2 (80 % Eto)	T (0)	51	a	62	d	30	a	26	abc	28	abcd
	NT1 (25)	38	b	67	abcd	32	a	31	a	24	abcd
	NT2 (50)	35	bc	68	abcd	26	ab	23	abcd	27	abcd
	NT3 (75)	29	bcd	79	abc	13	bcd	19	bcd	26	abcd
I3 (100 % Eto)	T (0)	53	a	65	cd	32	a	25	abc	31	a
	NT1 (25)	30	bcd	72	abcd	30	a	28	ab	30	a
	NT2 (50)	31	bcd	76	abcd	18	abcd	26	abc	26	ac
	NT3 (75)	29	bcd	71	abcd	14	bcd	21	abcd	21	bd
I4 (120 % Eto)	T (0)	51	a	66	cd	29	a	27	abc	27	ab
	NT1 (25)	31	bcd	78	abcd	24	ab	29	ab	26	abcd
	NT2 (50)	35	bc	82	ab	21	abc	23	abcd	21	cd
	NT3 (75)	26	cd	83	a	5	d	14	d	23	abcd

T(till); NT (no-till); I (irrigation treatment)
Shoot height was taken as average height of six plants (n=6)
*Means followed by the same letter, within each column, do not significantly differ at the 5% level according to the LSD test.

Boomsma and Vyn (2007) found that thick mulch may produce shorter plants early in the season because of delayed emergence of crop shoots. Furthermore, cooler and wetter soil conditions resulting from a thick cover may lead to shorter plants. Our observations showed that thick mulch in no-till plots at 75 t/ha delayed emergence of potato plants and this resulted in shorter plants compared to till plots 45 DAP. Potato shoots emerged 1-2 weeks prior to no-till potato at all tested mulching rates. In the no-till treatment at 75 t/ha, potato plants emerged 2 weeks after the potatoes planted using the till treatment. Shorter shoot heights and lower plant number in no-till potato may also be attributed to root growth behavior. Roots in no-till system were fluffy and concentrated on the top of the soil surface. Tap roots look-like fiber roots, taproot of potato plants is cut, forcing a fibrous growth pattern. While in till system, tap roots were obvious and clear and grown deeply beneath the soil. In her experiment, Mundy *et al.*, (1999) showed that in no-till system, the plant population and growth rate were lower than in till system early in the season. However, plant population and growth reached the same level as with plant in till system later in the season. In another study by Liu Mingchi (2001), he observed that decreasing the soil moisture negatively reduced the plant height, number of leaves, fruit weight, and number. Plant height increased with an increase in the amount of irrigation per treatments (Ehret *et al*. 2012; Yuan *et al*. 2003)

Table 11 shows that, with the exception of no-till potato at 75t/ha at 60% Eto, none of the treatments significantly reduced the potato shoot number 45 DAP compared to till (0t/ha). However, after 75 DAP the shoot number in till potato (0t/ha mulch) was significantly higher than the no-till potato at 75 t/ha at 120% and 60% Eto. Similarly, there were no significant differences in the shoot number among the different irrigation treatments after 35 or 75 DAP in no-till potatoes at all mulching rates. The above results are in agreement with (Norman *et al.* 2002; Moniruzzaman 2006), who showed that application of surface dry grass mulch to sweet corn (Norman *et al*.2002) and lettuce (Moniruzzaman 2006), increased leaf number compared to the no mulch treatments.

Regarding leaf number, results showed that the till potato (0t/ha mulch) significantly increased leaf number of potato shoots in comparison to all no-till potato and irrigation treatments at various rates, 45 DAP (Table 11). Leaf number in no-till potatoes at various rates and irrigation treatments increased with time. Most of the no-till potato treatments significantly increased leaf number in comparison to till potato at all irrigation treatments. Leaf number in all no-till potato treatments were similar under all irrigation treatments, 75 DAP. The same results were achieved by Liasu and Abdul (2007), who recorded that mulching with wild sunflower straw resulted with a higher leaf number per tomato plants compared to the no mulch treatments. In his thesis, Komla (2013), observed that the plant canopy of sweet pepper in the mulch treatments were bigger than that of no mulched treatments. The branch numbers of tomato plants was higher under straw mulch compared to the control without mulch (Gandhi and Bains 2006). Another study by Ojeniyi*et al*. (2007) found that the number of branches of chilli using *Gliricidia* mulch was significantly higher compared to the branches in no mulch treatments. Moreover, number of branches in okra was high in the dry grass mulch compared to the control (Norman *et al*. 2011). Meanwhile, in his research Yuan *et al.* (2003) observed that the branch number is affected by the amount of water applied; it was recorded that the highest branch number was observed in the treatments where amount of water applied was 1 and 1.25 times of water surface evaporation (Ep).

The root dry weight was significantly higher in till potato (0t/ha mulch) in comparison to all no-till treatments at various irrigation treatments, 45 DAP (Table 12). Root and shoot dry weight was not significantly different in no-till potato under different irrigation treatments after 45 DAP (Table 12 and Figure 21). However, the shoot and root dry weight for most no-till potato increased with time, but (after 117 DAP) with some variation among treatments. Root dry weight in no-till potato at 75t/ha at 120, 80 and 60% Eto was significantly lower than the till potato (0t/ha mulch) at 120 % Eto, 117 DAP. Interestingly, root dry weight in no-till potato at 25 t/ha was similar to till potato at different irrigation treatments at 117 DAP.

Table 11. Effect of different irrigation rates and mulch treatments on shoot and leaf number (Summer 2014)

Irrigation Treatments	Mulch rates (ton/ha)	Shoot number DAP				Leaf number DAP			
		45		75		45		75	
I1 (60 % Eto)	T (0)	5	a	5	a	12	ab	14	e
	NT1 (25)	3	ab	3	bc	9	cde	19	ab
	NT2 (50)	3	ab	3	abc	7	cdef	18	abc
	NT3 (75)	2	b	3	c	6	f	18	abcd
I2 (80% Eto)	T (0)	4	ab	4	abc	13	a	14	de
	NT1 (25)	4	ab	2	c	9	cde	19	a
	NT2 (50)	4	ab	3	c	10	bc	17	abcde
	NT3 (75)	3	ab	3	c	7	def	19	abc
I3 (100% Eto)	T (0)	4	ab	3	abc	13	a	15	cde
	NT1 (25)	3	ab	3	bc	9	cde	18	abc
	NT2 (50)	4	ab	3	bc	8	cdef	18	abc
	NT3 (75)	3	ab	3	c	8	cdef	17	abcde
I4 (120% Eto)	T (0)	4	ab	4	ab	13	a	15	bcde
	NT1 (25)	4	ab	3	bc	9	cde	19	a
	NT2 (50)	4	ab	3	bc	9	cd	18	abc
	NT3 (75)	3	ab	3	c	7	ef	20	a

T(till); NT (no-till); I (irrigation treatment)
Shoot and leaf number was taken by counting the number of shoots and leaves per six plants (n=6)
*Means followed by the same letter, within each column, do not significantly differ at the 5% level according to the LSD test.

Table 12 also shows that the shoot dry weight in no-till potato at 25t/ha at 80% Eto was significantly higher than the till potato at the same irrigation treatment, 117 DAP. In general most no-till treatments at various irrigation treatments produced lower shoot dry weight 45 DAP in comparison to the till potato (0t/ha mulch) . However, shoot dry weight increased with time (after 117 DAP)(Figure 22). The difference in root and shoot dry weight between no-till mulch and till treatments is an indication that potato plants in till systems are longer and bigger than the shallow roots in no-till system. It could be that roots penetrate deeply in the soil (up to 40 cm), or that they have a high density unlike non-mulched treatments. In the latter, roots dominated the upper top layers of the soil, yet they spread vigorously with high density of root hairs.

Table 12. Effect of different irrigation rates and mulch treatments on root and shoot dry weight (Summer 2014)

Irrigation treatments	**Mulch rates (ton/ ha)**	**Root dry weight (g) DAP**		**Shoot dry weight (g) DAP**	
		45	**117**	**45**	**117**
I1 (60 % Eto)	T (0)	13 a	9 abc	75 ab	61 abc
	NT1 (25)	5 c	5 bcd	26 e	44 bc
	NT2 (50)	3 c	3 d	22 e	57 bc
	NT3 (75)	2 c	4 cd	18 e	82 ab
I2 (80% Eto)	T (0)	12 ab	6 abcd	60 bcd	41 c
	NT1 (25)	5 c	9 ab	31 de	105 a
	NT2 (50)	5 c	5 bcd	45 bcde	46 bc
	NT3 (75)	2 c	4 d	20 e	54 bc
I3 (100% Eto)	T (0)	12 ab	6 abcd	67 abc	49 bc
	NT1 (25)	7 bc	5 abcd	43 cde	52 bc
	NT2 (50)	5 c	8 abc	36 cde	84 abc
	NT3 (75)	3 c	6 abcd	14 e	64 abc
I4 (120% Eto)	T (0)	15 a	9 ab	97 a	69 abc
	NT1 (25)	3 c	10 a	27 e	105 a
	NT2 (50)	5 c	7 abcd	33 de	58 bc
	NT3 (75)	3 c	4 cd	14 e	80 abc

T(till); NT (no-till); I (irrigation treatment)
Root and shoot dry weight was taken from two plants in the edge rows (n=2)
*Means followed by the same letter, within each column, do not significantly differ at the 5% level according to the LSD test.

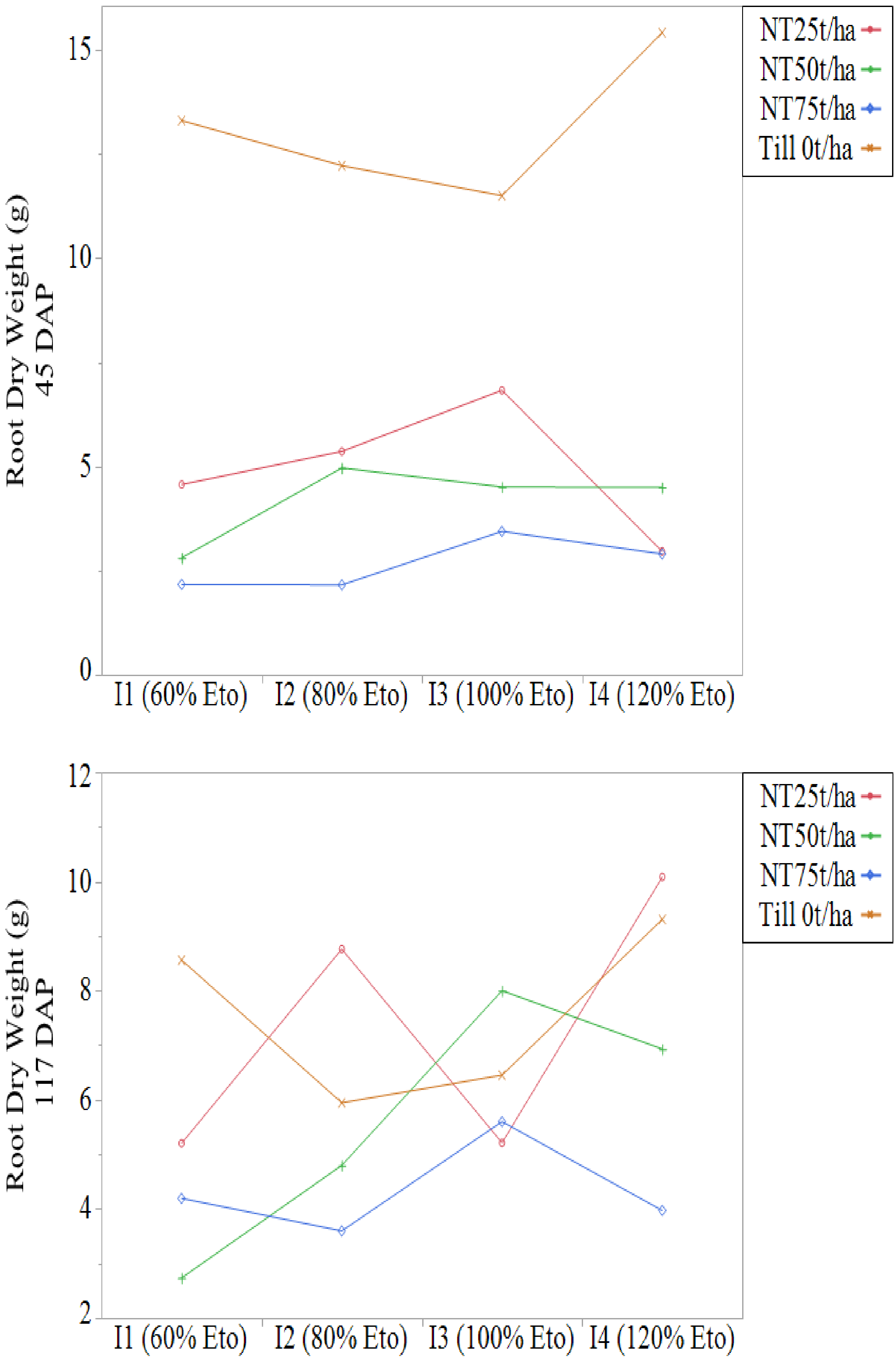

Fig. 21. Responses of root dry weight (g) at 45 and 117 days after planting (DAP) to different irrigation and mulching treatments

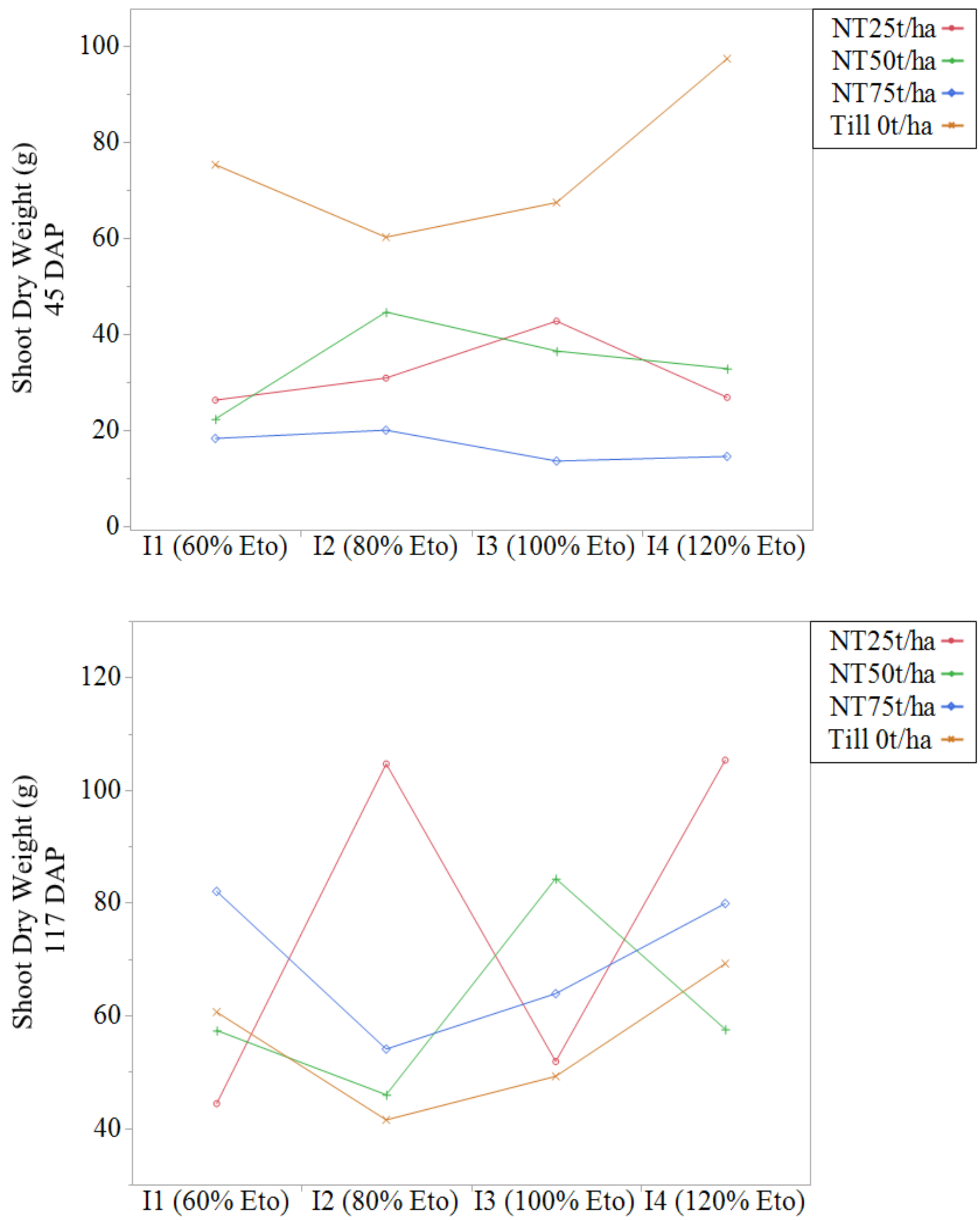

Fig. 22. Potato planted in boxes inside the greenhouse

3. Effect on Potato Yield

With the exception of the no-till potato at 75t/ha at 100% Eto, all treatments had no negative effect on the total number of tubers (Table 13). No-till potatoes at

25t/ha at 100% Eto gave the highest number of tubers. Interestingly, no-till potatoes at all tested mulches, produced significantly higher marketable tuber number than the till potato (0t/ha mulch) under all irrigation treatments (Figure 23). No-till potatoes at 50 and 75 t/ha at 120% Eto gave the highest marketable tubers in comparison to the rest of the treatments. Also, results show that the no-till potatoes at 75 t/ha at various irrigation rates gave the lowest nonmarketable tubers in contrast to the rest of treatments. This is may be due to the fact that potato tubers in no-till are produced on the soil surface, and they are surrounded by the mulch similar to a bird nest (Figure 24). Hence they won't be affected by soil aggregates.

Table 13. Effect of different irrigation and mulch treatments on marketable, non-marketable yield and total number of tubers (Summer 2014)

Irrigation treatments	**Mulch rates (ton/ ha)**	**Harvested tubers number (1000/ha)**				**Total number of harvested tubers (1000/ha)**	
		Marketable		Non-marketable			
I1 (60% Eto)	T (0)	12	f	429	abcd	441	abc
	NT1 (25)	49	de	464	abd	513	abc
	NT2 (50)	59	cde	362	abcd	421	abc
	NT3 (75)	79	bcd	281	c	361	abc
I2 (80% Eto)	T (0)	5	f	390	abcd	395	abc
	NT1 (25)	33	ef	485	abc	518	abc
	NT2 (50)	61	cde	366	abcd	427	abc
	NT3 (75)	85	bc	336	abcd	421	abc
I3 (100% Eto)	T (0)	18	f	374	abcd	392	bc
	NT1 (25)	60	cde	507	abc	566	a
	NT2 (50)	78	bcd	413	abc	491	ab
	NT3 (75)	57	cde	227	d	284	c
I4 (120% Eto)	T (0)	33	ef	466	acd	500	abc
	NT1 (25)	68	bcd	390	abcd	458	abc
	NT2 (50)	95	ab	391	abcd	486	abc
	NT3 (75)	123	a	290	b	412	abc

T(till); NT (no-till); I (irrigation treatment)
Yield quality was determined by separating harvested tubers into marketable (>6cm diameter) and non-marketable tubers (<6cm diameter);
*Means followed by the same letter, within each column, do not significantly differ at the 5% level according to the LSD test.

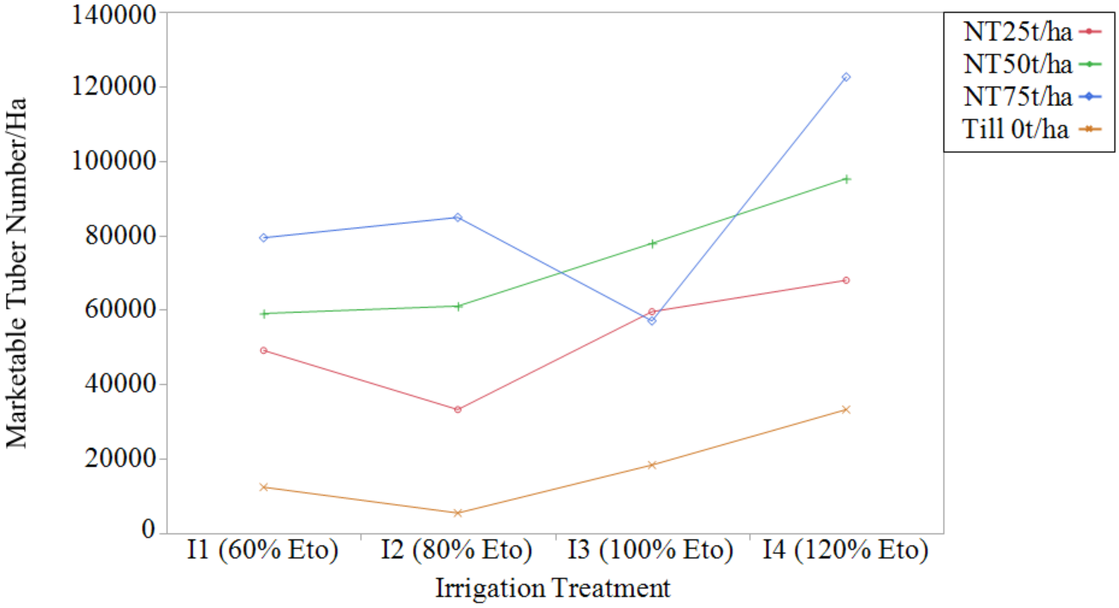

Fig. 23. Response of marketable tuber number (per ha) to different irrigation and mulching treatments

Fig. 24. Potato tuber under straw at harvesting time

Many researchers have reported the effect of mulch on the number of fruits such as bell peppers (Manuel *et al*. 2000), sweet corn (Norman *at al*. 2002), tomatoes (Awodoyin*et al.* 2007), chili plants (Venkanna 2008) and sweet pepper (Dauda 2011). In all the studies, a higher fruit number per plant was observed due to the application of mulch. Similar results were recorded where the fruit number in mulched tomato plants was high compared to the non-mulched treatments during the first week of production (Liasu and Abdul 2007).

Fakhari *et al*. (2013) observed that the yield and the numbers of tubers per potato plant were affected by the various irrigation regimes. The highest yield of potato was observed in the full irrigation regime. Many researchers speculated that there is a relationship between the total yield of crops and the amount of water (Cakir 2004; Payero *et al*. 2006). Yuan *et al.* (2003) used five different irrigation treatments and showed that the yield of the total yield and marketable tubers increased when irrigation was prolonged. Moreover, Fakhari *et al*. (2013) showed that highest yield was observed with 100 % and 80 % irrigation in comparison to 60%. They attributed the low yield in 60 % to the competition between tubers for resources.

Results show that all no-till potato treatments at various irrigation rates significantly increased marketable yield in comparison to the till potato (Table 14 and Figure 25). Marketable yield was significantly the lowest in the till potato (0 t/ha) at all irrigation treatments, but there were no significant differences among till potato treatments. High marketable yield was obtained with no-till potato at 75t/ha at 120%, 80% and 60% Eto. The marketable yield was the highest with the no-till potato at 75 t/ha at 120% Eto, in comparison to the rest of till and no-till potato. In addition, the marketable yield was similar in no-till potato at 25 t/ha under all irrigation treatments (Table 14 and Figure 25).

Regarding non marketable tuber weight, results showed that the non-marketable tuber weight varies among different treatments (Table 14). The no-till potato, at various mulching rates, produced more marketable yield than the till potato at various irrigation treatments. High non-marketable yield was produced in till potato at various irrigation treatments. As for the total tuber weight, Table 14 showed that all no-till potato treatments gave high yield in comparison to till potato (0t/ha mulch) at various irrigation treatments. The highest total yield observed was with 50 t/ha at 120% Eto and 75 t/ha 80% Eto.

Many researchers have reported the effect of mulch on the yield. Mundy (1999) evaluated the effects of various tillage treatments, conventional tillage, no-tillage, subsurface tillage, on crop yield, and soil physical. After comparing the yields of potato in different systems, Mundy (1999) reported that there were no significant difference in potato yields between no-tillage and subsurface tillage.

Table 14. Effect of different irrigation and mulch treatments on marketable, non-marketable and total weight of tubers (Summer 2014)

Irrigation treatments	**Mulch rates (ton/ ha)**	**Tuber weight (1000Kg/ha)**				**Total weight of tubers (1000Kg/ha)**	
		Marketable		**Non-marketable**			
I1 (60% Eto)	T (0)	4	g	28	abc	32	efg
	NT1 (25)	14	def	28	abc	43	abcdef
	NT2 (50)	14	def	25	abcde	39	bcdefg
	NT3 (75)	24	abcd	15	de	39	cdefg
I2 (80% Eto)	T (0)	1	g	23	abcde	24	g
	NT1 (25)	17	cdef	17	cde	34	defg
	NT2 (50)	14	ef	23	abcde	37	cdefg
	NT3 (75)	24	abc	30	ab	54	ab
I3 (100% Eto)	T (0)	5	g	31	ab	36	defg
	NT1 (25)	15	def	32	ab	47	abcde
	NT2 (50)	21	bcde	27	abc	48	abcd
	NT3 (75)	14	ef	15	e	29	fg
I4 (120% Eto)	T (0)	9	fg	34	a	42	abcdef
	NT1 (25)	20	bcde	27	abcd	46	abcde
	NT2 (50)	28	ab	28	abc	56	a
	NT3 (75)	31	a	21	bcde	52	abc

T(till); NT (no-till); I (irrigation treatment)
Yield quality was determined by separating harvested tubers into marketable (>6cm diameter) and non-marketable tubers (<6cm diameter);
*Means followed by the same letter, within each column, do not significantly differ at the 5% level according to the LSD test.

In their experiment, Kar and Kumar (2007), noted that air dry tuber yields in mulched plots were 14.9 t/ha compared to the non-mulched plot with 11.2 t/ha. They also reported that higher yields were observed in the straw mulch treatments than the till system. They concluded that this could be related to higher conservation of soil moisture, suitable temperature and high phosphorous and potassium under the straw mulch.

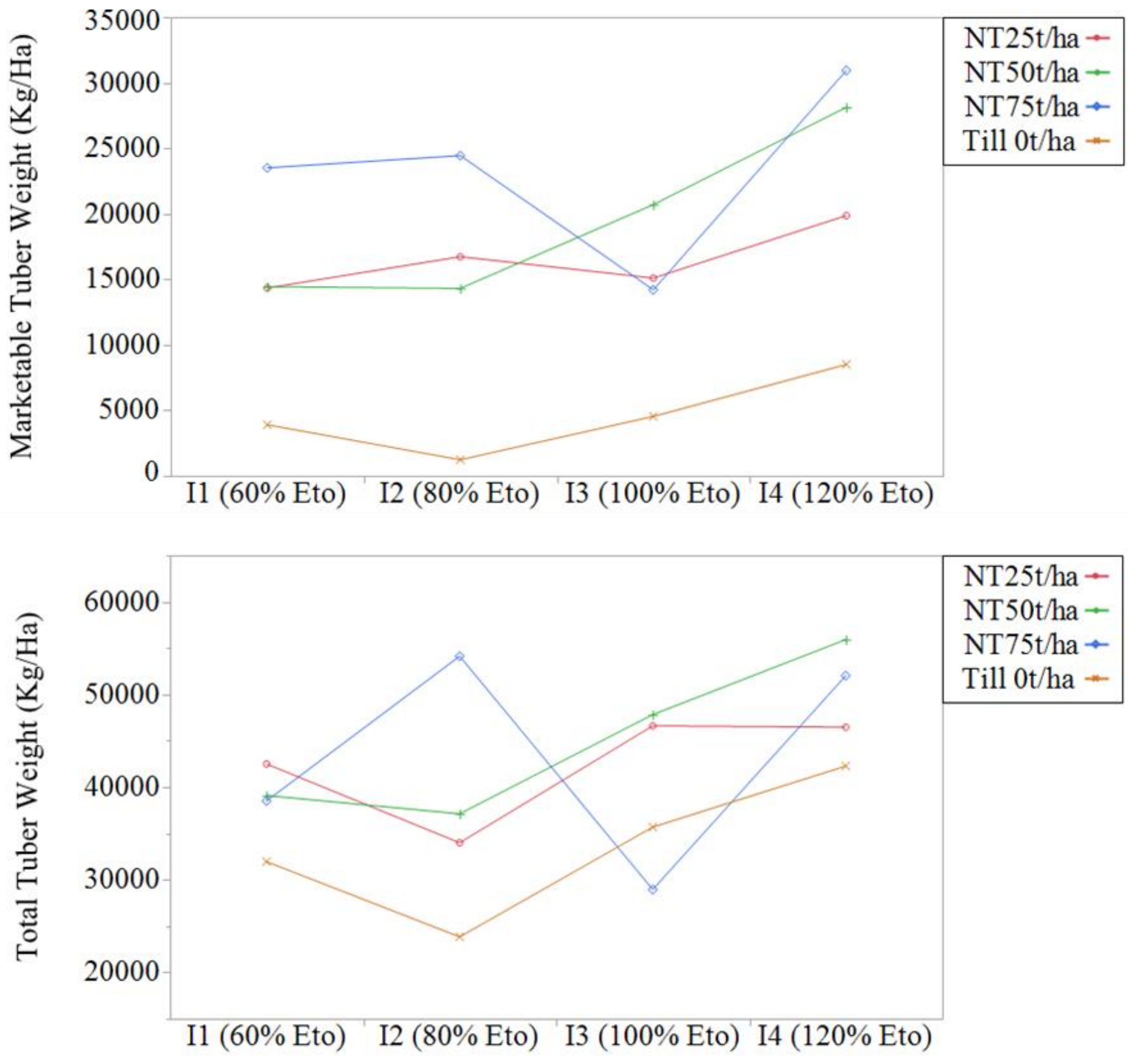

Fig. 25. Response of total tuber weight and marketable weight (kg/ha) to different irrigation and mulching treatments

Chili (Venkanna 2008), okra (Abd El-Kader *et al.* 2010), tomatoes (Gandhi and Bains 2006), and peppers (Norman *et al*. 2011) produced a higher yield in mulch compared to non-mulched treatments. Komla (2013) reported that no significant differences in marketable fruits were observed between different mulching treatments. He added that dry rice husks, empty palm bunches and cocoa pods increased marketable yield compared to the non-mulched control treatments.

Using different irrigation treatments in mulched and non-mulched plots, Kar and Kumar (2007) reported that water use efficiency and tuber production in mulched plots were not affected by the different irrigation treatments, but significant differences were observed in the non-mulched plot. In addition, straw mulch was found to increase the availability of phosphorous and potassium in the soil which positively affects the yield among different irrigation treatments.

Results also showed that the marketable yield (kg/ha) was significantly higher in straw mulch rates (25t/ha, 50 and 75 t/ha) compared to till (0t/ha) during the various irrigation treatments (Figure 22). Furthermore, the highest marketable yield was recorded in irrigation treatment 120% Eto at a 75t/ha straw mulch rate. The lowest marketable yield was recorded in irrigation treatment 80% Eto at the till treatment (0t/ha). The marketable yield of ofI3 at 75t/ha was low because two replicates were infested with some weeds which may have caused a lower yield than expected.

4. Effect on Soil Temperature

The maximum soil temperature observed was in 25 t/ha at % Eto with a value of 37°C (Figures 26 and 27). While the minimum soil temperature was observed in 50 t/ha at with a value of 16°C. As for the average temperature, the highest average was with 25t/ha mulch. Many researchers have stressed on the effect of mulching on the soil temperature. Agele *et al*. (2000) reported that mulching would reduce the soil temperature. In his research, Kar and Kumar (2007) found that the soil temperature is dependent on the availability of straw mulch. The average difference between mulch and non-mulch was 4-6 °C. This could be one of the reasons for high potato yield in the no-till mulched plots In addition; reduced soil temperature may increase the phosphorous, potassium and organic carbon availability which could lead to higher yield in the mulched systems (Kar and Kumar 2007). Hay and Allen (1978) recorded that the optimal soil temperature for potato production is between 15 and 18°C.

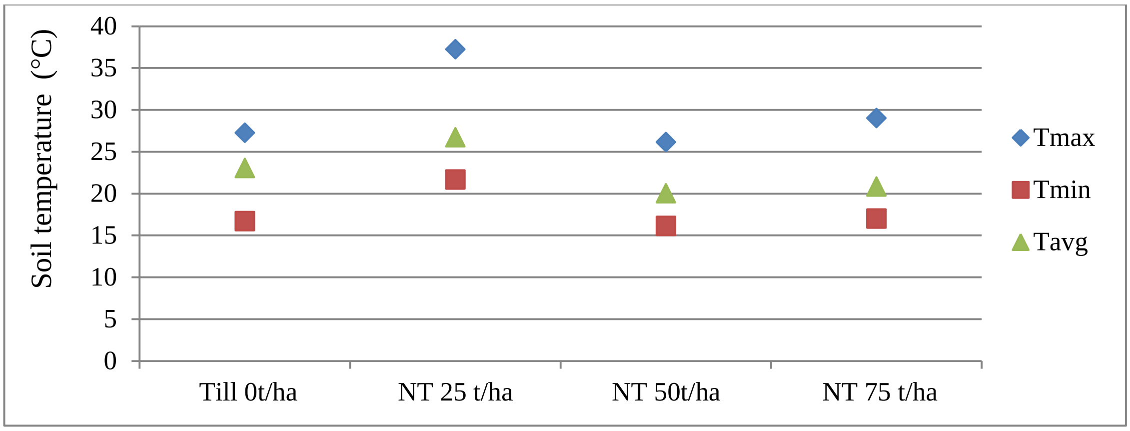

Fig. 26. Maximum, minimum and average temperatures under different mulching treatments

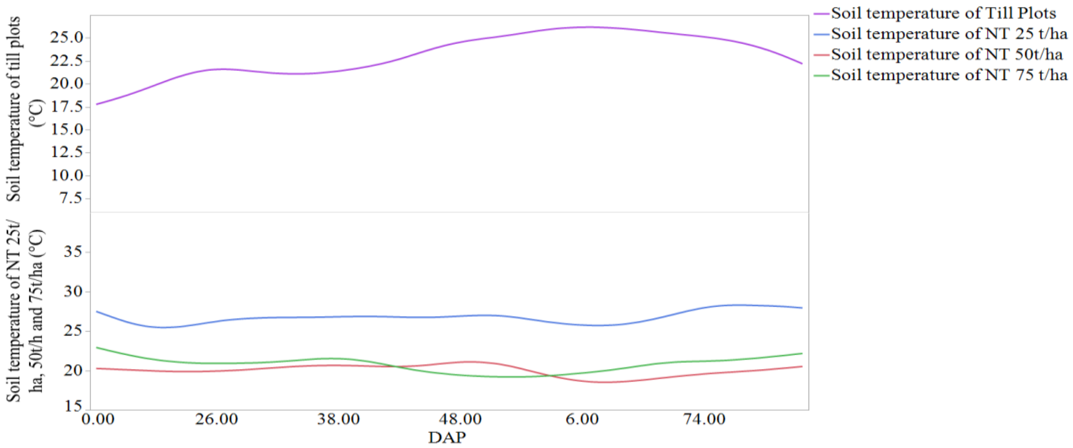

Fig. 27. Soil temperature of Till. NT 25t/ha, 50t/ha and 75 t/ha versus DAP

5. Effect on Water Productivity

The results in Table 15 show that the maximum water productivity was observed in no-till potato at 75t/ha with 80% Eto with a value of 8.3kg of potato tubers per m^3 of applied water (Kg/m^3). However, this water productivity was significantly higher than the water productivity of till (0t/ha mulch) at 80% Eto and no-till75t/ha at 100% Eto. Hence, the most appropriate system for having highest yield and lowest amount of water applied is irrigating potato at 80 % Eto with mulch at 75t/ha because it supplies the most profitable yield. Steduto (2012) reported that the range of the water productivity of potato is 4 to 11 kg/m^3. In their research, Rashidi *et al.* 2008 prevailed that the water productivity of potato in Iran ranged between potatoes, 1.92–5.25 kg/m^3. Also, Yaghmaei (1987) have recorded that the maximum water productivity value surpassed 5.43 kg/m^3. However, Akbari (1997) found that the minimum water productivity value was 4.31 Kg/m^3. Moreover, Rostami (1991) recorded that the minimum value for potato water productivity was 2.07 Kg/m^3. In his research, El Mokh*et al*., 2015 found that the maximum water productivity value for potato was 15.6 Kg/m^3 at 30 % evapotranspiration levels with 200 t/ha nitrogen.

6. Effect on Phelipanche aegyptiaca

Results showed that *Phelipanche* shoot number and dry weight varied among different treatments (Table 16). However, no-till potato at 50 and 75 t/ha at all irrigation rates were the most effective treatment in reducing shoot number, in comparison to till and other no-till treatments. No-till potato at 75t/ha at all irrigation rates significantly reduced shoot dry weight, in comparison to the till treatment. With the exception of no-till potatoes at 25 and 50 t/ha at 60%, all no-till potatoes under all irrigation regimes significantly reduced *Phelipanche* shoot dry weight, in comparison to the till potato treatment. In general we may conclude that no-till potato at all mulching and irrigation rates (Except 60%) reduced *Phelipanche* shoot number and dry weight, comparing to till potato at all irrigation treatments.

Table 15. Water productivity (Kg/m3) of potato at different irrigation and mulch treatments (Summer 2014)

Irrigation treatments	**Mulch rates (ton/ ha)**	**Water productivity (Kg/m3)**	
I1 (60% Eto)	T (0)	5.7	ab
	NT1 (25)	7.6	ab
	NT2 (50)	7.0	ab
	NT3 (75)	6.9	ab
I2 (80% Eto)	T (0)	3.7	b
	NT1 (25)	5.3	ab
	NT2 (50)	5.8	ab
	NT3 (75)	8.4	a
I3 (100% Eto)	T (0)	5.8	ab
	NT1 (25)	6.4	ab
	NT2 (50)	6.6	ab
	NT3 (75)	4.0	b
I4 (120% Eto)	T (0)	5.2	ab
	NT1 (25)	5.7	ab
	NT2 (50)	6.9	ab
	NT3 (75)	6.4	ab

T(till); NT (no-till); I (irrigation treatment)
*Means followed by the same letter, within each column, do not significantly differ at the 5% level according to the LSD test.

Kosterna (2014) reported that mulching caused a significant decrease in the weed population in vegetable crops. This is especially true during the beginning of the planting season. He added that at 20t/ha straw level was the most effective treatment in reducing weed pressure to the 10t/ha. Haidar and Sidahmed (2006) recorded that chicken manure alone at all tested rates was effective in reducing *Phelipanche* growth and infestation in eggplants early in the season in comparison with the control. Also, they reported that mixture of chicken manure and sulphur at 8 and 12 t/ha significantly reduced *Phelipanche* infestation 75 and 90 days after transplanting in eggplant.

Table 16. Effect of straw mulch and irrigation treatments on *Phelipanche aegyptiaca* shoot count (SC) and shoot dry weight (SDW) (Summer 2014)

Irrigation Treatments	**Mulch rates (ton/ ha)**	**SC in middle per 0.5 m^2**	**SDW(g)**
I1 (60% Eto)	T (0)	44.92 b	30.0 b
	NT1 (25)	34.25 bc	9.0 bc
	NT2 (50)	29.25 bc	7.0 bc
	NT3 (75)	0.00 c	0 c
I2 (80% Eto)	T (0)	42.50 b	18.0 b
	NT1 (25)	10.00 bc	2.16 c
	NT2 (50)	0.00 c	0 c
	NT3 (75)	0.00 c	0 c
I3 (100% Eto)	T (0)	122.50 a	36.0 a
	NT1 (25)	12.50 bc	6.0 bc
	NT2 (50)	12.50 bc	3.6 bc
	NT3 (75)	0.00 c	0 c
I4 (120% Eto)	T (0)	78.75 ab	17.0 ab
	NT1 (25)	27.34 bc	2.0 bc
	NT2 (50)	0.00 c	0 c
	NT3 (75)	0.00 c	0 c

T(till); NT (no-till); I (irrigation treatment)
*Means followed by the same letter, within each column, do not significantly differ at the 5% level according to the LSD test.

B. Greenhouse Experiment

1. Soil Analysis

Soil analysis showed the following results: Clay: 2.8 %, sand: 74.66 % and silt: 22.57 %. Hence, the soil is classified as Lomey sand, with a moisture content of 1.89 %, an organic matter content of 1.07 %. Also, the electrical conductivity was 0.00488dS/m, pH of 7.85, 17 ppm phosphorous (P), 80 ppm potassium (K) and 0 % calcium carbonate (CaCO3) (Bashour and Sayegh 2007).

2. Effect on Potato Growth

Results showed that shoot height varied among treatments 95 DAP (Table 17). However, all treatments at 120 Eto enhanced shoot height in comparison to all treatments and under various irrigation regimes. The highest shoot height was observed with till potatoes at 120% Eto. However, different mulching rates under each irrigation treatment were similar in their effect on shoot height. While, after 123 DAP shoot height and plant number were not significantly different among various irrigation and mulch treatments. Regarding plant number observed at 96 DAP, results showed that plant number with 75 t/ha at 120 % Eto was significantly high compared to 100 % Eto at the same irrigation treatment. In 80 % Eto at 75 t/ha, it was noticed that there was delayed emergence where the height at 96 DAP was zero because no shoots were grown above the straw mulch level.

Table 17. Effect of irrigation rates and mulch treatments on shoot height and plant number (Fall 2014)

Irrigation treatments	Mulch rates (ton/ ha)	Shoot height in cm DAP				Number of plants	
		96		123		96 DAP	
I1 (60% Eto)	T (0)	18	bcde	38	a	1	ab
	NT1 (25)	60	abcde	0	a	2	ab
	NT2 (50)	58	abcde	55	a	2	ab
	NT3 (75)	68	abcde	75	a	2	ab
I2 (80% Eto)	T (0)	29	bcde	40	a	2	a
	NT1 (25)	48	abcde	44	a	2	a
	NT2 (50)	42	abcde	41	a	1	ab
	NT3 (75)	74	abcd	70	a	2	ab
I3 (100% Eto)	T (0)	6	de	27	a	1	ab
	NT1 (25)	46	abcde	42	a	1	ab
	NT2 (50)	13	cde	25	a	1	ab
	NT3 (75)	0	e	35	a	0	b
I4 (120% Eto)	T (0)	11.1	a	110	a	2	a
	NT1 (25)	91	ab	89	a	2	a
	NT2 (50)	84	abc	88	a	2	a
	NT3 (75)	83	abc	88	a	2	a

T(till); NT (no-till); I (irrigation treatment)
Shoot height was taken by measuring the height of the plants in the boxes
Number of plants was measured by counting the total number of plants in the box
*Means followed by the same letter, within each column, do not significantly differ at the 5% level according to the LSD test.

Table 18 shows that none of the treatments had a significant effect on crop shoot number at 95DAP. However, the effect of leaf number varies among treatments 95DAP. The highest leaf number was observed in all treatments at 120% Eto. The leaf number at 96 DAP was significantly low at 75 t/ha at 100 % Eto compared to 120 %, 80 % and 60 % Eto. While after 123 DAP, neither the mulching rate nor the irrigation treatments, significantly affected the leaf number. Also, results showed that irrigation had no significant effect on crop shoot number at different mulching rates. Till and not-till treatments at 120% produced higher shoot and root dry weight, compared to all treatments. Shoot and root dry weight was significantly higher in till at 120% Eto and with no-till at 50 and 75 t/ha at 60% Eto. In 80 % Eto at 75 t/ha, due to the delayed emergence, the shoot and leaf number at 96 DAP was zero because no shoots were grown above the straw mulch level at this date.

Table 18. Effect of irrigation rates and mulch treatments on shoot number, leaf number and average shoot and root dry weight (Fall 2014)

Irrigation treatments	Mulch rates (ton/ha)	Shoot number DAP		Leaf number DAP				Average shoot and root dry weight (grams)	
		95		95		123		123 DAP	
I1 (60% Eto)	T (0)	1	ab	3	cde	9	a	26	bc
	NT1 (25)	1	ab	5	bcde	0	a	26	c
	NT2 (50)	2	a	7	abcde	8	a	30	abc
	NT3 (75)	1	ab	8	abcd	7	a	29	abc
I2 (80% Eto)	T (0)	1	a	6	abcde	10	a	28	bc
	NT1 (25)	1	ab	5	bcde	9	a	28	bc
	NT2 (50)	1	ab	3	cde	8	a	27	bc
	NT3 (75)	1	ab	8	abcd	11	a	28	bc
I3 (100% Eto)	T (0)	1	ab	2	de	7	a	28	bc
	NT1 (25)	1	ab	6	bcde	8	a	28	bc
	NT2 (50)	1	ab	3	de	7	a	27	bc
	NT3 (75)	0	ab	0	e	7	a	27	bc
I4 (120% Eto)	T (0)	2	a	14	a	14	a	34	a
	NT1 (25)	1	ab	12	ab	13	a	31	abc
	NT2 (50)	2	a	10	abc	11	a	31	abc
	NT3 (75)	1	ab	12	ab	14	a	31	ab

T(till); NT (no-till); I (irrigation treatment)
Shoot and leaf number was taken by counting the number of shoots and leaves in the box
Average shoot and root dry weight was taken for all the plants in the box
*Means followed by the same letter, within each column, do not significantly differ at the 5% level according to the LSD test.

3. Effect on Yield

Except for no-till at 25t/ha at 120% Eto, all tested mulching rates at various irrigation treatments were similar in their effect on the total number of tubers (Table 19). The highest tuber collected was observed with no-till potato at 25 t/ha at 120% Eto. But the tubers were small in size. Till and no-till potato at various rates at 120% Eto and no-till at 75t/ha at 60% produced the highest tuber weight. However, the tuber weight in till potato (0 t/ha) at 120% Eto gave the highest yield, in comparison to all various treatments.

Table 19. Effect of irrigation and mulch treatments total number and weight of tubers (Fall 2014)

Irrigation treatments	**Mulch rates (ton/ ha)**	**Total number of tubers (1000/ha)**		**Tuber weight (Kg/ha)**	
		123 DAP		**123 DAP**	
I1 (60% Eto)	T (0)	104	b	648	d
	NT1 (25)	104	b	1,871	bcd
	NT2 (50)	167	ab	3,675	bcd
	NT3 (75)	167	ab	4,533	abcd
I2 (80% Eto)	T (0)	167	ab	1,427	cd
	NT1 (25)	63	b	673	d
	NT2 (50)	250	ab	3,185	bcd
	NT3 (75)	208	ab	3,696	bcd
I3 (100% Eto)	T (0)	63	b	1,560	cd
	NT1 (25)	63	b	638	d
	NT2 (50)	63	b	585	d
	NT3 (75)	61	b	60	d
I4 (120% Eto)	T (0)	313	ab	10,667	a
	NT1 (25)	458	a	7,506	abc
	NT2 (50)	250	ab	8,283	ab
	NT3 (75)	250	ab	8,006	abc

T(till); NT (no-till); I (irrigation treatment)
*Means followed by the same letter, within each column, do not significantly differ at the 5% level according to the LSD test.

C. Feasibility Study of No-Till Potato

Figure 28 represents an economical study to investigate the feasibility of growing potatoes in no-till system. It is very obvious that growing potatoes using straw mulch technique on a short term (first season) is not economically feasible; however, on the long term (second season) and because mulch can be reused on the next season, the price of mulch on will be negligible . Hence keeping everything else constant the gross margin of mulch treatments will be more profitable than till treatments in the second season (Figure 29). This necessitates the significance of shifting from traditional methods in growing potato (till) to the no-till potato by using surface mulch (strawponic production of potato). The no-till system or what is referred to as conservation agriculture (CA) provides a way of combining profitable agriculture with environmentally friendly practices that ensure sustainability (FAO, 2014). This system is a more ecologically friendly farming system that conserves water and sustains higher levels of productivity. The no-till system for potato production could be feasible in the MENA region for various reasons. Among these reasons are: labor is cheap, drought and water scarcity prevail, lower costs of farm power, less soil compaction, high yield, high water retention and better biodiversity.

Potato economical study (first season straw mulch usage)			
Expenses ($)	Type	Till	Mulch
Quantity potato tubers needed (kg per hectare)	Spunta	$ 1,720	$ 1,720
Straw mulch (first season usage)	Mulch 25t/ha		$ 6,750
	Mulch 50t/ha		$ 13,500
	Mulch 75t/ha		$ 20,250
Fertilizers (Kg/ha)	NPK 15/15/15 - kg	$ 574	$ 574
	NPK 20/20/20 + T.E. kg	$ 302	$ 302
Pesticides		$ 2,000	$ 1,700
Irrigation system		$ 3,000	$ 3,000
Land rent (ha)		$ 1,500	$ 1,500
Tractor and machine expenses	Plowing	$ 200	$ -
	Disking	$ 60	$ -
	Leveling	$ 30	$ -
	Seed Drill	$ 70	$ -
	Harvesting	$ 60	$ -
Casual workers	Planting	$ -	$ 480
	Weeding	$ 480	$ 60
	Spraying pesticide	$ 216	$ 216
	Straw removal	$ -	$ 360
	Harvesting	$ 240	$ 240
Irrigation (fuel & electricity)		$ 400	$ 400
Total operating expenses			
Till 0t/ha		$ 10,852	
NT 25t/ha			$ 17,602
NT 50t/ha			$ 24,352
NT 75t/ha			$ 31,102
Total revenue (yield quantity (kg/ha) x selling price ($))			
Revenue (yield x price) Till		$ 14,716.87	
Revenue (yield x price) NT25t/ha			$ 18,656
Revenue (yield x price) NT50t/ha			$ 19,799
Revenue (yield x price) NT75t/ha			$ 19,102
Gross margin (total revenue - operating expenses)			
Till0t/ha		**$ 3,864.47**	
NT25t/ha			**$ 1,054**
NT50t/ha			**$ (4,253)**
NT75t/ha			**$ (11,700)**

Fig. 28. Economical study for growing potato in the first season of mulch usage

Potato economical study (second season mulch usage)			
Expenses ($)	**Type**	**Till**	**Mulch**
Quantity potato tubers needed (kg per hectare)	Spunta	$ 1,720.00	$ 1,720.00
Straw mulch (second and third season usage)	Mulch 25t/ha		$ -
	Mulch 50t/ha		$ -
	Mulch 75t/ha		$ -
Fertilizers (Kg/ha)	NPK 15/15/15 - kg	$ 574.00	$ 574.00
	NPK 20/20/20 + T.E. kg	$ 302.40	$ 302.40
Pesticides		$ 2,000.00	$ 1,700.00
Irrigation system		$ 3,000.00	$ 3,000.00
Land rent (ha)		$ 1,500.00	$ 1,500.00
Tractor and machine expenses	Plowing	$ 200.00	$ -
	Disking	$ 60.00	$ -
	leveling	$ 30.00	$ -
	Seed Drill	$ 70.00	$ -
	Harvesting	$ 60.00	$ -
Casual workers	Planting	$ -	$ 480.00
	Weeding	$ 480.00	$ 60.00
	Spraying pesticide	$ 216.00	$ 216.00
	Straw removal	$ -	$ 360.00
	Harvesting	$ 240.00	$ 240.00
Irrigation (fuel & electricity)		$ 400.00	$ 400.00
Total operating expenses			
Till 0t/ha		$ 10,852.40	
NT 25t/ha			$ 10,552.40
NT 50t/ha			$ 10,852.40
NT 75t/ha			$ 10,852.40
Total revenue (yield quantity (kg/ha) x selling price ($))			
Revenue (yield x price) Till		$ 14,716.87	
Revenue (yield x price) NT25t/ha			$ 18,656.24
Revenue (yield x price) NT50t/ha			$ 19,798.91
Revenue (yield x price) NT75t/ha			$ 19,102.13
Gross margin (total revenue - operating expenses)			
Till0t/ha		**$ 3,864.47**	
NT25t/ha			**$ 8,103.84**
NT50t/ha			**$ 9,246.51**
NT75t/ha			**$ 8,549.73**

Fig. 29. Economical study for growing potato in the second season of mulch usage

CHAPTER V

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

A. Summary

Potato crops responded well under the no-till system of different irrigation scheduling. By using surface barley straw mulch increased the potato production by a range 10-30 % of no till potatoes. Water productivity was different among different irrigation and mulch treatments in the till and no-till system. Results concerning potato production from both field and greenhouse experiments showed that the mulch treatment with 75 t/ha at 80 % Eto significantly increased the potato yield with the highest water productivity.

B. Conclusion

It can be concluded from this study that:

- The highest marketable yield was in no-till potato at 75t/ha at 120% Eto with a value of 31 t/ha in comparison to all till and no-till treatments.
- No-till potato treatments at various irrigation treatments significantly increased marketable yield in comparison to the till potato.
- The highest total yield for till (0t/ha) was at 120 %Eto with a value of 42 t/ha and in no-till at 50t/ha at 120%Etowith a value of 56t/ha

C. Recommendations

Based on these studies conducted for the effect of straw mulch and irrigation on potato growth and development it is recommended that:

- This study could be promising gate for production of potato in small areas where water is limited.
- This study could be very efficient for the organic growers who are planting on small scale level
- Further studies should be conducted to determine the effect of straw mulch on the potato tuber quality since the high percentage of marketable tubers was noticed in the no-till is an advantage.
- More future studies on integrated straw mulch and irrigation rates and their effect on increasing the yield of potato are needed.
- Further studies should be done to investigate the effect of soil temperature on enhancing the growth and development of potato.
- Further studies should be done to investigate the benefit of other crop residues on potato growth and yield
- Further studies should be done to know the effect of straw on water retention and biodiversity.
- Straw mulch technique serves a very important role especially in areas where water is limited through preserving soil moisture under the soil and hence decreasing the amount of water applied.

BIBLIOGRAPHY

Abd El-Kader, A.A., Shaaban, S.M. and Abd El-Fattah, M. S. (2010). "Effect of irrigation level and organic compost on okra (Abelmoschusesculentus l.) grown in sandy calcareous soil". Agriculture and Biology Journal of North America 1(3): 225 – 231.

Abou-Jawdah, Y., Sobh, H., and Saad, A.T. (2001). "Incidence of potato virus diseases and their significance for a seed certification program in Lebanon". *PhytopathologiaMediterranea*, 40: 113–118.

Agele, S.O., Iremiren, G.K. and Ojeniyi, S.O. (2000). "Effect of tillage and mulching on the growth, development and yield of late season tomato (Lycopersiconesculentum) in the humid South of Nigeria". *Journal of Agricultural Science* 134: 55-59.

Ahmad, M.U.D., Masih, I. and Turral, H. (2004). "Diagnostic analysis of spatial and temporal variations in crop water productivity: A field scale analysis of the rice-wheat cropping system of Punjab, Pakistan". *Journal of Applied Irrigation Science* 39(1): 43-63.

Akbari, M. (1997)."Effects of Sprinkler and Furrow Irrigation on Quantitative and Qualitative Components of Potato". Research note: Iranian Ministry of Agricultural Research and Education Organization, Esfahan Agricultural Research Center, No: 79.101.

Alva, A.K., Hodges, T., Boydston, R.A. and Collins, H.P. (2002)."Effects of irrigation and tillage practices on yield of potato under high production conditions in the Pacific Northwest". *Communications in Soil Science and Plant Analysis* 33(9-10): 1451-1460.

Aulakh, P.S. and Sur, H.S. (1999). "Effect of mulching on soil temperature, soil moisture, weed population, growth and yield in pomegranate". *Progressive Horticulture* 31(3/4): 131-133.

Awodoyin, R.O., Ogbeide, F.I. and Oluwole, O. (2007)."Effects of three mulch types on the growth and yield of tomato (Lycopersiconesculentum Mill.)and weed suppression in Ibadan, Rainforest-savanna Transition Zone of Nigeria". *Tropical Agricultural Research and Extension*.

Ayanlaja, S.A. and Sanwo, J.O. (1991). "Management of soil organic matter in the farming systems of the low land humid tropics of West Africa: a review". *Soil Technology* 4(3): 265-279.

Bashour, I.I. and Sayegh, A.H. (2007). *Methods of analysis for soils of arid and semi-arid regions*. Rome: Food and Agriculture Organization of the United Nations.

Bescansa, P. (2006). “Particulate Organic Matter as a soil quality indicator in semiarid agricultural soils”. In: Geophysical Research Abstracts, 8, 06328.

Bescansa, P., Imaz, M.J., Virto, I., Enrique, A. and Hoogmoed, W.B. (2006). “Soil water retention as affected by tillage and residue management in semiarid Spain”. *Soil and Tillage Research* 87(1): 19-27.

Boomsma, C.R. and Vyn, T.J. (2007). “Plant-to-plant uniformity is essential for optimum yield in no-till continuous corn”. Purdue Extension AY.

Bowen, W.T. (2003). “14 Water Productivity and Potato Cultivation”. *Water Productivity in Agriculture: Limits and Opportunities for Improvement* 1, 229.

Budnik, K., Laing, M.D. and Da Graca, J.V. (1996). “Reduction of yield losses in pepper crops caused by Potato Virus Y in KwaZulu-Natal, South Africa, using plastic mulch and yellow sticky traps”. *Phytoparasitica* 24(2): 119-124.

Bushnell, J. and Welton, F.A. (1931). “Some effects of straw mulch on yield of potatoes”. *J. Agric. Res* 43: 837-845.

Cakir R. (2004). “Effect of water stress at different development stages on vegetative and reproductive growth of corn”. *Field Crops Res.* 89: 1-16.

Campanhola, C. (2013). “Policy Support Guidelines for the Promotion of Sustainable Production Intensication and Ecosystem Services (Vol. 19-2013)”. Rome: Wolfgang Prante.

Cannon, M. (2003). *Grow Irish Potatoes in the home garden*. Louisiana State University Agricultural Center Cooperative Extension Vegetable Garden Hints Pub. # 1903.

Chalak L. and Sabra N. (2007). “Country Report on the State of Plant Genetic Resources for Food and Agriculture”. Second Report, FAO.

Cheshire, M.V., Bedrock, C.N., Williams, B.L., Chapman, S.J., Solntseva, I. and Thomsen, I. (1999). “The immobilization of nitrogen by straw decomposing in soil”. *European Journal of Soil Science* 50(2): 329-341.

Curwen, D. and Massie, L.R. (1984). “Potato irrigation scheduling in Wisconsin”. *American Journal of Potato Research* 61(4): 235-241.

Darwish, T., Atallah, T., Hajhassan, S. and Chranek, A. (2003). “Management of Nitrogen by Fertigation of potato in Lebanon.” *Nutrient cycling in Agroecosystems* 67(1): 1-11.

Daudabelel, M. (2012). “Effects of grassed and synthetic mulching materials on growth and yield of sweet pepper (Capsicum annum) in Mubi”. *Nigeria Journal of Agriculture and Social Sciences* 8: 97-99.

Dawes, D.S., Dwelle, R.B., Kleinkopf, G.E. and Steinhorst, R.K. (1983). “Comparative growth analysis of Russet Burbank potatoes at two Idaho locations”. *American Potato Journal* 60(10): 717-733.

Dean, B.B. (1994). *Managing the potato production system*. Food Products Press.

Derpsch, R., Friedrich, T., Kassam, A. and Li, H. (2010). “Current status of adoption of no-till farming in the world and some of its main benefits”. *International Journal of Agricultural and Biological Engineering* 3(1): 1-25.

Dilipkumar, G., Sachin, S.S. and Rajesh, K. (1990). “Importance of mulch in crop production”. *Indian Journal of Soil Conservation* 18: 20-26.

Döring, T.F., Brandt, M., Heß, J., Finckh, M.R. and Saucke, H. (2005). “Effects of straw mulch on soil nitrate dynamics, weeds, yield and soil erosion in organically grown potatoes”. *Field Crops Research* 94(2): 238-249.

Duiker, S.W. and Lal, R. (1999). “Crop residue and tillage effects on carbon sequestration in a Luvisol in central Ohio”. *Soil and Tillage Research* 52(1):73-81.

Dvořák, P., Tomášek, J., Kuchtová, P., Hamouz, K., Hajšlová, J. and Schulzová, V. (2012). “Effect of mulching materials on potato production in different soil-climatic conditions”. *Roman. Agric. Res* 29: 201-209.

Dvorak, P., Tomasek, K.H. and Hamouz, K. (2010). “Cultivation of organic potatoes with the use of mulching materials”. *ZeszytyProblemowePostępówNauk Rolniczych*, 557.

Edwards, L. M., Volk, A., & Burney, J. R. (2000). “Mulching potatoes: Aspects of mulch management systems and soil erosion”. *American Journal of Potato Research,* 77(4), 225-232.

Ehret, D.L., Frey, B., Forge, T., Helmer, T. and Bryla, D.R. (2012). “Effects of drip irrigation configuration and rate on yield and fruit quality of young highbush blueberry plants”. *HortScience* 47(3): 414-421.

Ekelöf, J., Guamán, V., Jensen, E.S. and Persson, P. (2015). “Inter-Row Subsoiling and Irrigation Increase Starch Potato Yield, Phosphorus Use Efficiency and Quality Parameters”. *Potato Research* 58(1), 15-27.

El Mokh, F., Nagaz, K., Masmoudi, M.M. and Mechlia, N.B. (2015). “Yield and Water Productivity of Drip-Irrigated Potato under Different Nitrogen Levels and Irrigation Regime with Saline Water in Arid Tunisia”. *American Journal of Plant Sciences* 6(04): 501.

Eshel, G., Egozi, R., Goldwasser, Y., Kashti, Y., Fine, P., Hayut, E., ...and DiSegni, D. M. (2015). “Benefits of growing potatoes under cover crops in a Mediterranean climate”. *Agriculture, Ecosystems & Environment*, 211, 1-9.

Extensive agriculture (Encyclopedia Britannica Online); available from http://www.britannica.com/topic/extensive-agriculture; Internet; access 11 June 2015.

Fakhari, R., Tobeh, A., Hasanzadeh, N., Barghi, A. and Shiri, M. (2013). "Studying effects of different irrigation levels and planting patterns on yield and water use efficiency in potato (*Solanumtuberosum*L.)".

FAO. (2008). "The potato - International Year of the Potato 2008"; available from http://www.fao.org/potato-2008/en/potato/index.html; Internet; access July 19, 2015.

FAO. (2013a). "Crop Water Information: Potato"; available from http://www.fao.org/ nr/water/cropinfo_potato.html; Internet; access July 19, 2015.

FAO. (2013b). "FAO - Water Development and Management Unit - Crop Water Information: Potato"; available from http://www.fao.org/nr/water/ cropinfo_potato.html; Internet; access July 19, 2015.

FAO.(2015a). "Conservation Agriculture". Retrieved July 19, 2015, from http://www.fao.org/docrep/006/y4690e/y4690e0a.htm

FAO. (2015b). "FAO:AG: Conservation Agriculture"; available from http://www.fao. org/ ag/ca/; Internet; access July 19, 2015.

FAO. (2007). "Country Report on the State of Plant Genetic Resources for Food and Agriculture"; available from http://www.fao.org/docrep/013/i1500e/ lebanon.pdf; Internet; access July 19, 2015.

Ferreira, T.C. and Carr, M.K.V. (2002)."Responses of potatoes (*Solanumtuberosum* L.)to irrigation and nitrogen in a hot, dry climate: I. Water use. *Field Crops Research* 78(1): 51-64.

Gandhi, N. and Bains, G.S. (2006)."Effect of mulching and date of transplanting on yield contributing characters of tomato". *Journal of Research. Punjab Agriculture*. University of India 43(1): 6-9.

Geerts, S., Raes, D., Garcia, M., Miranda, R., Cusicanqui, J. A., Taboada, C., ...and Mhizha, T. (2007). "Calibration of the FAO-AquaCrop Model for the Under-Utilized Crop Quinoa (Chenopodium quinoa Willd.)".

Geerts, S., Raes, D., Garcia, M., Miranda, R., Cusicanqui, J., Taboada, C., ...and Mhizha, T. (2007). "Calibration and validation of the FAO-AquaCrop model for the under-utilized crop quinoa (Chenopodium quinoa Willd.) in the Bolivian Altiplano". In: Proceedings of the ASA-CSSA-SSSA 2007 International Annual Meeting: "A century of integrating crop, soil and environment".

Geerts, S., Raes, D., Garcia, M., Miranda, R., Cusicanqui, J., Taboada, C., ...and Mendoza, J. (2007). “Modeling the crop water productivity of quinoa (Chenopodium quinoa Willd) under field conditions with the FAO-AquaCrop model”. In: Proceedings del Congreso Internacional de la Quinua (Vol. 1, pp. 32-33).

Griffin, T.S. and Honeycutt, C.W. (2009). “Effectiveness and efficacy of conservation options after potato harvest”. *Journal of Environmental Quality* 38(4): 1627-1635.

Haidar, M.A., Sidahmed, M.M., Darwish, R. and Lafta, A. (2005). “Selective control of Orobancheramosa in potato with rimsulfuron and sub-lethal doses of glyphosate”. *Crop Protection* 24: 743-747.

Haidar, M.A., Iskandarani N., Sidahmed M and Darwish R. (2005). “Susceptibility of Orobancheramosa and potato tolerance to rimsulfuron”. *Crop Protection* 24: 7-13.

Haidar, M.A., Farah Abi Mosleh, Ninette Karam and Anthony Ghandour. (2014). “Phelipancheramosa control in potato with fluridone”. *Journal of Agricultural Science and Technology* B.4(10): 771-778.

Harris, P.M. (Ed.). (2012). *The potato crop: the scientific basis for improvement*. Springer Science & Business Media.

Haverkort, A.J. and Harris, P.M. (1987). “A model for potato growth and yield under tropical highland conditions”. *Agricultural and Forest Meteorology* 39(4): 271-282.

Havlin, J.L. and Schlegel, A.J. (1990). “Increasing soil organic matter with soil/crop management”. *Better Crops with Plant Food* 74: 7-9.

Havlin, J.L., Schlegel, A.J. and Tribune, K.S. (1990). “Crop Rotation and Tillage Effects on Soil Organic Matter”. In: Conservation tillage: proceedings, Great Plains Conservation Tillage Symposium, August 21-23, 1990, Bismarck, North Dakota (No. 131, p. 225). Great Plains Agricultural Council.

Hay, R.K.M. and Allen, E.J., 1978. “Tuber initiation and bulking in the potato (Solanumtuberosum) under tropical conditions: The importance of soil and air temperature”. *Trop. Agric. Trinidad* 55: 289–295.

Hester, J.B. (1937). “The value of cover crops in potato production in Eastern Virginia”. *American Journal of Potato Research* 14(1): 9-18.

Hou, X.Y., Wang, F.X., Han, J.J., Kang, S.Z. and Feng, S.Y. (2010).“Duration of plastic mulch for potato growth under drip irrigation in an arid region of Northwest China”. *Agricultural and Forest Meteorology* 150(1): 115-121.

Ismail, S.M., Ozawa, K. and Khondaker, N.A. (2007). “Effect of irrigation frequency and timing on tomato yield, soil water dynamics and water use efficiency under drip irrigation”. In: Proceedings of the Eleventh International Water Technology Conference (Vol. 1, pp. 15-18).

Jaafar, H., Khraizat, Z., Bashour, I., and Haidar, M. (2015). “Water Productivity of Origanumsyriacum under different irrigation and nitrogen treatments using an automated irrigation system”. *WIT Transactions on Ecology and the Environment* 196: 211-219.

Jacks, G.V., Brind, W.D. and Smith, R. (1955). “Mulching”. *Commonwealth Bur. Soil Sci. Tech. Comm,* 49.

Jalil, A.M., M.A. Azad and A.M. Faroque (2007). “Effect of different mulches on the growth and yield of two potato varieties”. *J. biological Sci*. 4(3): 331-333.

Ji, S. and Unger, P.W. (2001).“Soil water accumulation under different precipitation, potential evaporation, and straw mulch conditions”. *Soil Science Society of America Journal* 65(2): 442-448.

Jones, O.R., Hauser, V.L. and Popham, T.W. (1994). “No-tillage effects on infiltration, runoff, and water conservation on dryland”. *Transactions of the ASAE* 37(2): 473-479.

Jordán, A., Zavala, L.M. and Gil, J. (2010). “Effects of mulching on soil physical properties and runoff under semi-arid conditions in southern Spain”. *Catena* 81(1), 77-85.

Kar, G. and Kumar, A. (2007). “Effects of irrigation and straw mulch on water use and tuber yield of potato in eastern India”. *Agricultural Water Management* 94 (1): 109-116.

Karam, F., Amacha, N., Fahed, S., Asmar, T.E. and Domínguez, A. (2014). “Response of potato to full and deficit irrigation under semiarid climate: Agronomic and economic implications”. *Agricultural Water Management* 142: 144-151.

Kashyap, P.S. and Panda, R.K. (2001). “Evaluation of evapotranspiration estimation methods and development of crop-coefficients for potato crop in a sub-humid region”. *Agricultural Water Management* 50(1): 9-25.

Kashyap, P.S. and Panda, R.K. (2003). “Effect of irrigation scheduling on potato crop parameters under water stressed conditions”. *Agricultural Water Management* 59(1): 49-66.

Khalak, A. and Kumaraswamy, A.S. (1993).“Weed bio-mass in relation to irrigation and mulching, and economics of mulching potato crop under conditions of acute water scarcity”. *Journal of the Indian Potato Association* 20(3-4): 185-189.

Kleinkopf, G.E. (1983). "Potato". *Crop Water Relations*. Teare, J.D. and Peet, M.M. (ed.).

Kleinkopf, G.E., Brandt, T.L. and Olsen, N. (2003)."Physiology of Tuber Bulking". Idaho Potato Conference.

Kolbe, H. (2003). "Einfluss des Klimas". In: Moller, K., Kolbe, H., Bohm, H. (Eds.), *HandbuchOkologischerKartoffelbau*. Leopoldsdorf, Austria, pp. 14-19.

Komla, A.N. (2013). "Effect of Organic Mulch on Growth and Yield of Sweet Pepper (*Capsicum annuum* L.)" Doctoral Dissertation, University of Ghana.

Lal, R. (1987). "Managing the soils of sub-Saharan Africa". *Science* 236(4805): 1069-1076.

Lal, R. and Moldenhauer, W. C. (1987)."Effects of soil erosion on crop productivity". *Critical Reviews in Plant Sciences* 5(4): 303-367.

Li, S.Q. and Li, S.X. (2000). "Evaluation of the summer fallow efficiency in Guanzhong Area, Shaaxi Province". *Ecol-Agricultural Research* 8(2): 54–57.

Li, S.X., Wang, Z.H., Li, S.Q., Gao, Y.J. and Tian, X.H. (2013). "Effect of plastic sheet mulch, wheat straw mulch, and maize growth on water loss by evaporation in dryland areas of China". *Agricultural Water Management* 116: 39-49.

Li, S.X. and Xiao, L., (1992). "Distribution and management of dry lands in the People's Republic of China". *Advances in Soil Sciences* 18: 147–302.

Li, Y.S. (1982). "The relationship between soil water dynamics and wheat production". *Shaanxi Agricultural Sciences* 2: 5–8.

Liasu, M.O. and Abdul, K.K.A. (2007). "Influence of *Tithoniadiversifolia* Leaf Mulch and Fertilizer Application on the Growth and Yield of Potted Tomato Plants". *American Eurasian Journal of Agriculture and Environmental Science* 2(4): 335-340.

Lynch, D.R. and Tai, G.C.C. (1989). "Yield and yield component response of eight potato genotypes to water stress". *Crop Science* 29(5): 1207-1211.

Mahmood, M., Farroq, K., Hussain, A. and Sher, R. (2002). "Effect of mulching on growth and yield of potato crop". *Asian J. Plant Sci* 2: 132-133.

Manuel, C.P., Allison, M.D. and Stafford, M.A.C. (2000). "Comparison of organic and synthetic mulch for bell pepper production at three levels of drip irrigation". *Proc. Fla. State Horticulture Society* 113: 234-236.

Marutani, M. and Cruz, F. (1989). "Influence of supplemental irrigation on development of potatoes in the tropics". *HortScience* 24(6): 920-923.

McKee, R.K. (1978). "*The Potato Crop, the scientific basis for improvement: Editor: PM Harris. Pp. xv+ 730"*. Chapman and Hall, Andover.

Mingchi, L., Takayuki, K., Munehiro, T. and Hang, C. (2001)."Effect of soil moisture on plant growth and fruit properties of strawberry". *ActaHorticulturaeSinica* 28(4): 307-311.

Molden, D. (1997). "Accounting for water use and productivity". (Vol. 1). Iwmi.

Molden, D., Murray-Rust, H., Sakthivadivel, R. and Makin, I. (2003). "A water-productivity framework for understanding and action". Water productivity in agriculture: Limits and opportunities for improvement, 1-18.

Molden, D., Oweis, T., Steduto, P., Bindraban, P., Hanjra, M.A. and Kijne, J. (2010). "Improving agricultural water productivity: between optimism and caution". *Agricultural Water Management* 97(4): 528-535.

Moniruzzaman, M. (2006). "Effects of Plant Spacing and Mulching on Yield and Profitability of mulch in arid region of India". *Agrochemica* 31: 183-202.

Mundy, C., Creamer, N.G., Wilson, L.G., Crozier, C.R. and Morse, R.D. (1999). "Soil physical properties and potato yield in no-till, subsurface-till, and conventional-till systems". *Horttechnology* 9(2): 240--247.

Norman, J.C., Asante, I. and Nartey, I.T. (2002). "Mulching effects on growth, partitioning and yield of sweet corn". *Ghana Journal of Horticulture* 1: 16 - 20.

Norman, J.C., Opata, J. and Ofori, E. (2011). "Growth and yield of okra and hot pepper as affected by mulching". *Ghana Journal of Horticulture* 9: 35-42.

Ojeniyi, S.O., Awodun, M.A. and Odedina, S.A. (2007). "Effect of Animal Manure, Amended Spent Grain and Cocoa Husk on Nutrient Status, Growth and Yield of Tomato". *Middle –East Journal of Scientific Research* 2 (1):33-36

Pabin, J., Lipiec, J., Wlodek, S. and Biskupski, A. (2003). "Effect of different tillage systems and straw management on some physical properties of soil and on the yield of winter rye in monoculture". *International Agrophysics* 17(4): 175-182.

Pavlista, A.D. (2001). "G1437 Green Potatoes: The Problems and the Solution".

Payero, J.O., Melvin, S.R., Irmak, I. and Tarkalson, D. (2006). "Yield response of corn to deficit irrigation in a semiarid climate." *Agric. Water Manage* 84(1-2): 101-112.

Peet, M. (2001). "Sustainable practices for vegetable production in the south". North Carolina State University.

Potato Growth and Irrigation Scheduling (irrigation management); available from https://cropwatch.unl.edu/potato/plant_growth; Internet; accessed 11 February, 2015.

Potato: Planting, Growing and Harvesting Potato Plants; available from http://www.almanac.com/plant/potatoes; Internet; accessed 11 February, 2015.

Rashidi, Majid and Gholami, Mohammad. (2008). "Review of crop water productivity values for tomato, potato, melon, watermelon and cantaloupe in Iran". *Int. J. Agric. Biol.* 10: 432-436.

Rathore, A.L., Pal, A.R. and Sahu, K.K. (1998)."Tillage and mulching effects on water use, root growth and yield of rainfed mustard and chickpea grown after lowland rice". *Journal of the Science of Food and Agriculture* 78(2): 149-161.

Rostami, R. 1991. "Effect of polyethylene mulches and Irrigation method on soil temperature and yield of melon". M.S. Thesis, Ahvaz University.

Russel, J.C. 1940. "The effect of surface cover on soil moisture losses by evaporation". *Soil Sci. Soc. Am. Proc.* 4, 65–70

Sabra A. and Haidar M.A (Corr).(2012). "Invasive Weed Mapping of Lebanon". *Journal of Agricultural Science and Technology* B2: 1010-1015.

Sammis, T.W. (1980). "Comparison of sprinkler, trickle, subsurface, and furrow irrigation methods for row crops". *Agronomy Journal* 72(5): 701-704.

Sammis, T.W. and Hanson, E.G. (1980)."Potato and lettuce response to irrigation methods and practices". A Compilation of trickle irrigation papers (USA). No. 78-2020.

Schachtschabel, P. (1957). "Rowe-Dutton, P.: The mulching of vegetables". (Techn. Comm. No. 24.) Commonwealth Agricultural Bureaux, Farnham Royal, Bucks. 1957. 169 S., 9 Abb. DM. 11, 80. *ZeitschriftfürPflanzenernährung, Düngung, Bodenkunde* 78(2-3): 237-237.

Scott, H. (1921). American Society of Agronomy.

Seckler, D.W. (1996). "The new era of water resources management: from" dry" to" wet" water savings" (Vol. 1).IWMI.

Sharma, P.K., Kharwara, P.C. and Tewatia, R.K. (1990). "Residual soil moisture and wheat yield in relation to mulching and tillage during preceding rainfed crop". *Soil and Tillage Research* 15(3): 279-284.

Shen, J.Y., Zhao, D.D., Han, H.F., Zhou, X.B. and Li, Q.Q. (2012). "Effects of straw mulching on water consumption characteristics and yield of different types of summer maize plants". *Plant Soil Environ* 58(4): 161-166.

Shengxiu, L. and Ling, X. (1992). “Distribution and management of dry lands in the People’s Republic of China”. In: *Advances in soil science* 147-302. New York: Springer.

Shock, C.C., Feibert, E.B.G. and Saunders, L.D. (1998).“Potato yield and quality response to deficit irrigation”. *HortScience* 33(4): 655-659.

Shu-xuan, C.X.Z.L. and Youg-zhong, T. (1982). “The Properties of Coloured Polyethylene Films and Their Application as Plastic Mulches in Vegetable Production”. *Journal of Zhejiang Agricultural University,* 1, 016.

Simonne, E., Ouakrim, N. and Caylor, A. (2002). “Evaluation of an irrigation scheduling model for drip-irrigated potato in southeastern United States”. *HortScience* 37(1): 104-107.

Simonne, E.H., Dukes, M.D. and Haman, D.Z. (2004).“Principles and practices of irrigation management for vegetables”. *Vegetable Production Guide for Florida.* University of Florida, Gainesville, FL, 33-39.

Simonne, E.H., Dukes, M.D., Hochmuth, R.C., Studstill, D.W., Avezou, G. and Jarry, D. (2006). “Scheduling drip irrigation for bell pepper grown with plasticulture”. *Journal of Plant Nutrition* 29(10): 1729-1739.

Singh, N. and Ahmed, Z. (2008).“Effect of mulching on potato production in high altitude cold arid zone of ladakh”.*Potato Journal* 35(3-4).

Slater, J.W. (1968). “The effect of night temperature on tuber initiation of the potato”.*Eur. Potato J*. 11: 14–22.

Söğüt, T. and Öztürk, F. (2013).“Effects of harvesting time on some yield and quality traits of different maturing potato cultivars”. *African Journal of Biotechnology* 10(38): 7349-7355.

Steduto, P. (2012). “Crop yield response to water”. Rome: Food and Agriculture Organization of the United Nations, 192-201.

Stet Holland (Spunta); available from http://www.stet.nl/en/?page_id=1402; Internet; accessed 19 February, 2015.

Stieber, T.D. and Shock, C.C. (1995). “Placement of soil moisture sensors in sprinkler irrigated potatoes”. *American Potato Journal* 72(9): 533-543.

The Plant (The potato); available from http://www.fao.org/potato-2008/en/potato/index.html; Internet; accessed 11 February, 2015.

Thurston, H.D. and Abawi, G. (1997). “Effects of organic mulches, soil amendments, and cover crops on soil-borne plant pathogens and their root diseases”. Slash/mulch systems: sustainable agriculture in the tropics, 147-157.

Unger, P. W. and Agassi, M. (1995). “Common soil and water conservation practices”. *Soil erosion, conservation, and rehabilitation*. CRC, Boca Raton, FL, 239-266.

Unger, P.W. (1978). “Straw-mulch rate effect on soil water storage and sorghum yield”. *Soil Science Society of America Journal* 42(3): 486-491.

Unger, P.W. (2002). “Conservation tillage for improving dryland crop yields”. *CienciadelSuelo* 20(1): 1-8.

Unger, P.W. and Parker, J.J. (1976).“Evaporation reduction from soil with wheat, sorghum, and cotton residues”. *Soil Science Society of America Journal* 40(6): 938-942.

Venkanna, Y. (2008). “Effect of mulches, organics and organic solutions on growth, yield and quality of chilli (capsicum annuum l.)Cv. Byadagidabbi in northern transition zone of Karnataka”.Thesis, University of Agricultural Science.Dharwad, Karnataka, India.

Wang, F.X., Wu, X.X., Shock, C.C., Chu, L.Y., Gu, X.X. and Xue, X. (2011). “Effects of drip irrigation regimes on potato tuber yield and quality under plastic mulch in arid Northwestern China”. *Field Crops Research* 122(1): 78-84.

Wang, J., Fu, B., Qiu, Y. and Chen, L. (2001). “Soil nutrients in relation to land use and landscape position in the semi-arid small catchment on the loess plateau in China”. *Journal of Arid Environments* 48(4): 537-550.

Water Development and Management Unit - Crop Water Information: Maize. FAO - Water Development and Management Unit - Crop Water Information: Maize.

Wright, J.L. and Stark, J.C. (1990). “Potato. Irrigation of Agricultural Crops”. Agronomy Monograph No. 30. ASA-CSSA-SSSA, Madison, WI.

Yaghmaei, A., 1987. “Comparison of yield, chemical and qualitative properties of twelve potato variety in semiarid regions”. M.S. Thesis, Tehran University, Iran

Yuan, B, Nishiyama, S. and Kang, Y. (2003). “Effect of drip irrigation regimes on the growth and yield of drip- irrigated potato”. *Agric Water Manage.* 63(31): 153:167.

Yuan, B.Z., Nishiyama, S. and Kang, Y. (2003).“Effects of different irrigation regimes on the growth and yield of drip-irrigated potato”. *Agricultural Water Management* 63(3): 153-167.

Zaniewicz-Bajkowska, A., Franczuk, J. and Kosterna, E. (2009).“Direct and secondary effects of soil mulching with straw on fresh mass and number of weeds, vegetable yield”.*Polish J. Environ. Stud* 18(6): 1183-1188.

Zehnder, G.W. and Hough-Goldstein, J. (1990). “Colorado potato beetle (Coleoptera: Chrysomelidae) population development and effects on yield of potatoes with and without straw mulch”. *Journal of Economic Entomology* 83(5): 1982-1987.

Zhang, S., Lövdahl, L., Grip, H., Tong, Y., Yang, X. and Wang, Q. (2009). “Effects of mulching and catch cropping on soil temperature, soil moisture and wheat yield on the Loess Plateau of China”. *Soil and Tillage Research* 102(1), 78-86.

Zhang, Y.X., Yang, J.L., Liu, W., Li, L., Gao, Y.J., Xiao, L.L., ... and Tian, L.G. (2009). “Effects of nitrogen rate on nitrogen uptake and utilization of winter wheat and residual nitrate in soil under straw mulch [J]”. *Agricultural Research in the Arid Areas*, 2, 035.

Zhang, Z.X. and Wu, J.L. (1994). “Study on the techniques for conservation of water during summer fallow period in precipitation deficient year”. In: Chen, W.Q., Xin, N.Q. (Eds.), *Strategies for Comprehensive Development of Agriculture in North China*. China’s Agricultural Science and Technology Press, Beijing, 195–198.

Zhao, H., Xiong, Y.C., Li, F.M., Wang, R.Y., Qiang, S.C., Yao, T.F. and Mo, F. (2012). “Plastic film mulch for half growing-season maximized WUE and yield of potato via moisture-temperature improvement in a semi-arid agroecosystem”. *Agricultural Water Management* 104: 68-78.