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Adnan Taha A. M. AL-GHAWRY

MANAGEMENT OF SUPPLEMENTAL AND DEFICIT IRRIGATION FOR WHEAT PRODUCTION UNDER THE MEDITERRANEAN CLIMATIC CONDITIONS

DEPARTMENT OF AGRICULTURAL STRUCTURES AND IRRIGATION

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ÇUKUROVA UNIVERSITY
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Adnan ALGHAWRY

PhD DISSERTATION

DEPARTMENT OF AGRICULTURAL STRUCTURES AND IRRIGATION

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ABSTRACT

PhD THESIS

MANAGEMENT OF SUPPLEMENTAL AND DEFICIT IRRIGATION FOR WHEAT PRODUCTION UNDER THE MEDITERRANEAN CLIMATIC CONDITIONS

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This study evaluated the effect of three different supplemental and conventional irrigation strategies on crop water stress index (CWSI), midday flag leaf water potential Ψ_l, leaf stomatal conductance g_s, chlorophyll content (SPAD), economical parameters, yield, yield components and quality of wheat (*Triticum aestivum* L. Adana 99) using sprinkler line-source system during 2014 and 2015 seasons in the Mediterranean region. The irrigations strategies considered were: (1) conventional irrigation (CI); (2) supplemental irrigation (SI) during flowering (SIF); (3) SI during grain filling (SIG); and (4) SI both during flowering and grain filling (SIFG). The above strategies were tested under four irrigation levels 100% (I_1), 75% (I_2), 50% (I_3), 25% (I_4) levels and rain-fed (I_5) was also included in the study.

Full conventional treatment achieved the highest yield and yield components and the deficit irrigation 75% had the greatest WUE. A higher grain yield was obtained when the irrigation was applied at CWSI values less than 0.26. The highest chlorophyll reading of CI_{100} was 17.8% greater than the lowest value in RF. The higher grain yield was achieved when the seasonal g_s reached to 207.4 mmol/m^{2}s in CI and to 169.21 mmol/m^{2}s in SI. High determination coefficient between Ψ_l with grain yield was obtained which could be useful in improving the irrigation water management of winter wheat in the field. In relation to full SI strategies, SIFG and SIF generated the maximum (668.53 $/ha) and minimum net income (424.22 $/ha), respectively. The findings showed positive response between the quality parameters such as protein ratio, wet gluten content and sedimentation volume, and water stress depend on the applied water quantity and which stage the stress occurred.

Keywords: Supplemental irrigation, conventional irrigation, physiological parameters, net income, grain quality.

ÖZ

DOKTORA TEZİ

AKDENİZ İKLİM KOŞULLARINDA BUĞDAY ÜRETİMİNDE TAMAMLAMA VE KISINTILI SULAMANIN YÖNETİ

Adnan ALGHAWRY

ÇUKUROVA ÜNİVERSİTESİ
FEN BİLİMLERİ ENSTİTÜSÜ
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Bu çalışmada üç farklı tamamlama ve konvansiyonel sulama stratejisinin, bitki su stresi indeksi (CWSI), gün içi bayrak yaprak su potansiyeli Ψ_l, yaprak stoma iletkenliği g_s, klorofil içeriği (SPAD), ekonomik parametreler, Akdeniz Bölgesi'nde 2014 ve 2015 yetiştirme dönemlerinde çizgi kaynaklı yağmurlama sistemi kullanılarak yetiştirilen buğday (*Triticum aestivum* L. Adana 99) bitkisinin verim, verim unsurları ve kalitesi üzerine etkisi değerlendirilmiştir. Dikkate alınan sulama stratejileri: (1) geleneksel sulama CI; (2) çiçeklenme döneminde tamamlama sulama (SIF); (3) dane dolumu döneminde tamamlama sulama (SIG); ve (4) çiçeklenme ve tane dolumu (SIFG) sırasında tamamlama sulama. Yukarıdaki stratejiler dört sulama seviyesi altında test edilmiş %100 (I_1), %75 (I_2), %50 (I_3), %25 (I_4) ve sulamasız (I_5) konu da dahil edilmiştir.

CI_{100} konusu en yüksek verim ve verim bileşenlerini sağlamış ve % 75 su seviyesi en yüksek WUE ile sonuçlanmıştır. Sulama CWSI'nin 0.26'dan daha düşük değerlerinde uygulandığında daha yüksek tane verimi elde edilmiştir. En yüksek klorofil içeriği okuması CI_{100} konusunda belirlenmiş ve sulamasız konudaki en düşük değerden %17.8 daha yüksek olmuştur. En yüksek dane verimi mevsimlik ortalama stoma iletkenliği CI konusunda 207.4 mmol/m^2s ve SI konusunda ise 169.21 mmol/m^2s değerine ulaştığında sağlanmıştır. Ψ_l ile verim arasında belirlenen yüksek determinasyon katsayısı kışlık buğdayın su yönetimini iyileştirmede kullanılabilir. SIFG ve SIF tam sulama stratejileri sırasıyla en yüksek (668.53 $/ha) ve en düşük net geliri (424.22 $/ha) sağlamışlardır. Araştırma bulguları protein oranı, ıslak gluten içeriği ve sedimentasyon hacmi gibi tane kalite parametreleri ile su stresi arasında pozitif ilişkiler olduğunu göstermiş olup, ilişki su eksikliğinin hangi büyüme döneminde meydana geldiğine bağlı olarak değişmektedir.

Anahtar Kelimeler: Tamamlama sulama, geleneksel sulama, fizyolojik parametreler, net gelir, tane kalitesi

EXTENDED ABSTRACT

This study evaluated the effect of three different supplemental and conventional irrigation strategies on crop water stress index (CWSI), midday flag leaf water potential Ψ_l, leaf stomatal conductance g_s, chlorophyll content (SPAD), economical parameters, yield, yield components and yield quality of wheat (*Triticum aestivum L. Adana 99*) using line-source sprinkler system during 2014 and 2015 growing seasons in the Mediterranean region.

The irrigations strategies considered were: (1) conventional full and deficit irrigation (CI); (2) supplemental irrigation during flowering growth stage (SIF); (3) supplemental irrigation during grain filling growth stage (SIG); and (4) supplemental irrigation both during flowering and grain filling stages (SIFG). The above strategies were tested under four irrigation levels 100% (I_1), 75% (I_2), 50% (I_3), 25% (I_4) and rain-fed (I_5) treatment was also included in the study. In conventional strategy, irrigations were scheduled when 50% of available water being depleted in depth of 90 cm and replenished to near field capacity for the full irrigation next to the sprinkler lateral.

Full conventional treatment achieved the highest grain yield 5868 and 8258 kg/ha during both of dry and wet season, and dominated significantly in biomass yield at harvesting on the full supplemental irrigation treatments SIFG, SIF and SIG (except SFG_{100} in 2015), whereas there were not any significant differences between the high irrigation treatments ($CI_{100,75}$ and $SIFG_{100}$) in weight of 1000 grain. The results confirmed the effect of supplemental irrigation at grain filling stage (SIG and SIFG strategy) to increase the 1000 grain-weight comparison with irrigation at flowering stage. LAI increased with increasing of applied water until its maximum value at anthesis stage than started to decline gradually towards the end of the growing season.

Seasonal evapotranspiration (ET_a) values were lower in the first year due to the severe drought by 20.2% for SIG_{100} and 24.2% for $SIFG_{100}$ as compared to the

second year. Full conventional treatment produced the greater biomass yield and grains number per spike in both seasons.

Apparently in wet season, the harvest index of winter wheat achieved its maximum value under deficit irrigation (75%) for each strategy however the findings under this level also appeared relatively high in the dry season, The deficit conventional irrigation level 75% had the greatest water use efficiency 1.26 and 1.35 kg/m^3 during the dry and wet growing seasons, and the deficit supplemental irrigation SIF_{25} resulted in the lowest WUE. The yield response factor K_y value varied depending on water stress and growth stage where the smallest value was obtained under conventional strategy and greatest value under supplemental irrigation during flowering.

The crop water stress index was estimated for the irrigation strategies considered. Available soil water and grain yield were correlated linearly to CWSI, these relations could be employed in predicting the yield response to water stress. A higher grain yield was obtained when the irrigation was applied at CWSI values less than 0.26. Based on those results, CWSI could be used as a good indicator to improve irrigation scheduling of winter wheat in the Mediterranean region.

The increasing in SPAD values under low irrigation levels and RF was early in the first season refer to occurring water stress that accelerated to develop growth stages faster and made SPAD index higher compared to high irrigation levels treatments. The highest chlorophyll reading of CI_{100} increased by 17.8% over the lowest value in RF where SPAD index reached to its maximum value in watery and milky grain stages, hence this sensitive period could be employed as good predictor for wheat grain yield in different irrigation strategies.

The flag leaf stomatal conductance was correlated linearly with grain yield, where the higher grain yield was achieved when the seasonal g_s reached to 207.4 mmol/m^2s in CI and to 169.21 mmol/m^2s in SI, and the stomatal closure responded well to low, moderate and severity drought that means stomatal responses affected by soil moisture content higher than leaf water status, these relations of g_s could be

used as a physiological indicator to measure water stress effect on growth and productivity of wheat.

Leaf water potential was influenced by both soil water potential and growth stage that prolong drought period which leads to a decline in Ψ_l value in the advanced growth stage which reduced the efficiency of the physiological processes and made Ψ_l more negative. High determination coefficient between Ψ_l with grain yield was obtained which could be useful in improving the irrigation water management of winter wheat in the field.

The lower deficit irrigation treatments resulted in negative net return in dry season but positive in wet season. Depending on gross income and production cost values of full supplemental irrigation strategies, SIFG and SIF generated the maximum (668.53 $/ha) and minimum net income (424.22 $/ha), respectively.

CI_{75} produced more yield and net income in comparison with $SIFG_{100}$ that although irrigation amount of $SIFG_{100}$ was higher but the yield and net income were 7.65 and 26% lower, furthermore CI_{75} saved 23.3% of water with small grain yield reduction of 4.35% as compared to CI_{100}. Therefore CI_{75} can be recommended to maximize yield and net income under limited water resources

In this study, higher water stress occurring in the dry year helped to improve the grain quality and made it richer than wet year. The findings showed positive response between the quality parameters such as protein ratio, wet gluten content and sedimentation volume, and water stress depend on the applied water quantity and which stage the stress occurred.

$SIFG_{75}$ treatment was the best irrigation strategy for high grain quality parameters (with small yield reduction as compared to CI_{100}), it could be recommended to obtain high yield and good quality indicators under Mediterranean conditions.

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LIST OF ABBREVIATIONS

CI	: Conventional Irrigation
SIFG	: Supplemental Irrigation during Flowering and Grain filling stages
SIF	: Supplemental Irrigation during Flowering
SIG	: Supplemental Irrigation during Grain filling stage
DAP	: Days After Planting
ET_a	: Crop Evapotranspiration
SWC	: Soil Water Content
e_a	: Actual vapour pressure
e_s	: Saturated vapour pressure
T_c	: Canopy Temperature
T_a	: Air Temperature
VPD	: Vapor Pressure Deficit
CWSI	: Crop Water Stress Index
Ψ_l	: Leaf Water Potential
g_s	: Leaf Stomatal Conductance
LAI	: Leaf Area Index
SPAD	: Soil Plant Analysis Development

1. INTRODUCTION

One of the most important challenges facing the world is to produce enough food continuously increasing population with limited water resources (Wallace, 2000). Wheat (*Triticum aestivum* L.) is one of the most important crops, providing over 20% of the calories consumed by the world's population (Braun et al., 2010). The demand for wheat follows rapidly growing populations and is expected to increase by 60% in the third world by 2050 (Rosegrant and Agcaoili, 2010). In the year 2050, the world population is estimated to be 9 billion, while the demand for wheat is estimated to reach more than 900 million tons (Dixon et al., 2009).

On the other hand it is noticed that water resources scarcity in Turkey is increasing, the quantity of consumed water annually in Turkey is about 44 billion m^3, and the yearly renewable water magnitude is 112 billion m^3. Agriculture utilizes about 75% of the total water consumption annually (DSI, 2015). Wheat crop has high priority in using which is grown in most parts of the world, from near-arctic to near-equatorial latitudes. It is the most important crop among the cereals by area planted and is followed in importance by corn, barley and sorghum. The amount of wheat traded internationally exceeds that of all other grains. Furthermore, the protein and caloric content of wheat is greater than that of any other food crop.

The total bread wheat production of Mediterranean region is 75.2 MT (12% of global production 644 MT, and total harvested area is 18.1 Mha (9% of world harvested area), Turkey is the second biggest producer with percent 22% (after France 47%) during 2010-2013 (MED-Amin, 2015). In relation to years of carrying out present research (2014 and 2105), the wheat harvested area in Turkey amounted 7.7, 7.9 million ha; it produced 15.3, 18.5 million tons, and consumed 17.5, 17.8 million tons according to the latest data (Grain World Markets and Trade, 2015). According to Pala et al. (2011), average yield gaps in Morocco ranged from 98-207% in rain-fed areas and from 51-89% in irrigated areas.

Similarly yield gaps of 82-125% and 61-201% have been reported in Syria and Turkey, respectively.

Deficit irrigation (DI), defined as the application of irrigation water below the full crop ET, is an important tool to increase the efficiency of water use (English et al., 2002). Supplemental Irrigation (SI) the application of a limited amount of water to rain-fed crops that can normally grow without irrigation, to increase and stabilize production. This is different from conventional full irrigation, which is applied in areas having very low rainfall where no economical crop production can be achieved without irrigation. The water productivity indicator is useful to identify the best irrigation scheduling strategies for deficit SI of cereals (Zhang and Oweis, 1999). Deficit irrigation can be considered as a key strategy for increasing on-farm water productivity in water-scarce dry areas (Zhang, 2003). In water scarcity areas, adoption of deficit irrigation can reduce the amount of water needed by plants and the saved water can increase the irrigated area which will increase total production. Generally, when the farmers are faced with water scarcity and they cannot provide full irrigation the whole farm, they have two options (Oweis and Hachum, 2003): in the first case, they may apply all the water available for irrigation over a part of the farm and leave the remaining part as rain-fed. In the second case, they may apply less water to irrigate the whole farm (deficit irrigation). The quantitative comparison of deficit and full irrigation strategies showed that deficit irrigation was more useful for obtaining higher total production as compared full irrigation.

The agricultural sector and water security in the Mediterranean region are facing many environmental challenges including climate change (increasing temperature and potential evapotranspiration, decreasing rainfall and increasing the drought spells), water scarcity, rapid population growth and urbanization (FAO, 2016). With an increasing demand in fresh water resources in the Mediterranean region, farmers are challenged to manage irrigation water in a more efficient way. This can only be achieved with having a comprehensive knowledge

on the amount and timing of crop water requirement. Hence, the research importance highlighted to mitigate these challenges effects by monitoring irrigation scheduling under different supplemental and conventional irrigation strategies that can help the farmer in management of irrigation water during different growth stages of crop to increase yield production, where in general, the Mediterranean region of Turkey suffers from lack of rainfall needed in sensitive growth stages of wheat (flowering and grain filling stages) during March to May. Developing optimal supplemental irrigation strategy for improving wheat production in the region is important for reducing part of a food gap through this strategic crop.

The objective of this research was to determine the effect of the supplemental and conventional irrigation applied at the critical growth stages on grain yield and yield components such as weight of 1000 grains and grains number per spike, growth parameters such as biomass dry matter and leaf area index during wheat growth stages until harvest. Additionally, the research carried out to develop the water productivity using limited amount of water consequently, increasing the water use efficiency in land area unit. Furthermore this study aimed to evaluate the physiological parameters such as crop water stress index CWSI, midday flag leaf water potential Ψ_l, chlorophyll content (SPAD) and stomatal conductance g_s and its relations to grain yield in optimal and in water-stress on winter wheat (*Triticum aestivum* L. Adana 99) using sprinkler line-source system.

The study also aimed to examine and compare the economic feasibility of agriculture with conventional and supplemental irrigation strategies in the Mediterranean region in order to maximize the net benefit from optimal wheat production (no maximizing yield) and determine the appropriate SI and CI amount especially under limited water and land resources. Additionally, this work was carried out to evaluate the effect of conventional and supplemental irrigation applied at the critical growth stages on grain yield and bread-making properties (protein content, wet gluten content, and sedimentation value) in order to improve

wheat quality, and to study the correlation of different quality parameters and grain yield.

2. LITERATURE REVIEW

2.1. Water and Crop Characteristics

Mediterranean region is characterized by a short rainy season (November–April), increasing water deficit and thermal stress during wheat grain filling stage. Adequate water at or after anthesis period not only allows the plant to increase photosynthesis rate but also gives extra time to translocate the carbohydrate to grains (Zhang and Oweis, 1998) which improves grain size and thereby lead to increase grain yield. Zhang et al. (2006) carried out a water-deficit study and observed biomass yields of wheat between 15 and 20 ton/ha depending on irrigation quantity and its application growth stage. However this range was between 20.9 and 10.1 ton/ha for full irrigation treatment and rain-fed, and recommended that water deficit should be applied in milky grain stage of wheat to reduce the yield losses (Tari, 2016). A study was conducted to determine the suitable irrigation dose to compensate yield and bread-making quality under the Mediterranean ecological conditions for two years. The supplemental irrigation caused the grain yield to increase significantly up to 58%. The root depth of the wheat and barley crops reaches from (1 to 1.5 m), available moisture depleting ratio (p) to 0.55 and the sensitive irrigation period (tillering, heading and grains filling) stages so it taken in account no thirsting (stress) at these stages (Ismail, 2002).

Padhi et al. (2010) found that grain yield, straw and leaf area index have significant differences among treatments where the full irrigation treatment resulted in the high significant and it started in reducing within increasing of the stress levels and soil moisture depletion. Rao et al. (2012) found on wheat using line source sprinkler irrigation significant effect under full irrigation and four deficit irrigation levels and the highest value of the total biomass, grain yield, harvest index, number grain/spike and 1000 grain weight was under full irrigation. Drought at the grain filling period also decreases individual grain weight but the

decrease is often due to decrease in grain filling duration rather than decrease in grain filling rate (Saini and Westgate, 2000; Wardlaw and Willenbrink, 2000). Drought at an early stage of the grain filling period decreases the number of endosperm cells and number of starch granules per cell, which are also the reasons for a decrease in grain size (Fábián et al., 2011). Highest average grain yield of wheat was attained from the highest irrigation level (full irrigation) with 7-day interval as 8340 kg/ha, and the lowest yield was obtained from rain-fed treatment with 2940 kg/ha in the arid Southeast Anatolia Project (GAP) region of Turkey (Sezen and Yazar, 2006).

Leaf area index (LAI) is the main physiological determinant of the crop yield (Mubeen et al., 2013). Rajala et al. (2009) reported that drought reduces photosynthesis, plant water content and leaf area development. Maximum leaf area index at anthesis in wheat is usually (Trethowan et al., 2002). Huang et al. (2005) stated increasing grain yield was noted with increasing biomass yield.

Musick and Porter (1990) stated that Harvesting Index (HI) varies between 0.38 and 0.60 for high-yielding wheat varieties under irrigation. Kang et al. (2002) observed the controlled soil contents can improve the grain yield and harvest index and reported HI values of 0.24-0.29 under rain-fed conditions and 0.25-0.45 under irrigated conditions in the Loess Plateau of China. The appropriate irrigation and controlled soil water content can increase harvest index as a result of the good water supply during the reproductive stage (Sezen and Yazar, 2006; Bandyopadhyay et al., 2010).

The positive relationship between grain yield and morphological traits (spike length, peduncle length, awn length and grains/spike) under water stress conditions (Villegas et al., 2001). Water stress at anthesis reduces pollination and thus less number of grains is formed per spike which results in the reduction of grain yield (Ashraf, 1998). Moisture stress is known to reduce biomass, tillering ability, grains per spike and grain size at any stage when it occurs. So, the overall effect of moisture stress depends on intensity and length of stress (Bukhat, 2005).

Water use efficiency for grain yield of wheat was increased from 0.97 to 1.10 kg/m^3 by supplemental irrigation, although WUE for dry matter was not affected by it (Zhang et al., 1998). One study (Li et al., 2001b) suggests that limited supplemental irrigation during the growth season can significantly increase WUE and wheat yield. Rao et al. (2012) found the highest value of water productivity under DI_{46} and the lowest value under full irrigation, but the highest mean WP of 1.28 kg/m^3 in wheat was observed in ET_{75} irrigation treatment, however the highest grain yield was under full irrigation in comparison to deficit irrigation levels. Several studies have reported WUE values that were higher under water deficit than high irrigation condition, especially when irrigation is applied in the critical stages of plant development (Mandal et al., 2005). However, Farre and Faci (2006) observed that water use efficiency decreased with decreasing irrigation.

Somme et al. (2005) found that water use efficiency for wheat range between (0.44 kg/m^3) for rainy control to (1.04 kg/m^3) for full supplementary irrigation treatment. In all the cases, IWUE values related to deficit irrigations were higher than those of full irrigation. IWUE increased with decreasing irrigation amounts and/or water use (Yazar et al., 2009). Many technologies to improve water productivity and the management of scarce water resources are available. Among the most promising and efficient-proven technologies are: (i) supplemental irrigation (SI) for optimizing the use of the limited water available from renewable resources in rain-fed areas, and (ii) water harvesting (WH) for improved farmer income in drier environment (Oweis and Hachum, 2003). Zwart and Bastiaanssen (2004) reported the range of crop water productivity (CWP) of wheat varied between 0.6 and 1.7 kg/m^3, and this offers tremendous opportunities for maintaining or increasing production with 20-40 % less water resources, the reasons for the variability of CWP as climate, irrigation water management, and soil (nutrient) management. Supplementary Irrigation (SI) as watering strategy or technique for addition small amounts of water when rainfall fails (not enough) to provide sufficient moisture in order to improve and stabilize production. The

results provide evidence that water resources are limited, deficit irrigation with drought stress concentrated in the vegetative stages, is a valuable option to stabilize the yields at a high level. The saved water from this technique can be diverted to irrigate other areas and crops or for other purposes (Kipkorir et al., 2001). Kang et al. (2002) found that the wheat crop during the maturity stage has low sensitivity for water stress so the irrigation process could be stopped. The potential returns of irrigation scheduling are derived from three factors: increased irrigation efficiency, reduced cost of irrigation and the opportunity cost of water (English et al., 1990). Under conditions of limited water distributed equally over the total growing season involving crops with different K_y values, the crop with higher K_y value will suffer a greater yield loss than the crop with a lower K_y value (Moutonnet, 2000).

2.2. Physiological Characteristics

Canopy surface temperature measured with infrared thermometers (IRT) or other remote infrared sensors provide an important tool to detect water stress in a crop, which has been in practice for some decades. The crop water stress index (CWSI) is the most frequently used index to quantify crop water stress based on canopy surface temperature under different crops and climatic conditions, for example, Yazar et al. (1999); Chen et al. (2010); Taghvaeian et al. (2012); DeJonge et al. (2015) for corn; Yuan et al. (2004); Gontia and Tiwari (2008) for wheat; Yazar et al. (2002); Barbosa da Silva and Rao (2005). O'Shaughnessy et al. (2011); Argyrokastritis et al. (2015) for cotton.

Jackson et al. (1977) found a crop with sufficient water supply will result in T_c-T_a being either zero or negative, versus T_c-T_a being positive for a crop with limited water supply. In Mediterranean environments where the VPD increases sharply from 1 to values of 2-3 kPa at the end of grain filling (Condon et al., 1992; Sato et al., 2006) but consistent with Zhang et al. (1998), this type of Mediterranean environment is characterized by a low VPD during winter and in the spring when it seldom rises above 1 kPa.

The maximum differences between T_c and T_a (upper limit) which is equal to 2°C in winter wheat (Idso et al., 1981; Howell et al., 1986). The CWSI was calculated for winter wheat based on the following baseline equation $T_c - T_a = 0.4 - 1.5VPD$ (Alderfasi et al., 2001). CWSI values below zero or over 1 were observed by various researchers suggesting dependency of the CWSI values on the local condition (Ca´rcova et al., 1998; Yuan et al., 2004).

Gontia and Tiwari (2008) stated the wheat CWSI values ranged from zero until 0.96 using different irrigation levels (including rain-fed). The seasonal CWSI for all treatments were 0.33 in farmer practice, 0.43 in FI, 0.56 in DI_{50}, 0.61 in DI_{16} and 0.65 in NI (no irrigation) of winter wheat (Zia, 2012). As an index for irrigation scheduling, CWSI can predict when to irrigate (Irmak et al., 2000; Kacira et al., 2002), but it cannot provide how much to irrigate.

Chlorophyll content is an important factor in determining the mesophile conductance, photosynthesis rate and dry matter production (Majidian et al., 2008; Moghadami, 2008). Drought increases senescence by enhancing chlorophyll degradation and nitrogen loss (Yang et al., 2001). Furthermore, drought decreased photosynthesis in wheat species (Shah and Paulsen, 2003; Dulai et al., 2006; Liu et al., 2006). The majority of chlorophyll lost from leaves subjected to drought stress is lost from the mesophyll cells (Richardson and Berlyn, 2001).

Total chlorophyll content per unit leaf area has been successfully determined using a portable chlorophyll meter (SPAD-502) on different crop plants (Uddling et al., 2007). Grain yield was associated significantly with SPAD readings at the heading stage (Bavec and Bavec, 2001) and in the middle of the grain-filling period (Jiang et al., 2004) under rain-fed and irrigated conditions in winter wheat. Sulok et al. (2012) found the highest SPAD value (49.13) was under well-watered treatment followed by 41.13, 36.73 and 29.75 SPAD units under mild, moderate and severe water stress treatments respectively. Chlorophyll content (SPAD reading) showed steady increase with irrigation water supply, SPAD reading at I_{100} (38.9) was 38% higher than the control I_0 (28.2) (Ninou et al.,

2013). Reduction in chlorophyll concentration in dry condition is due to the effect of drought stress on chlorophyll degradation (Bahavar et al., 2009). Under stressful conditions, maintaining chlorophyll concentration helps to photosynthesis stability in these conditions (Ahmadi and Sio-se Mardeh, 2004).

Plant stomata are the gate between plant and atmosphere and play a vital role in plant responses to environmental conditions (Nilson and Assmann, 2007). The stomatal opening/closing mechanism plays a major role in the regulation of plant water status (Hsiao and Lauchli, 1986). Stomata close as leaf-to-air vapour pressure deficit (VPD) increases irrespective of soil water availability (Oren et al., 1999).

Stomatal conductance is important for determining the amount and efficiency with which water is used by cereal crops and for determining the productivity of these crops (Condon et al., 2002). Stomatal conductance and uptake of CO_2 are reduced by water deficit which ultimately affects the growth of crop plants, the researchers have reported the decline in photosynthesis due to water stress resulting in variations in stomatal and non-stomatal response of the plant (Graan and Boyer, 1990; Ort et al., 1994). Borrell et al. (2000) stated that varieties with higher chlorophyll content stay green for longer, maintain more photosynthetically active leaves and show higher stomatal conductance (transpiration efficiency) under post-anthesis drought conditions.

The significant and positive correlation between stomatal/chlorophyll parameters with yield indicated that under stressed condition, if some physiological traits (stomatal/chlorophyll) are below optimum it can significantly affects net assimilates production which will eventually reduce the yield (Zlatev, 2004; Ahmadi and Sio-se Mardeh, 2005) which showed that most of the physiological traits significantly affected the grain yield in wheat crop. Ahmed et al. (2010); Olszewski et al. (2009) Found significant decreases in g_s by increasing drought stress on wheat. Bahar et al. (2009) reported under Mediterranean conditions that

average g_s measures of all durum wheat genotypes at early milky, late milky and early dough maturity periods were 294, 225 and 167 mmol H_2O/m^2s, respectively.

The reductions of 62.59% in stomatal conductance occurred due to water stress with values ranged 473-400 mmol/m^2s under irrigated conditions to 220-128 mmol/m^2s under water stress conditions (Jatoi et al., 2012). Wheat cultivars regarding stomatal conductance that the g_s values ranged from (513-581 mmol H_2O/m^2s) at pre-anthesis to (239-356 mmol/m^2s) at post-anthesis under rain-fed and irrigated treatments respectively (Khakwani et al., 2013). Abdulqayyum (2011) found large range between irrigation treatments (80, 60, 40 and 20% FC) in stomatal conductance of wheat were (740, 680, 550 and 290 mmol/m^2s) respectively. Sato et al. (2006) applied supplemental irrigation on wheat two times in flowering and grain filling stages that the value of g_s in the SI_{100} treatment was higher than in the other regimes (SI_{50} and rain-fed) during the mentioned growth stages and the g_s values after first SI irrigation were higher than after the second. Certainly under mild or moderate drought stress stomatal closure causing reduced leaf internal CO_2 concentration is the major reason for reduced rates of leaf photosynthetic (Chaves, 1991; Cornic, 2000).

There is a strong link between stomatal conductance and photosynthesis in which leaf dehydration can lead to turgid loss of guard cells causing passive stomatal closure which reduce stomatal conductance and consequently the supply of CO_2 to fixation site is reduced (Ahmadi and Sio-se Mardeh, 2005), however, the ability of stomata to remain open in rain-fed conditions was closely linked to their greater capacity as compared with irrigated. Similar results were reported by El-Hafid et al. (1998). Flexas et al. (2004) reported that g_s is a more sensitive indicator of the severity and pattern of water stress development where, stomatal closure protects plants against excessive water loss. Photosynthesis, transpiration, stomatal conductance and yield were higher under irrigated situations than under drought stress conditions, (Mafakheri et al., 2010). This decrease in water content in leaves increased the leaf temperature that might have occurred due to increased

respiration and decreased transpiration resulting from stomatal closure, and water deficit significantly decreased stomatal conductance both at the vegetative and anthesis stages (Siddique et al., 2000). The net photosynthetic and transpiration rates, stomatal conductance (g_s), and intercellular CO_2 concentration in most plants decrease under drought stress (Perez-Perez et al., 2009; Wang et al., 2010).

Jiang et al. (2013) obtained that the lowest leaf water potential corresponding to lowest soil water content. For most wheat plants, the immediate response to water deficit is the decline in the leaf water potential (Ψ_1), which leads to stomatal closure and reduced photosynthesis. Prolonged drought can limit plant growth and biomass production (Puri and Swamy, 2001). There were significant differences in leaf water potential (Ψ_l) of wheat in mid-day among the three water regimes of full and deficit irrigation (FI, DI_{50}) and rain-fed (RF), the differences become larger while the season developed and the water stress increased where the values of (Ψ_l) ranged for (FI and RF) from -14.22 to -17.78 bar at flowering and from -18 to -24.03 bar at grain filling stage (Matić, 2008). Waraich and Ahmad (2010) applied one to four irrigations during different growth stages (tillering, stem elongation, anthesis and grain filling) and found that increasing number of irrigations significantly increased the values of water potential and osmotic potential. The maximum values (less negative) of water potential were observed after 10 days of anthesis, the progressive decreases were observed and the minimum values were recorded 30 days after anthesis in both the two years.

Decreasing the soil water content of root zone affects to decrease stomatal conductance via the leaf water potential consequence, the wheat grain yield decreases (Xue et al., 2006). Siddique et al. (2000) reported that the reason of decreased photosynthetic rate may be the decreased Ψ_l under water stress due to limited irrigation and exposure of wheat to drought led to noticeable decrease in leaf water potential. It was observed that during crop growth seasons, the leaf water potential, osmotic potential and relative water content dropped linearly with decreasing irrigation levels from 100% ET_o to 60% ET_o. This reduction in these

attributes might have caused partial closure of stomata that resulted in a significant decrease in stomatal conductance which limited the access of photosynthetic apparatus to CO_2 (Ali et al., 2014). Liang et al. (2002) reported when the growth rates of wheat started to decrease sharply during the three drying spells, the leaf water potentials were -0.9, -1.2 and -1.5 MPa, respectively, and declined to a very low level of -1.8 MPa at the end of the third drying spell.

According to Hsiao (1990), the most effective indicator of plant water status for irrigation scheduling is leaf water potential, which is related to transpiration rate, during the day that Ψ_l decreased with increasing transpiration. Huang et al. (2013) reported the values of leaf water potential during both growing seasons ranged from -0.82 MPa to -2.43 MPa depend on rows spacing between wheat plants.

2.3. Grain Quality Characteristics

Food security in the world is challenged by increasing food demand and threatened by declining water availability (Zwart and Bastiaanssen, 2004). Insufficient rainfalls during the grain filling period in the Mediterranean climates similar in the Turkey affect grain yield negatively (Erekul et al., 2011). Protein content and composition determine the bread making quality of wheat flour (Branlard et al., 2001).

Mary et al. (2001) reported that the water stress has played a key role to reduce the moisture percentage, while it increased protein and gluten contents. Water stress in the post-anthesis (grain filling period) was found to affect quality parameters where an increase in protein content and sedimentation volume, consistent with a decrease in grain yield, 1000 grains weight, bread volume and wet gluten were observed when a terminal water stress happened (Aslani et al., 2013). Noorka and Silva (2012) found under normal irrigation condition the protein contents of wheat ranged from 11.2-13.78% while under water stress condition it ranged from 12.47-13.92%.

Kiliç and Yağbasanlar (2010) concluded that drought stress increased the chlorophyll content, grain protein content and sedimentation. Tari (2016) reported that the water stress applied in the stem elongation stage and irrigation applied in the milk stage increased the protein ratios, where the highest protein ratios and gluten contents were obtained under the moisture conditions of the DDA treatment (full irrigation at milk stage) (14.5%) during the first year, and under the DAA (full irrigation at heading and milk stage) treatment (14.7%) during the second year in Konya Plain in Turkey. Erekul et al. (2012) stated that sedimentation values and wet gluten contents at different supplemental irrigation doses ranged between (27-37 ml) and (26.5-34.4%) in the first and second trial year. Grain protein content ranged between (12.4-14.7%) and (11.7-14.9%). Protein contents, sedimentation values and wet gluten contents without supplemental irrigation were significantly higher than the values obtained from the supplemental irrigations.

On the other hand, Gooding et al. (2003) found that the effect of drought stress imposed during grain development on the technological parameter sedimentation volume was dependent on the timing of stress application. In particular, restricting moisture between the first and the 14th day during grain filling on the quality characteristics significantly reduced sedimentation volume relative to water stress applied. Ozturk and Aydin (2004) observed that late water stress increased grain protein, sedimentation volume, and wet gluten content relative to the fully irrigated treatment in a red-grained winter bread variety. Naseri et al. (2010) who revealed that with the effect of water stress in wheat increased protein contents by 10.3-13.2% while Seleiman et al. (2011) reported that less irrigation and water stress increased protein content by 11.20-13.40% as compared to full irrigation. Saint-Pierre et al. (2008) expressed that with the application of supplemental irrigation the protein content begins to decrease as expected.

Johari-Pireivatlou and Maralian (2011) reported that the content of total protein in seeds increased by 5 to 13% in deficit and rain-fed conditions, as compared to full irrigated treatments. Protein percentages significantly affected by

water stress treatment. Irrigation termination at flowering stage significantly increased protein percentages to 12.9% compared with normal irrigation (11.8%), effect of drought stress on gluten percentage was significant where gluten percentage increased in drought stress condition compared to normal condition (Kanani et al., 2013). Moisture stress caused an increase in protein content and a reduction in thousand kernel weight (Rharrabtia et al., 2003a). Gooding et al. (2003b) discussed that high temperatures and water stress may lead to increased grain protein content.

2.4. Economical Evaluation

Attaining higher yields with increased productivity is only economical when the increased gains in crop yield are not offset by increased costs of other inputs (Oweis and Hachum, 2004). Eid et al. (2014) attained the best results under set sprinkler irrigation system and irrigation frequency three times per week with maximum wheat grain yield (5832 kg/ha) and net income 1289.3 $/ha; on the other hand, hand-move sprinkler system and irrigation frequency once per week achieved the lowest yield (3332 kg/ha) and net income (-199 $/ha) in Egyptian national research centre. Optimum water use in deficit irrigation is obtained by an economic analysis using yield and cost functions, if land is limiting, optimum irrigation strategy would be to apply the amount of water which maximizes net income as described by English and James (1990).

Many investigators have concluded that deficit irrigation can increase net farm income (Fardad and Golkar, 2002; Zhang et al., 2002). Ali et al. (2007) found highest net return of wheat under both land and water-limiting conditions was obtained using 2 irrigation (130 mm) amounted 87.1 and 154.3 $/ha with yield 3.3 t/ha however under 4 irrigations (265 mm) amounted 70.4 $/ha with yield 3.8 t/ha, and the lowest net income was negative (-74.5 $/ha) under the conditions of using 18 mm irrigation water since the cost of production was higher than gross return and yield was 1.8 t/ha. Dağdelen et al. (2009) stated that the reduction in the net

income of the deficit irrigation treatments T_{25} and T_{50} was significant and seemed to be non profitable with negative values were (-2672.5 and -877.7 $/ha) in the Aegean region of Turkey.

Reduced yield under deficit irrigation (especially in water-limiting situations) may be compensated by increased production from the additional irrigated area with the water saved by deficit irrigation. Tavakoli et al. (2010) reported the net benefit of wheat per hectare of 3 treatments (supplemental irrigation at planting, spring time in April and rain-fed) were 270.2, 287.1 and 285.6 $ under traditional management and under advanced management were 353.1, 582.1 and 504.0 $/ha.

Irrigated crops under full irrigation conditions became inappropriate choice for the most breeders so they relying on reducing of irrigation level economically to meet the loss by a proportion simple from yield revenue where the range is being limited of quantity and time of water stress within lowest yield profits (Payero et al., 2009). English and Raja (1996) found through their experiment of three levels of deficit irrigation that the costs of irrigation were largely reduced than the yield revenue, as it is being much feasible when the water cost is higher due to of water scarcity and accordingly under that condition; the deficit irrigation is being the optimal choice for farmer.

3. MATERIALS AND METHODS

3.1. Experimental Site

The experiment carried out in the Research Field of the Irrigation and Agricultural Structures Department at Çukurova University, (36˚59´N latitude, 35˚18´ E longitude and altitude of 35 m above sea level) located in Adana, Turkey, during the 2013/2014 and 2014/2015 wheat growing seasons using a local wheat variety (*Triticum aestivum* L. Adana 99).

3.2. Experimental Soil and Water

The soil of the experimental site is classified as Mutlu soil series (Palexerollic Chromoxeret, FAO, 2006), with clay texture throughout the soil profile. The other physical characteristics of the experimental soil were determined on soil samples taken from 0-30 cm layers down to 120 cm in the experimental site (Table 1). The volumetric soil water content values at field capacity (FC) and permanent wilting point (WP) of the root-zone were 40-41 and 19-24%, respectively. The average of bulk density was between 1.15 to 1.25 g/cm^3, Available water-holding capacity of the soil is 198 mm in the 120 cm soil profile. In addition, the chemical characteristics of the experimental soil also were measured (Table 1) where electrical conductivity of the saturation extract (EC) ranged between 0.51 and 1.13 dS/m, soil pH values varied from 7.62 to 7.78. The other parameters such as organic matter content, calcium carbonate (%), total cations and anions (me/l) were given in Table 1.

Water is obtained from an open channel irrigation system in the experimental area, and the quality is classified as (C_2S_1), and pH is 7.8, and the average of electrical conductivity is 0.78 dS/m.

Table 3.1. Description of the physical and chemical characteristics of the experimental soil

Soil depth (cm)	Particle size distribution (%)			Soil texture	Field Capacity (cm^3/cm^3)		Wilting Point (cm^3/cm^3)		Saturation Point (cm^3/cm^3)		Bulk Density (g/cm^3)
	sand	silt	clay								
00 - 30	28	21	51	C	40		24		51		1.19
30 - 60	28	19	53	C	40		23		54		1.16
60 - 90	28	18	54	C	41		22		55		1.15
90- 120	27	19	54	C	41		19		50		1.25
Soil depth (cm	pH	EC dS/m	Organic Matter %	$CaCO_3$ %	Cations (me/l)				Anions (me/l)		
					Ca^{++}	Mg^{++}	Na^{+}	K^{+}	HCO_3^{-}	SO_4^{-2}	Cl^{-}
00 - 30	7.68	1.13	1.23	5.99	1.62	0.53	0.63	0.10	1.79	0.40	0.62
30 - 60	7.62	0.87	0.98	6.38	1.79	0.74	0.70	0.07	1.50	1.17	0.59
60 - 90	7.75	0.62	-	6.65	2.71	0.85	0.74	0.05	1.53	1.93	0.69
90-120	7.78	0.51	-	7.40	2.78	0.84	0.76	0.04	1.50	2.17	0.71

3.3. Climate

Çukurova region is placed in semi-arid climate, with average annual rainfall about (650 mm). Weather data collected from an automatic recording meteorological station located at the experimental site. Precipitation, maximum and minimum air temperatures, air humidity, wind speed and solar radiation measured on a daily basis, and summarized for each growing season along with climatic data during the long-term of period 1960-2015 in Table 2.

Table 3.2. Climatic data of wheat growing seasons 2014/2015, 2013/2014 and long - term (1960 - 2015)

	Long - Term average (1960 - 2015)							
Climatic elements/Month	Nov.	Dec.	Jan.	Feb.	March	April	May	June
T-max (°C)	22.5	16.8	15	16.2	19.6	23.7	28.2	31.7
T-min (°C)	10.9	7.2	5.5	6.2	8.6	12.3	16.1	20.2
Average Temperature (°C)	15.5	11.2	9.6	10.6	13.6	17.5	21.8	25.7
Total Precipitation (mm)	76.7	129.0	106.2	87.2	67.6	55.8	46.6	20.1
RH- average (%)	63.9	67.6	66.1	66.2	66.5	67.7	67.0	67.0
Wind speed average (m/s)	1.2	1.4	1.5	1.5	1.6	1.6	1.7	1.8
SR (MJ/m^2/day)	8.6	6.4	7.2	10.0	13.5	17.0	20.0	21.8
Evaporation (mm)	66.4	45.1	45.6	52.5	82.9	114.0	163.0	207.2
	Growing season (2013/2014)							
Climatic elements/Month	Nov. 2013	Dec. 2013	Jan. 2014	Feb. 2014	March 2014	April 2014	May-2014	June 2104
T-max (°C)	24.5	16.1	17.6	18.7	20.9	30.7	27.9	-
T-min (°C)	10.7	3.9	5.7	5.2	8.1	11.3	14.8	-
Average Temperature (°C)	17.6	10.0	11.6	11.9	14.5	21.0	21.4	-
Total Precipitation (mm)	26.0	17.0	48.0	41.0	54.5	33.6	30.5	-
RH-max (%)	83.5	78.4	87.4	94.4	89.9	92.5	90.8	-
RH-min (%)	33.2	25.0	43.2	36.1	39.4	45.7	38.4	-
RH- average (%)	58.3	51.7	65.3	65.3	64.7	69.1	64.6	-
Wind speed average (m/s)	0.5	1.3	0.6	0.7	0.9	0.8	0.8	-
SR (MJ/m^2/day)	10.2	9.2	8.7	13.5	16.4	19.5	22.2	-
	Growing season (2014/2015)							
Climatic elements/Month	Nov. 2014	Dec. 2014	Jan. 2015	Feb. 2015	March 2015	April 2015	May-2015	June-2015
T-max (°C)	-	18.2	14	15.5	20.0	22.2	29.9	31.9
T-min (°C)	-	8.3	3.8	6.1	7.7	8.4	14.0	18.2
Average Temperature (°C)	-	13.3	8.9	10.8	13.9	15.3	22.0	25.1
Total Precipitation (mm)	-	70.5	62.0	85.0	96.3	25.0	65.0	15.0
RH-max (%)	-	90.3	86.6	90.4	90.9	92.0	91.2	90.5
RH-min (%)	-	49.6	46.0	50.2	41.8	41.4	36.7	40.9
RH- average (%)	-	70.0	66.3	70.3	66.4	66.7	64.0	65.7
Wind speed average (m/s)	-	0.7	0.8	0.9	0.8	0.8	0.7	1.1
SR (MJ/m^2/day)	-	7.5	8.0	9.7	16.0	19.8	23.5	24.4

3.4. Agronomic Practices

A local bread wheat variety, Adana 99 (*Triticum aestivum* L.) was sown at the appropriate time period for planting wheat in the Çukurova region on November 22, 2013 and on December 8, 2014. Harvesting carried out on 22nd of May in the first year and on 9th of June in the next year. The rate of seeds was (250 kg/ha) with an average row spacing of 16-18 cm with a planter. Also herbicides

(Arrat-1 g/4L water) and (perun 75 WG 1125 cc/1000 L, Dimetrin 2250 cc/1000 L and Dassoil 26-2N 1000 cc/1000 L) were sprayed one time on 7th March and 5th March against the weeds during the first and second cropping seasons.

Fertilizers were added at planting according to Turkish research recommendations where compound fertilizers of N-P-K (20-20-0) were applied (75 kg N, 75 kg P_2O_5) as pure matter per hectare at planting stage, the rest of N (2nd dose 75 kg/ha) was applied in the form of urea (46%N) during jointing (1/2/2014, 15/2/2015) and the 3rd dose at rate 75 kg/ha of ammonium nitrate 33% (ammonium 16.5% and nitrate 16.5%) was applied at flowering of crop stage.

3.5. Experimental Design and Treatments

3.5.1. Experimental Design

In the experiment line source sprinkler design was employed for studying the effect of conventional and supplemental irrigation strategies on wheat yield and yield components. Line-source sprinkler system allows various irrigation levels gradually decreasing towards the wetted perimeter (Hanks et al., 1976; Yazar et al., 1990). The line source sprinkler-irrigation strategy provided sufficient room to carry out research to find out what minimum amount of water should be applied to have maximum yield per amount of water applied (Hanks et al., 1976).

Separate sprinkler lines were employed for the main treatments and sprinkler lateral was laid out parallel to plant rows. The line source sprinkler system was used to assess crop yield response to different levels of deficit irrigation, where the applied irrigation water is uniformly distributed parallel to sprinkler lateral and water application gradually with distance away from the line source (or sprinkler head).

The space between the experimental units was 3.0 m, as shown in Figure 1. Double-nozzle sprinkler heads (4.5mm x 4.8mm) placed at 6 m intervals on the laterals, provide linearly decreasing wetting pattern under regulate operation pressure equals (3 bar nozzle pressure) 300 kPa pressure. Each line source has a

valve for on and off, and a flow meter was used to measure the amount of irrigation water applied. The sprinkler irrigation depth was measured by calibrated catch-cans, placed at the center of each irrigation level plot above the crop canopy following Winward and Hill (2007). The catch-cans were placed on grids of 3 m both sides of the lateral lines in all four replications.

The layout of the sprinkler line-source experiment, location of catch cans and neutron access tubes and experimental plot dimensions were shown in Figure 1. The catch cans and neutron access tubes were located in each replication in order to ensure reliable field data about the actually collected water from sprinklers and soil moisture content.

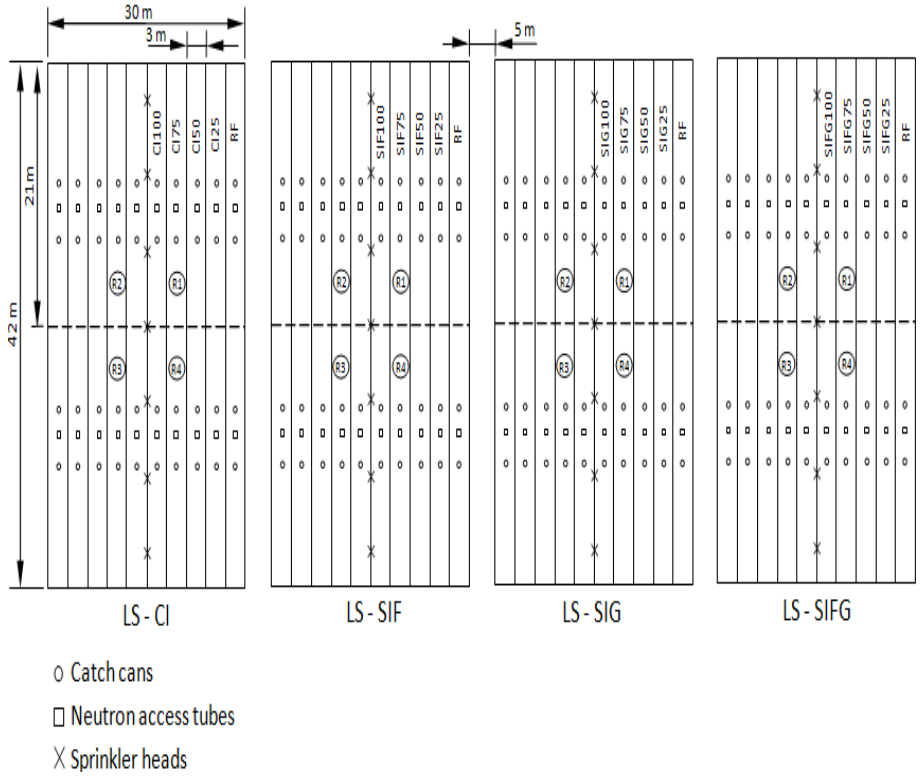

Figure 3.1. Schematic field layout of the line-source sprinkler system (LS), plot dimensions, location of catch-cans and neutron access tubes.

3.5.2. Treatments

Three different supplemental irrigation strategies and full irrigation along with rain-fed treatment were studied. Namely, (1) conventional full and deficit irrigation, (2) supplemental irrigation during flowering growth stage, (3) supplemental irrigation during grain filling growth stage and (4) supplemental irrigation both during flowering and grain filling stages. Five irrigation levels in each irrigation strategy, namely one full (I_1) and three deficit (I_2–I_4) irrigations were envisaged, a dry (rain-fed, RF) treatment I_5 was also included in the study. For each irrigation strategy, a line source sprinkler system was set up in the experimental field as depicted in Figure 1.

Strategy 1: Conventional irrigation, there were a full irrigation and three deficit irrigation levels (CI_{100}, CI_{75}, CI_{50} and CI_{25}) created by the water distribution pattern of the line source sprinkler system. Full irrigation treatment was applied when 50% of available water is depleted in the 90 cm soil profile depth, soil water deficit in the 90 cm root zone depth was replenished to near field capacity. The other irrigation treatments automatically received irrigation amounts approximately 75, 50, and 25% of full irrigation (CI_{100}) simultaneously.

Strategy 2: Supplemental irrigation was applied just during the flowering, soil water deficit was replenished to field capacity in plots adjacent to the sprinkler lateral (SIF_{100}) and the other plots received approximately 75, 50, and 25 % of SIF_{100}.

Strategy 3: Supplemental irrigation was applied just during the grain filling growth stage and soil water deficit was replenished to field capacity in plots adjacent to the sprinkler lateral (SIG_{100}) the other plots received approximately 75, 50, and 25 % of SIG_{100}, namely SIG_{75}, SIG_{50}, and SIG_{25}.

Strategy 4: Supplemental irrigation was applied during both flowering and grain filling growth stages ($SIFG_{100}$, $SIFG_{75}$, $SIFG_{50}$ and $SIFG_{25}$). At the beginning of the flowering and grain filling growth stages, soil water deficit in the 90 cm soil profile depth was replenished to field capacity in treatment plots next to the

sprinkler line ($SIFG_{100}$), the other plots received approximately 75, 50, and 25 % of $SIFG_{100}$.

The distance between line-source sprinkler system for each strategy was 30 m to avoid water interaction between the lines of sprinkler. Irrigation treatments were replicated four times under four line-source sprinkler systems.

3.6. Measurements and Observations

3.6.1. Water Characteristics

3.6.1.1. Soil Water Content Measurements

Soil water content was measured with gravimetric method (dry oven at 105^{o}C for 24h) at planting and harvesting by using hand-auger at 30 cm depth increments down to 90 cm soil profile. During the wheat growing season soil water content was monitored approximately every two weeks intervals and before water application, by a neutron probe (Model 503). Access tubes were installed to a depth of 90 cm in the middle of all plots.

The neutron probe was calibrated at the beginning of the growing season for the experimental field by correlating probe readings as count ratios with gravimetric soil water samples taken at the time of access tube installation by using 2 zones (wet and dry) in the field in area 4 m^2 each. The wet one treated with 2 m^3 of water, then soil moisture monitored every 2 days during 2 weeks from soil surface until 90 cm depth for 3 layers (30- 60- 90 cm). The volumetric water content (P_v) equations based on neutron probe readings were as following:

$$P_v \text{ (00-30 cm)} = 80.645\ CR - 13.976 \quad (R^2=0.91) \qquad (3.1)$$

$$P_v \text{ (30-60 cm)} = 72.993\ CR - 10.562 \quad (R^2=0.90) \qquad (3.2)$$

$$P_v \text{ (60-90 cm)} = 81.967\ CR - 8.343 \quad (R^2=0.92) \qquad (3.3)$$

Where CR: Count Ratio between average of neutron probe readings in soil and average of standard readings in water.

At the upper 30 cm the soil layer water content was measured by the gravimetric method. The first irrigation was applied when 50 % of the available soil water in 90 cm soil profile is depleted.

3.6.1.2. Crop Water Use (Evapotranspiration)

The evapotranspiration of wheat (ET_a) for individual plots was determined for seasonal total and between the growing stages by using the soil water balance equation (Allen et al., 1998) as follows:

$$ET = I + P \pm \Delta SW - D_P - R_O \quad (3.4)$$

Where I: The amount of applied water irrigation (mm) that is measured in the catch cans, P: The precipitation (mm) that is measured from the weather station at the site, $\pm\Delta$SW: is the change of soil water content (mm) between any consecutive irrigations in the 90 cm soil profile taken as effective root zone depth, D_P: the drainage from the bottom of the root zone below 90 cm depth, which is negligible and R_o: surface runoff occurring during the study seasons because rainfall intensity or sprinkler irrigation. R_o from the experimental plots was negligible as there was sufficient surface roughness (due to dry sowing) for water infiltration. Also there were low ridges of sowing lines.

3.6.1.3. Water Use Efficiency and Irrigation Water Use Efficiency (WUE- IWUE)

The values in kg grain per m^3 of the applied water were calculated for different treatments after crop harvest according to equations 5 and 6 (Kijine et al., 2002):

$$WUE\ (kg/m^3) = GY/(10\ ET_a) \quad (3.5)$$

$$IWUE\ (kg/m^3) = (Y_a - Y_d)/(10\ I) \quad (3.6)$$

Where: GY: grain yield production (kg/ha), ET_a: seasonal crop evapotranspiration (mm), $(Y_a - Y_d)$ the difference between treatments' yield under irrigation and rain-fed yield (kg/ha), I: applied water amount with irrigation for each treatments (mm).

3.6.1.4. Crop response factor (k_y)

Crop response factor is useful for optimizing irrigation strategy by making relationship between grain yield and the total applied water, in present study k_y was calculated from the relationship between decrease in relative yield and decrease in relative crop water consumption according to Doorenbos and Kassam (1979) using the following equation:

$$1-(Y_a/Y_m) = k_y\ [1- (ET_a/ET_m)] \quad (3.7)$$

Where k_y: yield response factor (or the sensitivity index of crop to water stress), Y_a: is actual yield (kg/ ha), Y_m: is maximum yield from the plot without water stress during the growing season (kg/ha); Y_a/Y_m: is relative yield, $1-(Y_a/Y_m)$: is decrease in relative yield; ET_a: is actual crop water consumption (mm) (or actual evapotranspiration mm during the growing season), ET_m: is maximum crop water consumption (mm) (or the maximum evapotranpiration mm corresponding to Y_m), ET_a/ET_m: is relative crop water consumption, $1-(ET_a/ET_m)$: P is decrease in relative crop water consumption.

3.6.2. Crop Characteristics

3.6.2.1. Crop Growth Stages

The crop stages of wheat namely emergence, tillering, heading, flowering, grain filling, physiological maturity and harvesting. The first season started planting on November 22 and harvesting on May 22, 2014 (182 DAP), however the crop planted on December 8 and harvested June 9 (184 DAP) in the next season. Growth stages differed in number of days until physiological maturity (no more dry matter accumulation and grains ready for harvest) depend on amount and period of applied water where low irrigation treatments reached to this stage early compared to high irrigation treatments, that earliness return to water stress.

3.6.2.2. Growth Parameters

Leaf Area Index (LAI) is the main physiological determination of crop yield. It's defined the ratio of green leaf area to ground area as follows (Busse et al., 2001):

$$LAI = \frac{\text{plant leaf area}}{\text{plant ground area}} \quad (3.8)$$

The area of collected green leaves was measured using a leaf area meter (cm^2) (LI-COR 3100 model, Lincoln, Nebraska), that machine was calibrated before working by using standard disk. The plants samples were taken randomly by cutting plants and measuring all the green leaves from fix 0.5 m long row section and regularly every two weeks interval in each plot from tillering stage until the end of season. The same plants samples were used to calculate the biomass dry matter every two weeks for experimental units.

3.6.2.3. Grain and Biomass Yield

Grain and biomass yields were hand obtained by cutting the plants in the harvested area (two meter long and 1.5 m wide) in the center rows of each plot, the

harvested yield was mechanically threshed, grain yield was separated, recorded and converted to ton/ha. Above ground of biomass yield (ton/ha) was measured every two weeks from emergence until harvest. Plant samples were taken by cutting all the plants in 50 cm long row sections in each plot. All plants samples were dried at 65^{o}C in the drying oven until constant weight is reached, and dry matter production was determined for each treatment.

Harvest Index (HI) was determined using the following formula:

$$HI = \frac{\text{grain yield}}{\text{above ground of dry biomass yield}} \quad (3.9)$$

3.6.2.4. Yield Components

Yield components such as weight of 1000 grains (g) and number of grains/spike were determined per treatment plot from each replication at harvest.

3.6.3. Physiological Parameters

3.6.3.1. Crop Water Stress Index (CWSI)

Canopy temperature and the corresponding air temperature measurements were taken from four directions (east, west, north and south) across the planted rows when the crop cover was greater than 70%. Canopy temperature (T_c) was recorded in ^{o}C using a portable infrared thermometer (IRT) (model RAYMX-4PTDG - Germany). The IRT canopy temperature readings were taken at a horizontal angle of 20° by targeting the upper side of the wheat canopy on clear sky conditions around solar noon time (12:00-14.00h) at distance of 1.0 to 1.5 m from the canopy (crop), measurements were made on sunlit leaves (not shaded leaves), (Erdem, et al., 2006) to assure that the measurements should be taken at maximum solar intensity. The mean canopy temperature for each plot was collected as the average of six readings. According to some research conclusions, midday canopy temperature is the best indicator to detect the crop water stress (Idso et al., 1981).

Dry and wet-bulb temperatures were measured with a psychrometer (Assmann Psychrometer, Sato Keiryoki MFG. Co., Ltd, Japan) at a height of 1.5 m in the open area adjacent to the experimental plots. Maximum and minimum temperatures, relative humidity, wind velocity, precipitation, and evaporation were measured daily using a meteorological station set next to the experimental location.

Canopy air temperature difference (CATD) (T_c-T_a) was calculated separately for both well-irrigated and non-irrigated treatments and plotted against VPD of the corresponding day. The equation showing the relation between lower baseline and upper baseline of (T_c-T_a) and VPD was developed from the scatter diagram by linear regression technique.

CWSI was calculated for each treatment depending on the following equation developed using the empirical approach of Idso et al. (1981):

$$CWSI = \frac{(T_c-T_a) - (T_c-T_a)_{LL}}{(T_c-T_a)_{UL}-(T_c-T_a)_{LL}} \quad (3.10)$$

Where (T_c - T_a): is the difference in the canopy and air temperature (^oC), LL represents the non-water-stressed baseline (lower baseline) and UL represents the non- transpiring upper baseline.

LL for the canopy-air temperature difference (T_c-T_a) versus the vapor pressure deficit (VPD) relationship was determined using data collected only from the unstressed treatments (FI). UL was computed according to the procedures explained by Idso et al. (1981). To verify the upper baseline, canopy temperatures of the fully stressed plants were determined several times during the growing season of wheat.

CWSI is the ratio of the vertical distance between the measured canopy and air temperature (T_c-T_a) and the lower baseline to the distance between the lower and upper baselines at the same vapor pressure deficit (VPD).

Vapor Pressure Deficit (VPD) is the difference between the amount of moisture in the air and how much moisture the air can hold when it is saturated , and it was calculated by subtracting the actual vapor pressure (e_a) from the saturation vapor pressure $e_s(T_a)$ at air temperature as following:

$$VPD = e_s(T_a) - e_a \quad (3.11)$$

The following three equations were used to calculate e_s and e_a (Weast et al., 1990). To find e_s in kPa from air temperature (T_a), the equations were as following:

$$e_s(T_a)=(0.6108*2.7183)\exp\frac{17.27*T_a}{T_a+237.3} \quad (3.12)$$

$$e_s(T_w)=(0.6108*2.7183)\exp\frac{17.27*T_W}{T_W+237.3} \quad (3.13)$$

e_a was calculated from this equation :

$$e_a = e_s(T_w)-0.000662\,(T_d-T_w) \quad (3.14)$$

Where: $e_s(T_w)$ is saturation vapor pressure at wet-bulb temperature and T_d-T_w is the difference between dry and wet temperature ^oC.

The key to develop the CWSI lies in defining the upper and lower baselines, to calculate these baselines, three main environmental variables are needed: plant canopy temperature (T_c), air temperature (T_a) and vapor pressure deficiency (VPD). The linear regression relationship between (T_c-T_a) and VPD was expressed for the calculation of the non-water-stressed baseline, (LL or LB) by using the empirical formula (Idso et al., 1981; Idso, 1982):

$$(T_c-T_a)_{LL} = A + B\ VPD \quad (3.15)$$

Where; VPD is the air vapor pressure deficit (kPa), A (intercept) and B slope of the linear regression coefficients relationship between (T_c-T_a) and VPD of the lower limit.

The maximum stressed baseline (UL or UB) (non-transpiring crop, stomata fully closed) is expressed as (Idso et al., 1981):

$$(T_c\text{-}T_a)_{UL} = A + B\ VPG \qquad (3.16)$$

Where A and B are the same with last eq., VPG the difference between the saturation vapor pressure evaluated at air temperature (T_a) and a temperature equal to T_a + A.

Treatments, full irrigation and rain-fed were chosen to develop the lower baseline (minimum stress) and upper baseline (maximum stress) respectively. The other treatments with different irrigation levels were used to assess different threshold CWSI values for irrigation scheduling.

3.6.3.2. Leaf Chlorophyll Content (SPAD value)

Flag leaf chlorophyll content was determined using chlorophyll meter SPAD-502 (Minolta,Osaka, Japan) which measures the chlorophyll content via light transmittance (absorbance of red light at 650 nm and infrared light at 940 nm).

Applied leaves were clean, dry (not wet from dew, irrigation or rain), intact with no sign of diseases or damage for using the instrument. Measurements are taken in any time of the day, Reading from instrument are not absulate chlorophyll values, instead each reading is Chlorophyll Concentration Index (CCI) which ranging from 0 to 99.9, CCI values are typically 40-60 for a healthy green flag leaf at anthesis of wheat accorgding to SPAD-502 mannual.

The SPAD reading values were taken from five plants per plot at three positions on the flag leaf: the base, the middle and the top of the leaf. The average per plot was computed automatically and used in the analysis. The measurements

SPAD values were recorded starting on 21st March and 10th April in 2014 and 2015 seasons. SPAD readings were calibrated before taking the first measurement in each usage that by holding the pinchers closed with nothing in the chamber until displaying the SPAD reading (n=0) on the screen.

3.6.3.3. Leaf Stomatal Conductance (mmol/m^{2}s)

The stomate at the leaf surface have guard cells that open and close the stomate to regulate the uptake of carbon dioxide and release of oxygen, as required for photosynthesis. The stomate must open up to allow for photosynthesis to occur, and during the process of letting carbon dioxide into the leaf, water vapor is lost to the atmosphere. When the stomate close to prevent excess water loss, photosynthesis is compromised.

Stomatal conductance estimates the rate of gas exchange (carbon dioxide uptake) and transpiration (water loss) through the leaf stomata as determined by the degree of stomatal aperture (and therefore the physical resistances to the movement of gases between the air and the interior of the leaf). Hence, the density, size and degree of opening of the stomata, with more open stomata allowing greater conductance, consequently indicating that photosynthesis and transpiration rates are higher. Stomata are also sensitive to light, RH, carbon dioxide, water stress, pathogens and pollutants, and that agro-chemical products affect stomatal responses.

Stomatal conductance (mmol H_2O/m^2s) was recorded by Delta-T porometer AP4 (Delta-T Devices Ltd., Cambridge, UK). This device measures the rate of relative humidity (RH) increase in a chamber clamped to the leaf surface, as water vapor is released through the stomata, this causes the chamber RH to rise. A rapid rise in RH indicates that the stomata are relatively open. The operating range for the porometer is 5-40°C and 10-70% RH.

The porometer was calibrated by using damp calibration plate during six steps where calibrated values decrease gradually until final step, according to

manufacturer's company the calibration normal and the porometer is ready to work in field if the curve error less than 10%.

The porometer readings were taken 5 times during the growing season, on days with clear sky (not cloudy and not in the shadow) around noon (11:00 a.m. - 02:00 p.m.). The leaves used were clean, dry, intact and green, with no sign of disease or damage on the upper (adaxial) surface of the flag leaf, with 4 plants in each treatment that started at heading and continued until plant reached dough maturity stage at approximately 10 days intervals.

3.6.3.4. Leaf Water Potential

Water potential is used to describe the water status of the soil and cells within leaves, although the processes involved are vastly different. Nevertheless, water potential is a useful concept because it can be used to describe the flow of liquid water through soils and through cell walls in the plant, from higher to lower water potential across a resistance.

In general, water potential is defined as the potential energy per unit volume of water with reference conditions to pure water at zero potential (atmospheric pressure and 20^{o}C). The scientific name given to deficit water is the "water potential" of the plant and the relationship of soil dryness to leaf water potential is straight forward as the soil becomes dryer, stem water potential will become more negative.

Leaf water potential (Ψ_l) was measured using a pressure chamber instrument (PMS Instrument Company, Model 615, Albany, USA), that an instrument is the most widely applied technique of measuring the approximate water potential of plant tissues. The sampled leaves were covered with a small plastic bag immediately after leaves excision to avoid the water loss during the transfer of each leaf to chamber. The time between chamber pressurization and leaf excision was quickly as possible and generally less than 15 sec. The leaf petiole was cut with sharp razor from the shoot and placed in chamber. The chamber was sealed and

gradually and slowly pressurized with a nitrogen gas. The pressure increases at some point which sap forces out of the xylem system and it is observed with a hand lens at the cut end of the leaf stem. The amount of pressure that it takes to cause water to appear at the cut surface determines how much tension the leaf is experiencing at this point the (balance pressure) is recorded as leaf water potential (bar) (Scholander et al., 1965).

Measurements were taken at midday with the sunny and clear sky on 4 healthy flag leaves of wheat plants per experimental unit. The leaf water potential readings were made two times at 9th April (139 DAP) and 27th April (157 DAP) in the first season whereas in the second year carried out at 28th April (142 DAP) and 14th May (158 DAP) respectively.

3.6.4. Grain Quality Characteristics

At present, the wheat grain commercial market is based on three quality parameters: grain protein, test weight, and gluten index. The gluten forms about 85% of total protein in bread wheat (this part is not soluble in water) and the other protein part (15%) are soluble in water. The ratio between soluble and insoluble proteins, which affects bread-making quality, is a function of the protein composition that is genetically controlled. Environmental factors, such as water and nitrogen nutrition also influence this ratio (Jia et al., 1996a,b; Stone and Nicolas, 1996a). Grain-protein content was determined by the Kjeldahl method according to method No. 46-10 as described in (AACC, 2000). The protein content was then calculated by multiplying the nitrogen content by a constant of 5.7 (Han and Yang, 2009).

Gluten quality does not only effect end-product quality, but plays an important role in processing so the wet gluten test provides information on the quantity and estimates the quality of gluten in wheat or flour samples. Gluten is responsible for the elasticity and extensibility characteristics of flour dough.

Wet gluten content was determined by the Gluto-Matic method using gluten washing device (Perten-Glutomatic system). In addition, this content was calculated by dividing total gluten content by the weight of the sample (Mudawi et al., 2016).

Sedimentation test gives information (indicators) about total protein where the positive relationship between both factors. The sedimentation value is determined by the procedure outlined in method No. 56-61-3 as described in (AACC, 2000).

3.7. Economical Analysis

Wheat production costs and sale prices were obtained from the Chamber of Farmer Association and Agricultural Provincial Directorate in Adana. Production costs include land rental, land taxes, fertilization, seeds, soil cultivation, plant protection, labour cost for agricultural processes, irrigation, harvesting, threshing, transportation and marketing costs.

Appling any technique depending on two sides, technical side and the other is economical side, hence the total costs, gross income and net income were discussed as a evaluation parameters to the effect of the conventional and supplemental irrigation using sprinkler irrigation system.

An economic analysis was performed using partial budgeting technique in order to determine the maximum net income, which was computed by subtracting all the production costs from gross incomes for all treatments. All calculations were done based on a unit area of one hectare (Sezen et al., 2011).

3.8. Statistical Analysis

The experiment was carried out by using split plots with randomized complete blocks design under two factors, the first one has four irrigation strategies (conventional irrigation, supplemental irrigation during flowering stage, supplemental irrigation during grain filling stage, and supplemental irrigation both

during flowering and grain filling stage), the second has four irrigation levels (100%, 75%, 50% and 25%) of crop water consumption, in addition to a dry treatment was included in the study where the experiment has implemented four replications, so every block contained 20 treatment plots, and the total experimental units were 80.

The experimental data were analyzed statistically by using computer software program SAS (Statistical Analysis System - Version 9.00 TS level 00M0 XP_PRO platform) and comparison between different treatments means are set up through (Duncan's Multiple Range Test) at 5% probability level.

4. RESULTS AND DISCUSSIONS

4.1. Water Characteristics

4.1.1. Irrigation Scheduling

The amount of irrigation water which applied is based on restoring root zone moisture deficit in 90 cm when 50% of available water is depleted to replenish it in effective root-zone depth to near field capacity for the full irrigation treatment next to the sprinkler lateral. The other treatments automatically received approximately linearly decreasing proportions (75, 50 and 25%) of the full irrigation amount. The amount of irrigation water applied was determined by measuring the water collected in the catch cans located in the center of each plot during an irrigation event. The sprinkling rate was estimated from the sprinkler discharge rate and duration for the line-source sprinkler system to the experiment. The greatest seasonal irrigation water applied was under full conventional irrigation treatment CI_{100} with values 276 and 188 mm in the first and second year, respectively. The applied irrigation water range of full SI treatments were, in $SIFG_{100}$ strategy varied between 246 to 163 mm in 2015 and 2014 growing seasons, the corresponding values for SIF_{100} strategy were 149 and 73 mm; for SIG_{100} strategy 247 and 144 mm for the first and second growing seasons, respectively (Table 1). I_2 through I_4 irrigation levels received less irrigation water as compared to I_1 level in all strategies.

During the first growing season, total precipitation was measured as 250.6 mm. This value was 241.8 mm lower than the long-term averages and 168.2 mm lower than the second experimental year. Applying irrigation during only one growth stage (SIF strategy) saved 46-61% water and reached to 11-13% when water was applied at two growth stages (SIFG strategy) compared to conventional irrigation during first and second year. Table 1 presents the time and quantity of irrigation for each treatment.

Table 4.1. Irrigation Scheduling during 2014 and 2015 growing seasons

Treatments	CI	SIFG	SIF	SIG	RF
Date	2013 / 2014				
18/12/2013	37.1	37.1	37.1	37.1	
20/01/2014	76.4				
31/03/2014	89.8	112.1	112.1		
07/04/2014				112.3	
24/04/2014	72.5	97.2		97.2	
Total					
100 %	275.8	246.4	149.2	246.6	250.6
75%	216.2	194.1	121.1	194.2	
50%	156.5	141.7	93.1	141.9	
25%	96.8	89.4	65.1	89.5	
Date	2014/2015				
02/04/2015	56.7				
16/04/2015		72.8	72.8		
21/04/2015	60.2				
24/04/2015				81.0	
04/05/2015	70.7				
09/05/2015		90.3		63.3	
Total					
100%	187.6	163.1	72.8	144.3	418.8
75%	140.7	122.3	54.6	108.2	
50%	93.8	81.6	36.4	72.2	
25%	46.9	40.8	18.2	36.1	

4.1.2. Distribution of Rainfalls during the Wheat Growing Seasons

In dry year, the total precipitation during the season recorded just 250.6 mm, however the rainfalls increased in the wet year to 418.8 mm, the first and second seasons were lower by 49.1 and 14.9% than long term. Hence the first wheat growing season can be classified as a drought year. In dealing with distribution the rainfalls during both seasons, throughout the first three months of December, January and February the monthly precipitation in 2014 season revealed lower than the second season and long-term with averages 51.2 and 67.1%, respectively (Figure 1). Furthermore the precipitation quantity of 2014 season during the tillering stage was insufficient, exactly in December (rain was only 17 mm) therefore the experiment was irrigated with equal quantity for all treatments against the drought for plant establishment. During the advanced growth stages (after

heading) the monthly precipitation in April for the first and second seasons appeared to be close to each other, whereas this average in May decreased by 53.0 and 28.3% for first and long-term lower than second year respectively.

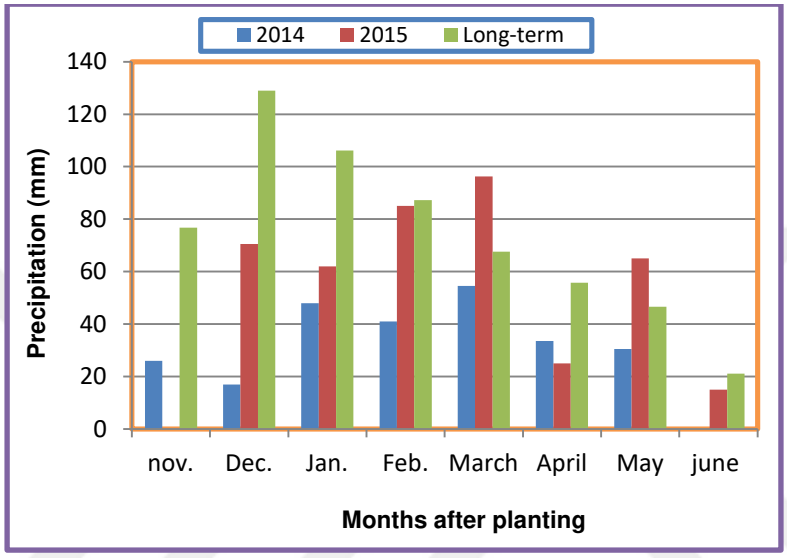

Figure 4.1. Trends of monthly values of precipitation in wheat growing seasons and long-term

4.1.3. Soil Water Content Measurements

In relation to the collected soil moisture content data during the crop growth stages, in the dry season the soil water content (SWC) appeared to be lower in the beginning of season at planting until tillering growth stage owing to no enough rain therefore equal irrigation was applied on 27 DAP with equal irrigation quantity amounted 37.1 mm to all treatments in the experiment to prevent the plants from drought in the first year.

Furthermore it was observed the CI strategy changes of moisture started after first irrigation application on 2014 (60 DAP), however under SIFG, SIF and SIG (which presented in Figure 2) soil moisture content started changing after irrigations on 31/3 (130 DAP), 31/3 and 7/4/2014 (137 DAP), respectively.

In relation to wet season due to sufficient rainfall, the soil water content values were higher during the first growth stages of winter wheat where the SWC started increasing after planting to reach its maximum value in the season on 78 DAP (369.6 mm/90cm) then decreased gradually until the lowest levels observed during heading, flowering and grain filling stages, which resulted in gradually increasing water stress during these periods. Furthermore, the SWC increased early in conventional strategy coupled with other strategies due to irrigation applied on 116 DAP at heading stage, whilst irrigation for SIFG and SIF strategies was in flowering stage (130 DAP). In relation to grain filling strategy, the soil water content continued to decrease more than SIF and SIFG strategies due to relatively late irrigation application on 138 DAP in grain filling stage.

Generally, the lowest soil water stress during all the growth stages of wheat occurred in conventional strategy that depended on plant water requirement instead of growth stage in supplemental irrigation strategies. In addition to, the values of soil moisture fluctuated gradually between FC (393 mm) and WP (207 mm/90 cm). Relative to the first year data, it was noted that the soil water content was below wilting point (WP) in the end of the season for RF, CI_{25} and $SIFG_{25}$, this also occurred with SIF strategy under 75, 50 and 25% levels during the grain filling stage as shown in Figure 2. However the soil moisture fluctuated gradually between FC and WP until the end of season for other treatments. In addition, the soil water content was high for CI during jointing and heading stages compared with other strategies because of irrigation on 22/1/2014. In the next season the moisture content for all irrigation strategies seemed between FC and WP and it was not reached to WP during the different growth stages until the end of the season. Additionally, the lowest SWC values during the season for supplemental irrigation strategies (FG, F and G) were noticed at 25% level that recorded 232.2, 225.6 and 267.7 mm/90cm, respectively on 152 DAP, while the lowest value for conventional strategy (CI_{25}) amounted 248.4 mm/90cm on 165 DAP.

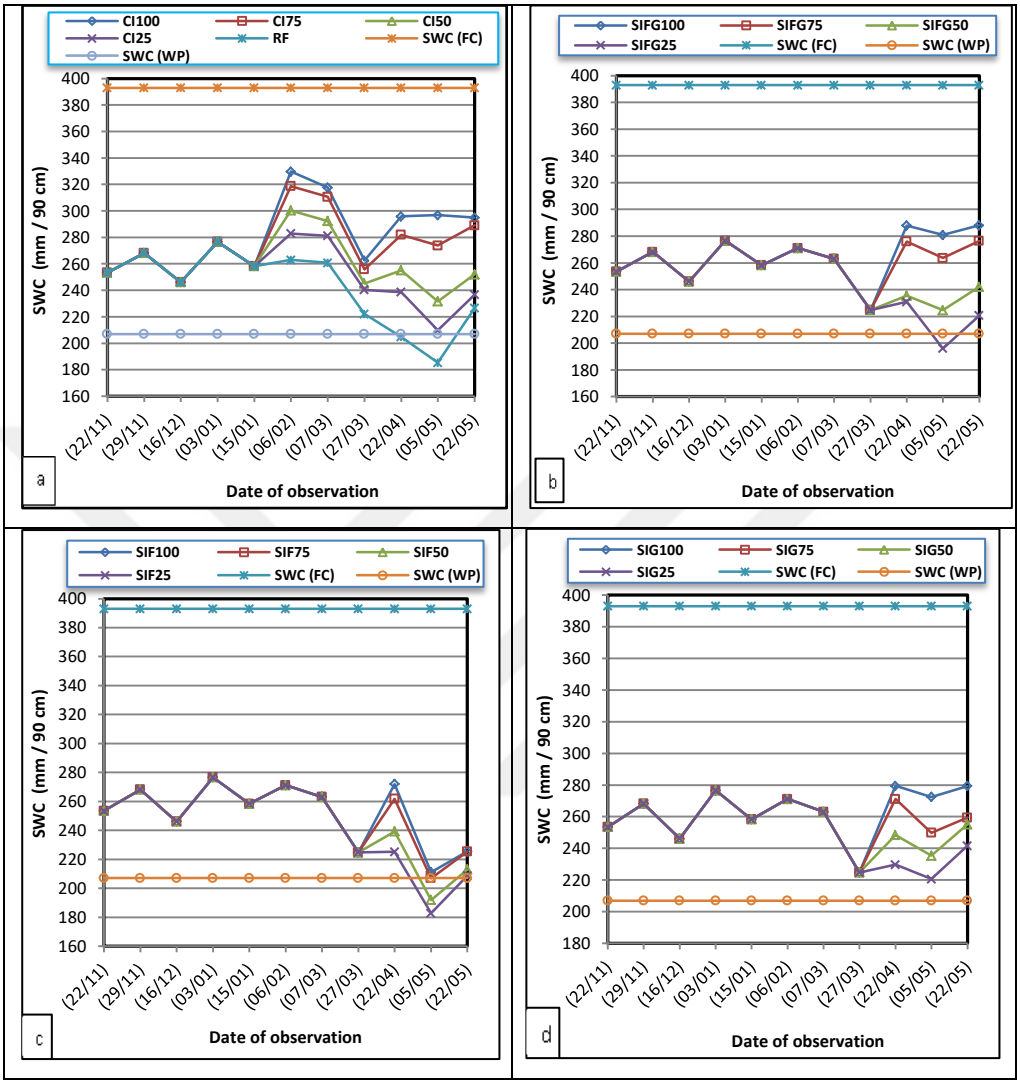

Figure 4.2. The effect of different irrigation levels on SWC under a) CI; b) SIFG; c) SIF and d) SIG in 2014 season

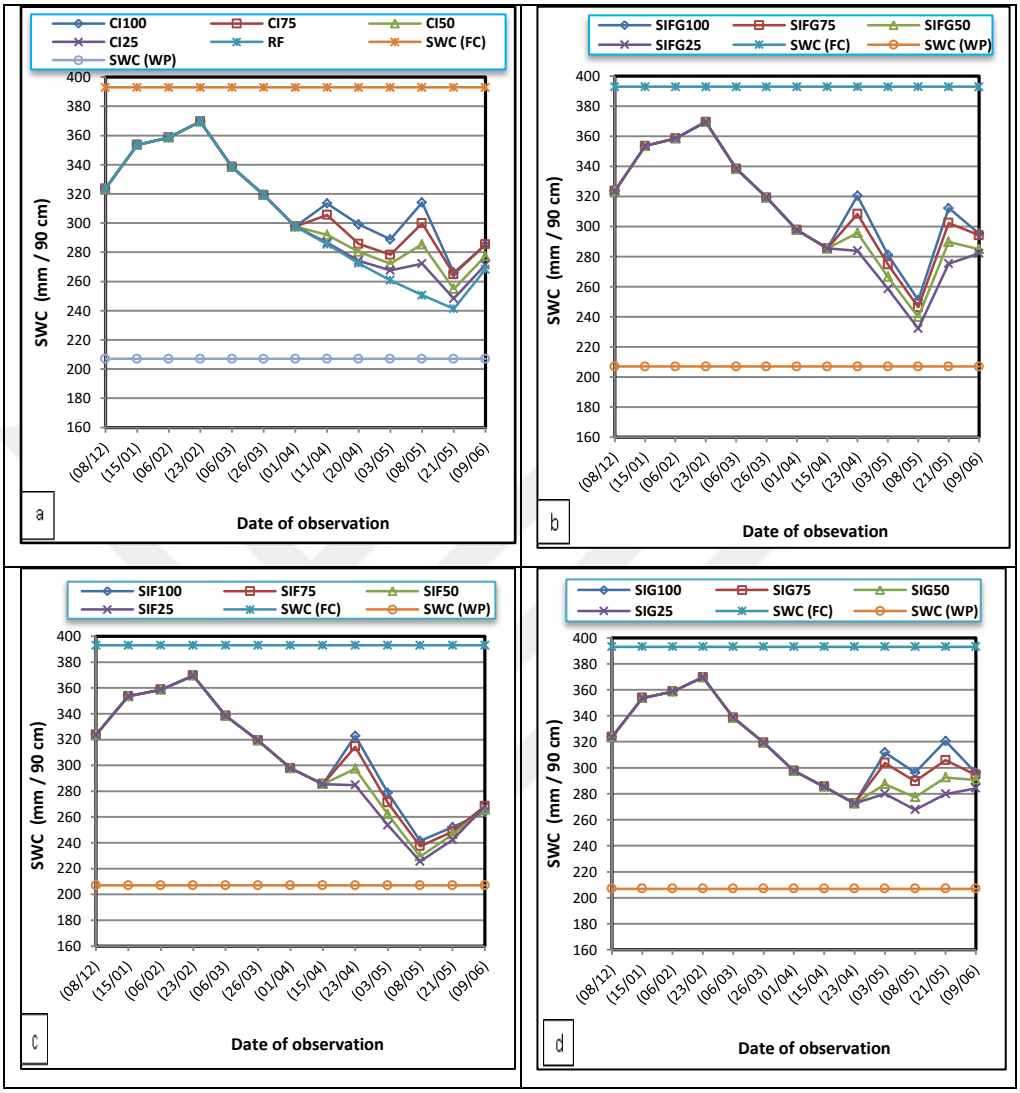

Figure 4.3. The effect of different irrigation levels on SWC under a) CI; b) SIFG; c) SIF and d) SIG in 2015 season

4.1.4. Crop Water Use (Evapotranspiration)

Since the precipitation during the 2014 growing season from November to March was relatively scarce at the experimental site, the evapotranspiration (ET_a) was mainly from applied irrigation water, hence the effect of supplementary

irrigation appeared strongly on crop parameters and the applied water amount greatly affected the crop evapotranspiration.

In general, ET_a increased with increasing irrigation quantity and the seasonal crop ET_a was higher at higher irrigation levels than the deficit irrigation levels. Seasonal ET_a of SI strategies in 2014 ranged from 462 mm for $SIFG_{100}$ strategy to 428 mm for SIF_{100} strategy, however, CI_{100} resulted in the highest value of 485 mm and the lowest value was measured in RF treatment as 293 mm, however in the wet year ranged from 645 mm for CI_{100} to 474 mm under RF treatment.

Mainly due to lower precipitation rates during the first year the seasonal ET decreased to 24.2% for $SIFG_{100}$ and 20.2% for SIG_{100} compared to the second year. The seasonal crop evapotranspiration of full conventional irrigation treatment was higher than full supplemental irrigation SIFG, SIF and SIG by 4.9, 13.3 and 2.9% in the 2014 growing season and the corresponding values in the second year recorded as 5.7, 16.9 and 9.1% respectively.

The relationships of seasonal actual evapotranspiration (ET_a) in the first and second year are presented in Figure 4 and 5 for CI, SIFG, SIF and SIG strategy, respectively.

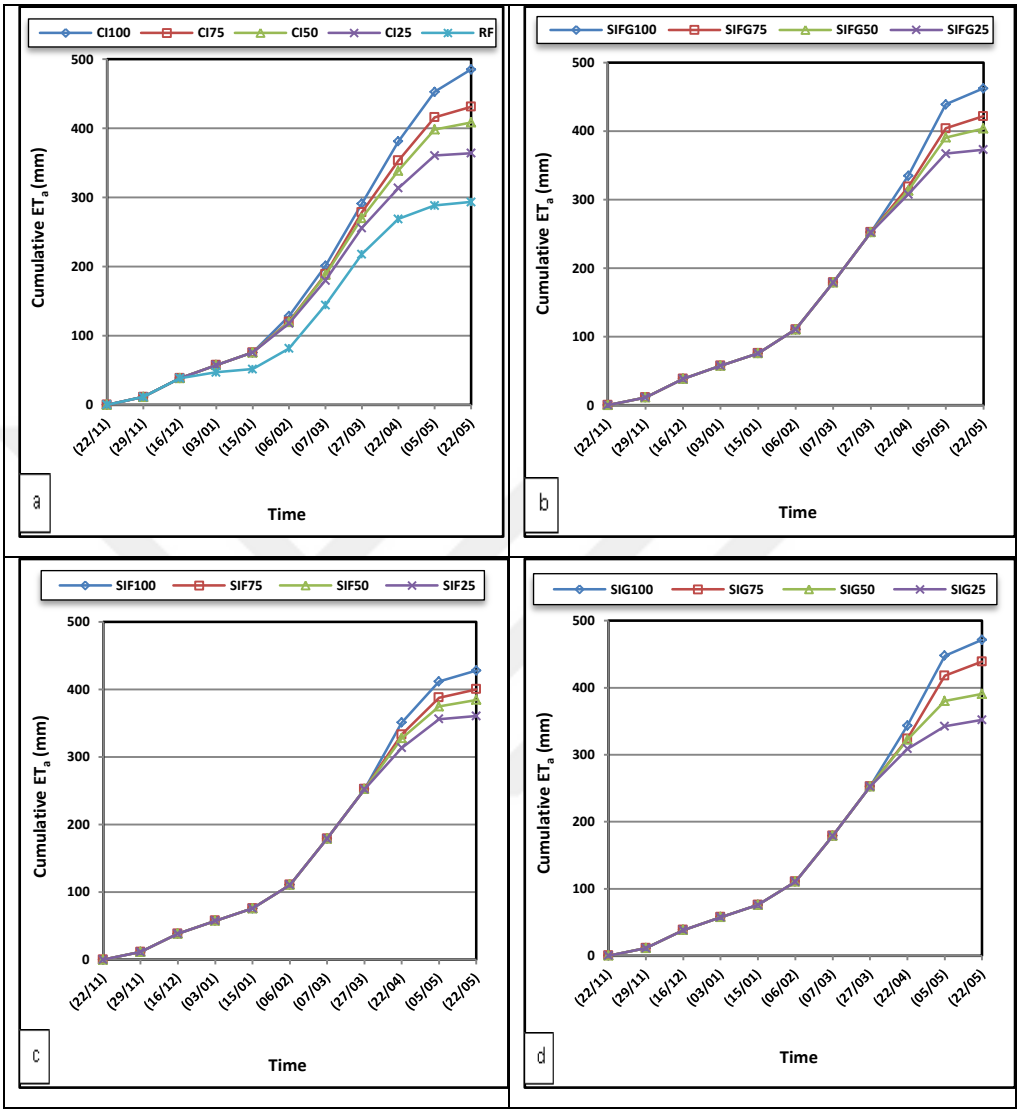

Figure 4.4. Shows accumulative (ET_a) in different irrigation level of a) CI; b) SIFG; c) SIF and d) SIG strategy during 2014 growing season

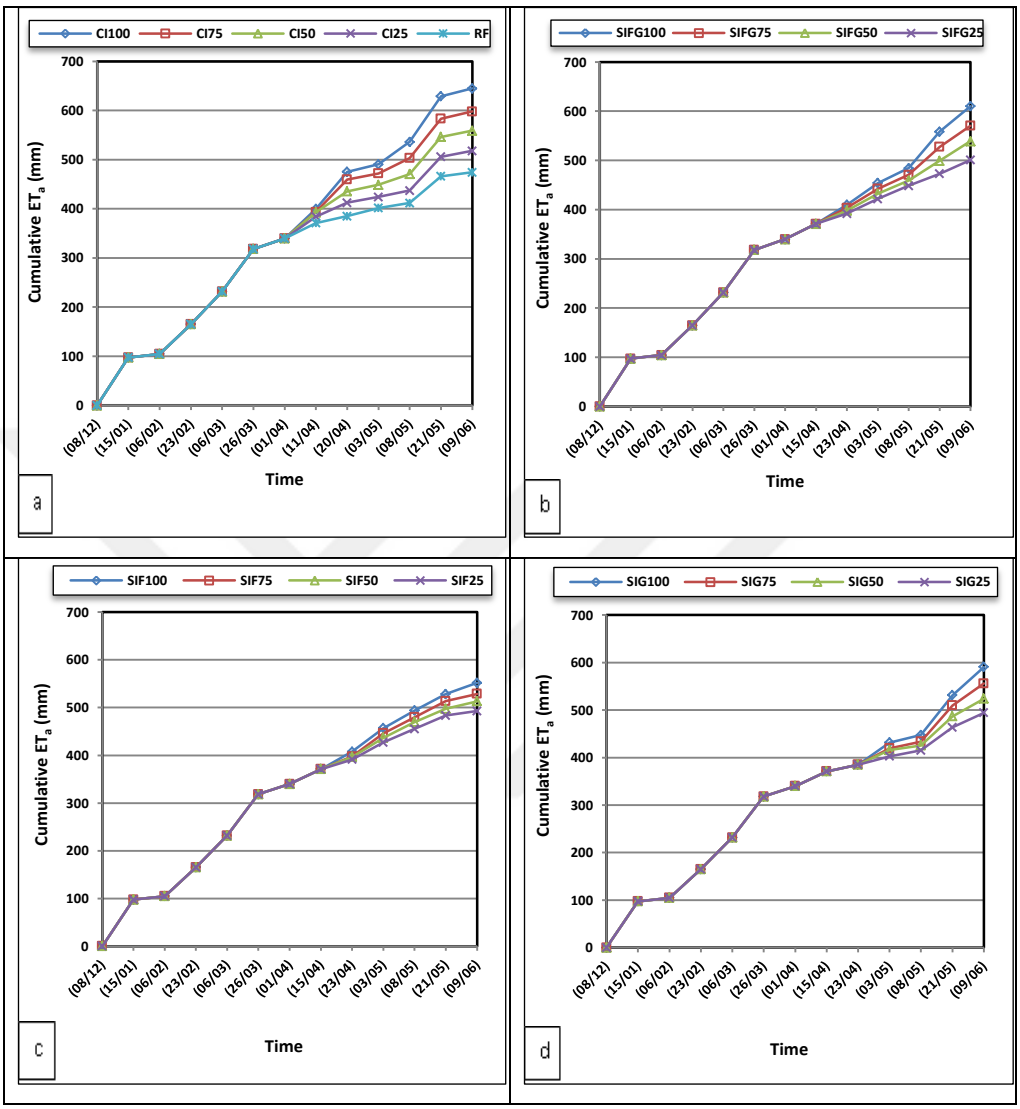

Figure 4.5. Shows accumulative (ET_a) in different irrigation level of a) CI; b) SIFG; c) SIF and d) SIG strategy during 2015 growing season

4.1.5. Water Use Efficiency (WUE) and Irrigation Water Use Efficiency (IWUE)

Water use efficiency is one the most important factor for improving the irrigation management and increase the yield production. In case of seasons, in 2014 the highest WUE (1.26 kg /m^3) was observed in deficit conventional

irrigation treatment CI_{75} and minimum was obtained in deficit supplemental irrigation treatment SIF_{25} as 0.75 kg/m^3. A similar results were obtained in the next year that the maximum grain yield per evapotranspiration unit (WUE) was recorded in CI_{75} with slight increase compared to first year amounted 1.35 kg/m^3 and the deficit supplemental irrigation SIF_{25} decreased the WUE until its minimum with reducing 14.0% compared with CI_{75} treatment. The increase of this treatment (CI_{75}) with highest WUE instead of CI_{100} because of the decreasing yield relatively under CI_{75} treatment compared to CI_{100} which uses higher water consumption. in related to irrigation scheduling effect and wheat growth stages on WUE that water applied once more in tillering stage increased significantly WUE by 14.1% over than when the irrigation applied at both stages flowering and grain filling stages in the first cropping year, and that significant enhancement in second season reached to 3.1% for applying deficit water in heading, flowering and grain filling stages over than irrigation in flowering stage, the findings are in confirming with Mandal et al. (2005) who stated the WUE values were higher when irrigation is applied in the critical stages of plant development. The findings of the current study showed that all supplemental irrigation treatments of 25 and 50% regimes were insignificant in the second experimental trail, however under the same irrigation regimes in the first season it was observed non-significant decrease just in CI and SIFG irrigation strategy in WUE of grain yield. Relative to supplemental irrigation strategies, the interaction of deficit and supplemental irrigation treatment $SIFG_{75}$ accomplished the highest value of WUE that prevailed significantly on the lowest value SIF_{25} by 42.6% and 12.9% in the years of 2014 and 2015 respectively. The highest values in the second year improved the water use efficiency of grain yield by 22.4, 7.1, 21.9 and 27.0% over than first year which correspond to SIFG, CI, SIF and SIG strategy respectively that owing to occurring an increase in ratio of wheat yield to the crop water use in the second season coupled with first season.

IWUE variations of the treatments were larger in values than WUE depended on the relative relationship between grain yield and applied water

amount (Table 2). That could be attributed to water used from soil storage, the values varied from a minimum of 0.33 kg/m^3 in SIF_{25} to a maximum of 1.46 kg/m^3 in $SIFG_{25}$ treatment in year study of 2014. This range between the highest and lowest value was larger in the next year where the minimum (0.2 kg/m^3) and maximum (1.95 kg/m^3) were observed in SIF_{25} and SIF_{75} respectively, the reasons of decreased IWUE until 0.20 kg/m^3 are: the first, declining the applied irrigation water under this treatment (SIF_{25}) to 18.2 mm, the second, production quantity (5745 kg/ha) was close to grain yield of rain-fed treatment which produced 5723 kg/ha.

The significant range of IWUE was relatively small compared to WUE, where it was not significant effect between supplemental irrigation treatments of SIG strategy (except level 25%) in the first year, whereas in the second year, the supplemental irrigation strategies recorded insignificant decreases in the lower irrigation regimes 50 and 25% (except SIF_{25} treatment).

The analysis of results in the first year revealed that the treatment receiving one irrigation in flowering stage (SIF) elevated IWUE by 12.2 and 25.0% against decreases in yield by 15.7 and 11.3% as compared by SIFG and SIG strategy respectively, however in wet year the IWUE increased by 28.5 and 35.3% and yield loss amounted 10.8 and 7.1% which correspond to the SIFG and SIG strategy respectively. Under supplemental irrigation strategy during flowering and grain filling of cropping season 2014 the low irrigation levels (25 and 50%) achieved relatively higher IWUI values (1.46 and 1.19 kg/m^3) compared to high irrigation levels (75 and 100%) amounted (1.04 and 0.98 kg/m^3), the same effect was observed in the second trail year of conventional strategy that the highest IWUE was obtained from the severe stress treatment (level 25%) with average 1.72 kg/m^3 and the lowest value was under full irrigated treatment recorded 1.35 kg/m^3, the results agree with (Yazar et al., 2009) found IWUE values related to deficit irrigation were higher than those of full irrigation and IWUE increased with decreasing irrigation amount and or water use. The opposite results were noticed in

the second year where the high irrigation levels (75 and 100%) recorded higher IWUE than lower irrigation levels (25 and 50%) under supplemental irrigation strategies, those results are in contrast to the finding of Rao et al. (2012); Yazar et al. (2009). On the other hand, those findings are in agreement with the conclusion of Farre and Faci (2006) who stated that water use efficiency decreased with decreasing irrigation. In reference to data of both years the IWUE of first year decreased by 22.1, 17.6 and 28.1% lower than second year which correspond to SIG, SIFG and SIF strategy respectively, the observed increase in the second year ascribed to increasing the harvested grain yield and reducing the applied irrigation quantity.

In general, the deficit irrigation level 75% for all supplemental irrigation strategies (SIF_{75}, SIG_{75} and $SIFG_{75}$) raised the water use efficiency and irrigation water use efficiency to the greatest values (except IWUE of SIFG treatment in the first year) compared to other levels (25, 50 and 100%) in both years of 2014 and 2015, therefore the deficit irrigation level 75% can be considered as the appropriate schedule of irrigation instead of full irrigation under each strategy for maximizing WUE and IWUE which lead to saving more water and achieving the better economic wheat grain yield under supplemental irrigation conditions in regions which facing water scarcity. These results similarity with some studies (Li et al., 2001b; Zhang et al., 1998) suggest that limited supplemental irrigation during the growth season can significantly increase WUE and wheat yield.

Table 4.2. The effect of interaction between the irrigation strategies and irrigation levels on WUE and IWUE in 2014 and 2015 growing seasons

Treatment	2014		2015	
	WUE	IWUE	WUE	IWUE
$SIFG_{100}$	1.06^{cd*}	0.98^{fg}	1.25^{def}	1.19^{f}
$SIFG_{75}$	1.07^{c}	1.04^{f}	1.31^{b}	1.44^{cde}
$SIFG_{50}$	1.03^{cdef}	1.19^{de}	1.18^{hi}	0.79^{g}
$SIFG_{25}$	1.01^{def}	1.46^{a}	1.19^{hi}	0.68^{g}
CI_{100}	1.21^{b}	1.22^{cde}	1.28^{bcde}	1.35^{def}
CI_{75}	1.26^{a}	1.38^{ab}	1.35^{a}	1.68^{bc}
CI_{50}	1.02^{def}	1.08^{ef}	1.29^{bc}	1.63^{bc}
CI_{25}	1.04^{cde}	1.36^{abc}	126^{def}	1.72^{b}
SIF_{100}	0.96^{gh}	1.10^{def}	1.24^{fg}	1.53^{bcd}
SIF_{75}	1.05^{cd}	1.42^{a}	1.28^{bcd}	1.95^{a}
SIF_{50}	0.94^{h}	1.24^{bcd}	1.16^{i}	0.72^{g}
SIF_{25}	0.75^{k}	0.33^{i}	1.16^{i}	0.20^{h}
SIG_{100}	0.99^{fgh}	0.88^{g}	1.24^{ef}	1.13^{f}
SIG_{75}	1.00^{efg}	0.97^{gf}	1.27^{cdef}	1.24^{ef}
SIG_{50}	0.99^{fgh}	0.98^{gf}	1.18^{hi}	0.63^{g}
SIG_{25}	0.89^{i}	0.75^{h}	1.19^{hi}	0.55^{g}
RF	0.84^{j}	.	1.20^{gh}	.

*The similar letters – treatments have no significant differences

4.1.6. Yield Response Factor K_y

The objective of this parameter was to determine the effect of conventional and supplemental irrigation on wheat crop response factor under Mediterranean conditions. The impact of water stress on yield is quantified by relationship between relative yield decrease $[1-(Y_a/Y_m)]$ and relative evapotranspiration deficit $[1-(ET_a/ET_m)]$ which was shown in Figures 6 and 7. The relation was linear and the results in the first experimental season showed that the supplemental and deficit irrigation occurred just once during the season at flowering stage elevated wheat response factor to its maximum value that surpassed by 5.5, 18.0 and 11.1% over than other irrigation strategies SIG, CI and SIFG respectively. However the results in wet season were close to each other with slight differences between strategies where K_y values ranged between 1.05 for conventional strategy and 1.18 under SIG strategy, whereas K_y for SIF and SIFG strategies were 1.14 and 1.12. The calculated crop response factor appeared lower in the wet season when compared

to dry season with decrease recorded 25.3, 25, 32.9 and 26.2% for irrigation strategies of SIFG, CI, SIF and SIG respectively, that refers to the high relative increase of yield losses [1-(Y_a/Y_m)] than water deficit [1-(ET_a/ET_m)] in first cropping season, therefore the results of crop response factor seems logical under extreme drought conditions for season was one of the most driest year in Turkey with decrease in rainfall by 49.1% lower than long-term average in Cukurova region. The previous results indicated that the K_y values of wheat were strongly influenced by deficit irrigation and wheat growth stages, so the response of water stress to wheat grain yield in both years of study 2014 and 2015 was the smallest in conventional irrigation strategy (K_y=1.4 and 1.05) and was the greatest in the supplemental irrigation during flowering stage (K_y=1.7 and 1.14) with greatest yield loss than the crop with lowest K_y value (Moutonnet, 2000).

Application of supplemental irrigation at two growth stages (flowering and grain filling stages) caused decrease in crop response factor to 4.9 and 5.0% lower than supplemental irrigation strategy in one stage (grain filling) during the first and second experimental years. The yield response factor K_y value varied depending on water stress and growth stage where the minimum value was obtained under conventional strategy and maximum value under supplemental irrigation during flowering. These results confirmed the wheat was not equally sensitive to water stress during growth stages, where the crop with higher K_y (SIF strategy) suffered a greater yield loss than the other strategies. Hence, according to present study supplemental irrigation during grain filing or during both flowering and grain filling more sensitive and effective to increase the yield in comparison with irrigation under SIF strategy.

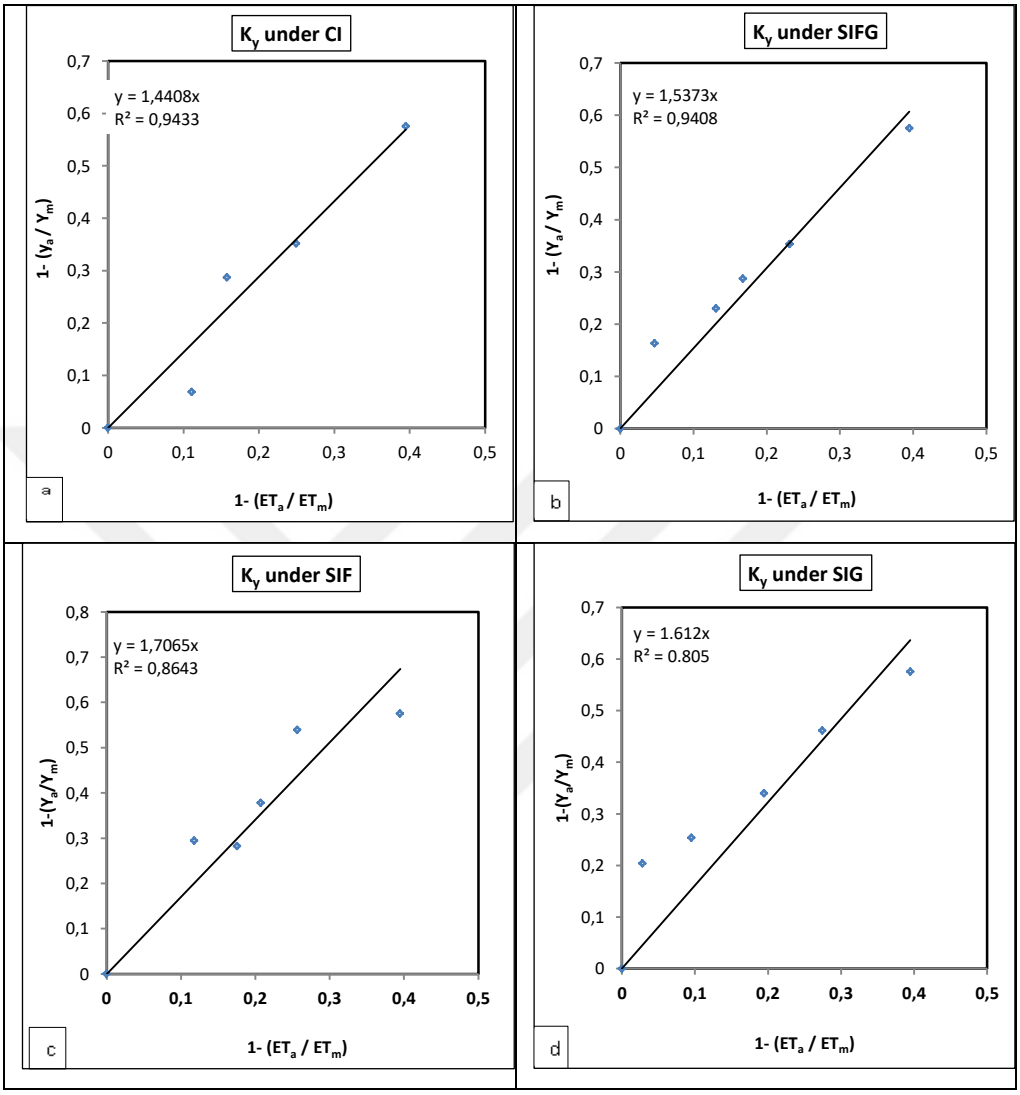

Figure 4.6. Relationship between relative yield deficit and relative evapotranspiration deficit for wheat under each irrigation strategy in 2014 season

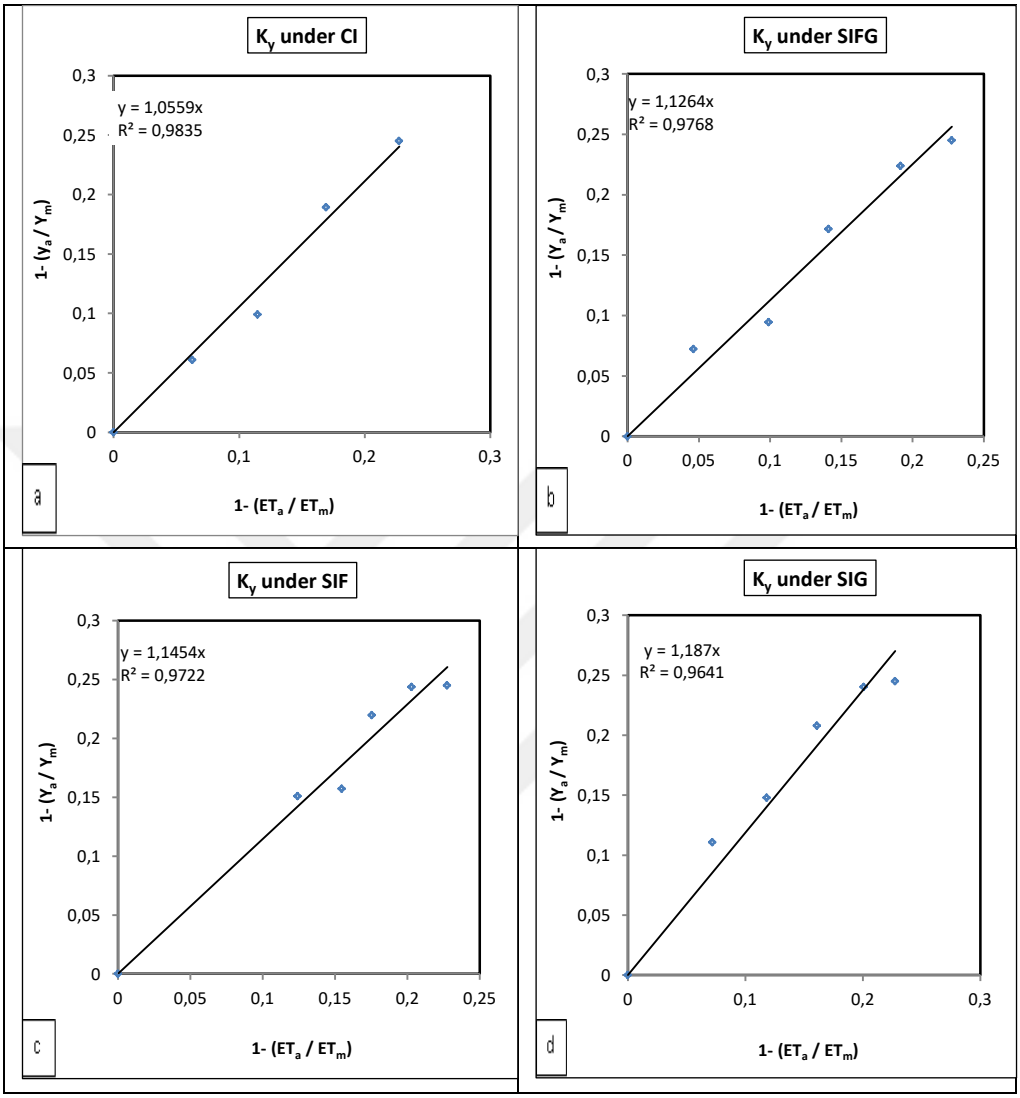

Figure 4.7. Relationship between relative yield deficit and relative evapotranspiration deficit for wheat under each irrigation strategy in 2015 growing season

4.2. Crop Characteristics

4.2.1. Crop Growth Stages

The present study was carried out to determine relation between growth and physiological parameters during growth stages and yield response when water stress was applied at flowering and grain filling stage. The water stressed

conditions (drought) negatively affects plant growth and development and causes a sharp decrease of plant productivity (Pan et al., 2002). Wheat growth stages were determined according to Zadoks growth scale using evaluation until appearance 50% for each stage (Zadoks et al., 1974). This evaluation was carried out continuously three times weekly by observing the growth stage precisely in the beginning, middle and end for full irrigation treatments during 2014 and 2015 seasons as presented in Table 3.

Table 4.3. Wheat development stages under full irrigation strategies

Growth stages	Dates of first season	DAP	Dates of second season	DAP
Sowing	22/11/2013	-	08/12/2014	-
Emergence	02/12/2013	11	19/12/2014	12
Tillering	24/01/2014	64	13/02/2015	68
Heading	19/03/2014	118	06/04/2015	120
Flowering	01/04/2014	131	16/04/2015	130
Grain milk maturity	16/04/2014	146	02/05/2015	146
Dough maturity	05/05/2014	165	23/05/2015	167
Physiological maturity	16/05/2014	176	04/06/2015	179
Harvest	22/05/2014	182	09/06/2015	184

4.2.2. Growth Parameters

4.2.2.1. Biomass Yield during the Growth Stages of Season

Biomass yield was reduced statistically by water deficit in most studied growth stages of wheat. The obtained results pertaining to 2014 season showed that until heading stage (119 DAP) in conventional irrigation strategy there was no significant effect between irrigation treatments CI_{75} and CI_{50} however the conventional treatments of $CI_{100,\ 75}$ overtopped significantly on the CI_{25} and RF treatments (Figures 8 and 9). In the second cropping year, the biomass data started collecting at 130 DAP, the obtained data were different with first season where the values of conventional irrigation treatments exhibited without any significant effect in biomass production that occurred due to proportion of SWC for all 4 treatments

of CI were close to each other until booting growth stage (111 DAP), however it noticed slight differences between CI_{100} and CI_{25} reached to 9.4%.

On 148 DAP in grain milky stage of cropping season 2014 the biomass yield values increased steadily where these values appeared convergent between symmetric irrigation levels of supplementary irrigation SIF and SIFG with range amounted 12.68 - 9.42 ton/ha in SIFG irrigation strategy and 12.76 - 9.79 ton/ha in SIF irrigation strategy for irrigation levels 100 - 25% respectively. In this respect, this range relatively revealed low for SIG irrigation strategy which varied 10.97 to 8.34 ton/ha. The findings of next year in grain milky stage (144 DAP) showed that the biomass range of supplemental irrigation strategies revealed smaller but with higher values compared with first season where the full supplemental irrigation of SIF and SIFG statistically increased biomass production significantly by 1.27 and 1.55 ton/ha compared to the same treatments under 25% irrigation level. In particular, supplemental irrigation in grain filling stage presented poor growth values coupled with other SI strategies. SIG_{25} achieved significant decrease 11.1% lower than SIG_{100} treatment. The relative increase of biomass yield values of SIF and SIFG irrigation strategies refer to irrigate early (130 DAP in both years) for these strategies compared to supplementary irrigation SIG.

As indicated in biomass yield data, it showed no significant between all irrigation strategies of 25% irrigation level (except CI_{25} at harvesting in the first year) also there was not any significance differences between the previous treatments and control treatment RF (except CI_{25} on 152 DAP in the second year and at harvesting in the first year) that return to the applied irrigation quantity of 25% level and rain-fed were relatively small and insufficient for raising the biomass yield higher in comparison with high irrigation levels.

At drought maturity (160 and 164 DAP in the first and second season) the biomass yield reached its maximum values where the highest value obtained in CI_{100} with average 20.74 and 22.11 ton/ha of 2014 and 2015 cropping seasons that dominated significantly on all studied irrigation treatments (except $SIFG_{100}$ and

CI_{75} treatments in both years). Additionally, in the first experimental year the irrigation strategy SIG exhibited (under its 4 irrigation levels) higher with slight increase compared to flowering irrigation strategy that happened due to the effect of the second supplemental irrigation of grain filling irrigation strategy. In case of second season, the low deficit irrigation levels (75 and 100%) of SIG strategy prevailed significantly by 7.9 and 8.0% over the same irrigation levels of SIF strategy, and the irrigated traits with 25 and 50% exhibited insignificant effect for previously given strategies.

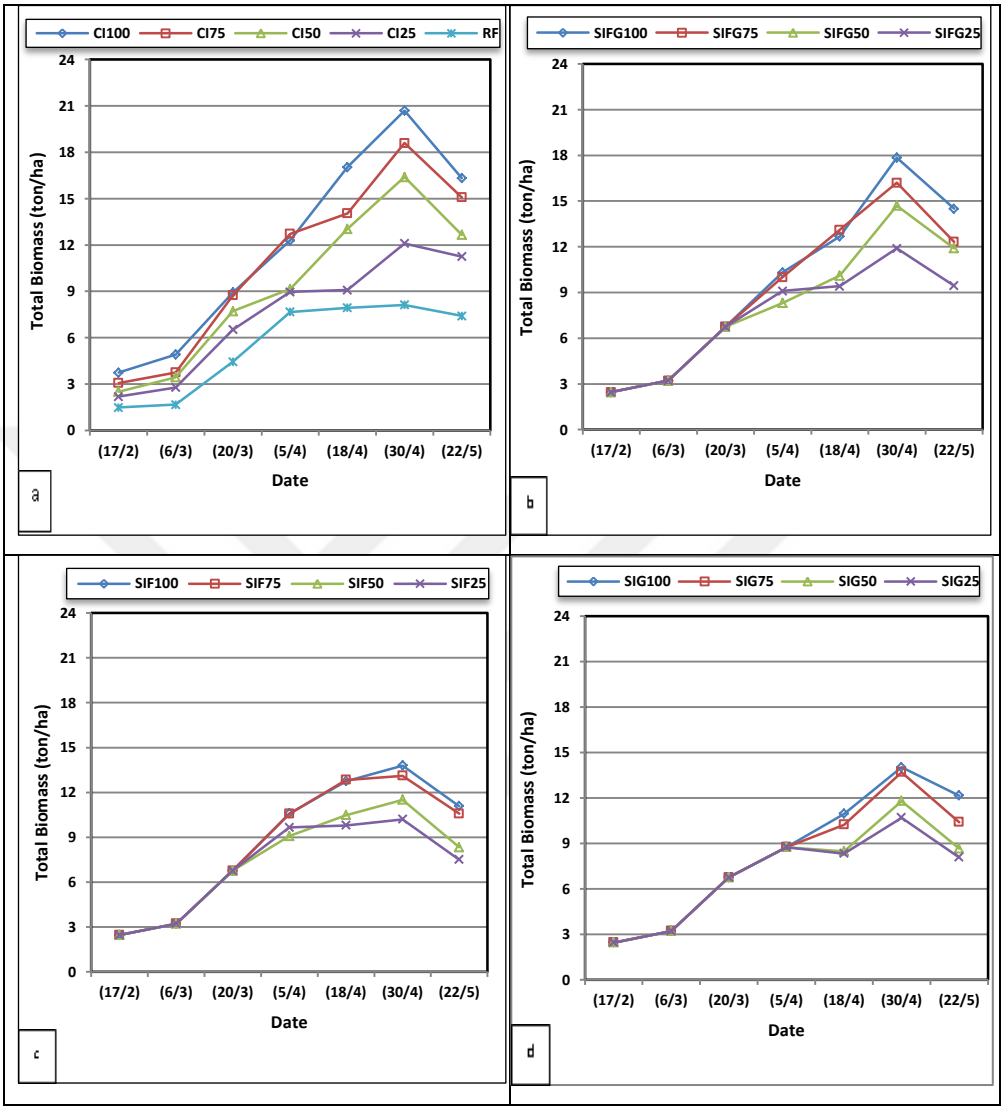

Figure 4.8. The relation between irrigation strategies under different irrigation levels and total biomass dry matter during the 2014 season

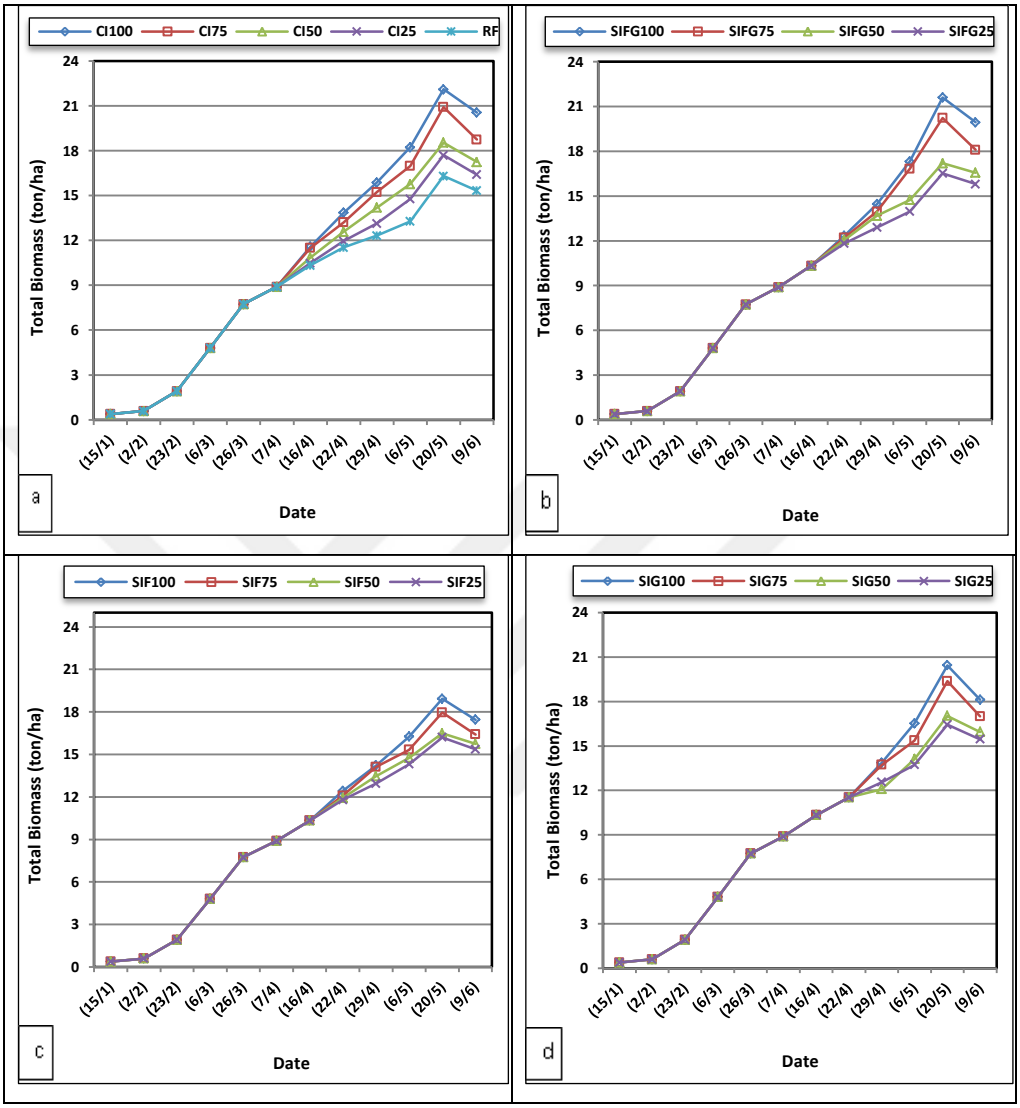

Figure 4.9. The relation between irrigation strategies under different irrigation levels and total biomass dry matter during the 2015 season

4.2.2.2. Leaf Area Index

Leaf area index one of the best component in evaluation the photosynthetic efficiency of winter wheat is LAI. The development of leaf area index under different strategies with growth stages was presented in Figures 10 and 11 and discussed as following: before anthesis (until 119 DAP) in the first year, it was

noted positive effect of conventional irrigation on LAI where the treatments CI_{100} and CI_{75} overtopped significantly with values 5.06 and 4.97 on the low irrigation level CI_{25} and rain-fed (control) with values of 3.07 and 1.71, but at anthesis stage leaf-green surface area became higher and it reached to its peak in the season where LAI values varied from 5.48 in full conventional irrigation to 2.78 in rain-fed treatment with high significant effect, furthermore it was noticed slight differences and no significant between irrigation levels 100, 75 and 50% for supplemental irrigation strategies of SIF and SIFG.

The results in regard to 2015 growing season, the deficit irrigation applied at heading stage (116 DAP) elevated LAI on 130 DAP significantly for CI_{100} and CI_{75} treatments with average 4.68 and 4.53 over the CI_{25} and RF which had 3.35 and 3.11, respectively. Development LAI continued to increase up to the highest values at the end of flowering stage (143 DAP) and the maximum increase of grain yield also was obtained under the same treatments which achieved maximum increase of LAI (positive relation between LAI and grain yield) where the severe drought stress treatment (rain-fed) led to obvious decrease in LAI by 39.4% and grain yield 30.6% lower the full conventional irrigation. The reason for increase of CI_{100} could be referred to the ability of irrigation to provide an optimal condition for absorbing water in the active root zone area of plants and causes more surface area for receiving sunlight, consequently raising photosynthesis rate and subsequent LAI. In case of full supplemental irrigation treatments, it was noted slight differences (insignificant) between those treatments SIFG, CI and SIF with averages were 6.16, 6.69 and 6.02 respectively.

For the response of LAI to interaction of conventional and supplemental irrigation treatments in the first season at anthesis, high irrigation levels (100 and 75%) of conventional and SIF irrigation strategies produced higher LAI and surpassed significantly over the CI_{25} by 43.0 and 35.7% in conventional irrigation, 53.6 and 41.8% in SIF_{25} strategy, respectively. In post-anthesis stage, LAI started to decline gradually towards the end of the season for all treatments during both

growing seasons. In the second week after anthesis in 2014 cropping season that no significant differences were observed between full conventional strategy (3.81) and full supplemental strategy $SIFG_{100}$ (3.18) in LAI, however these treatments dominated significantly on full supplemental strategy SIF_{100} (2.33), and the lowest significant differences were under water stressed treatments $SIFG_{25}$, SIF_{25}, SIG_{25}, and RF which amounted 1.69, 1.53, 1.68 and 1.60 respectively. Data obtained after anthesis at milky grain stage (150 DAP) in 2015 showed that the full supplemental irrigation $SIFG_{100}$ decreased LAI by 24.8% as compared with full conventional irrigation due to yellowness and shrinking the leaves more, consequently reducing the green surface area of SIFG treatments. In particular, the obtained LAI value of SIG_{100} at milky grain stage (150 DAP) remained constant (4.06) comparison with RF at anthesis stage (143 DAP) which produced 4.05, that ascribed to applying irrigation early on 138 DAP under SIG strategy. On the other hand, the LAI influenced noticeably by water quantity that the deficit irrigation level 50% decreased lower than full irrigation level by 21.2, 29.5, 43.1 and 29.8% in SIFG, SIF, SIG and conventional strategies, respectively, similar results were obtained by (Rajala et al., 2009; Trethowan et al., 2002). Soil stress and high temperature together caused leaves to senesce by the third week after anthesis (30/04/2014 and 20/05/2015) where in the first season the LAI values were smaller that ranged from 1.7 to 0.95 for $SIFG_{100\text{-}50}$ and between 0.94 to 0.64 under $SIG_{100\text{-}50}$ treatments, whilst in the second year the highest range was achieved for $CI_{100\text{-}50}$ with average varied from 2.03 to 0.94 and recorded the minimum range 0.76-0.72 for $SIF_{100\text{-}75}$ treatments.

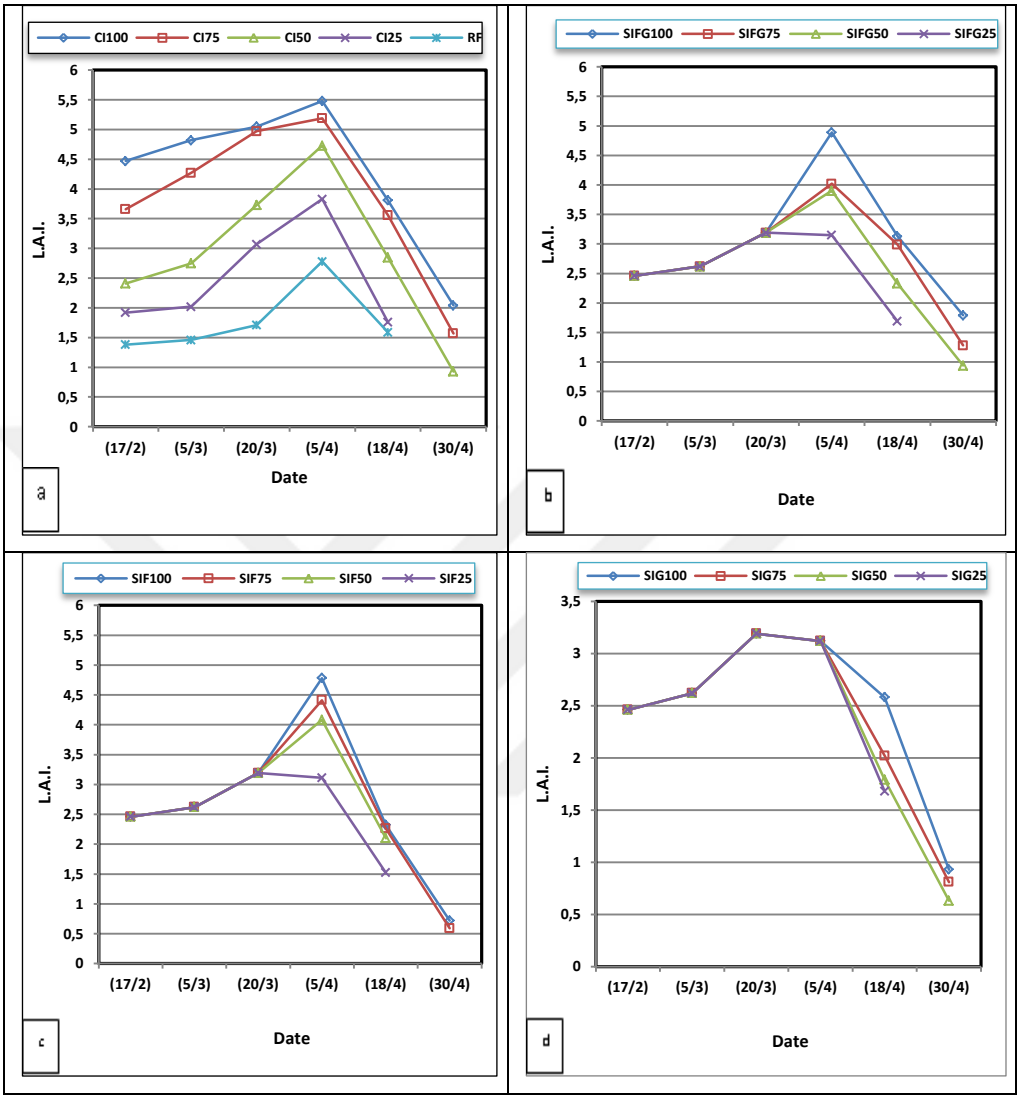

Figure 4.10. The relation between conventional, supplemental irrigation strategies under different irrigation levels on Leaf Area Index (LAI) during the 2014 season

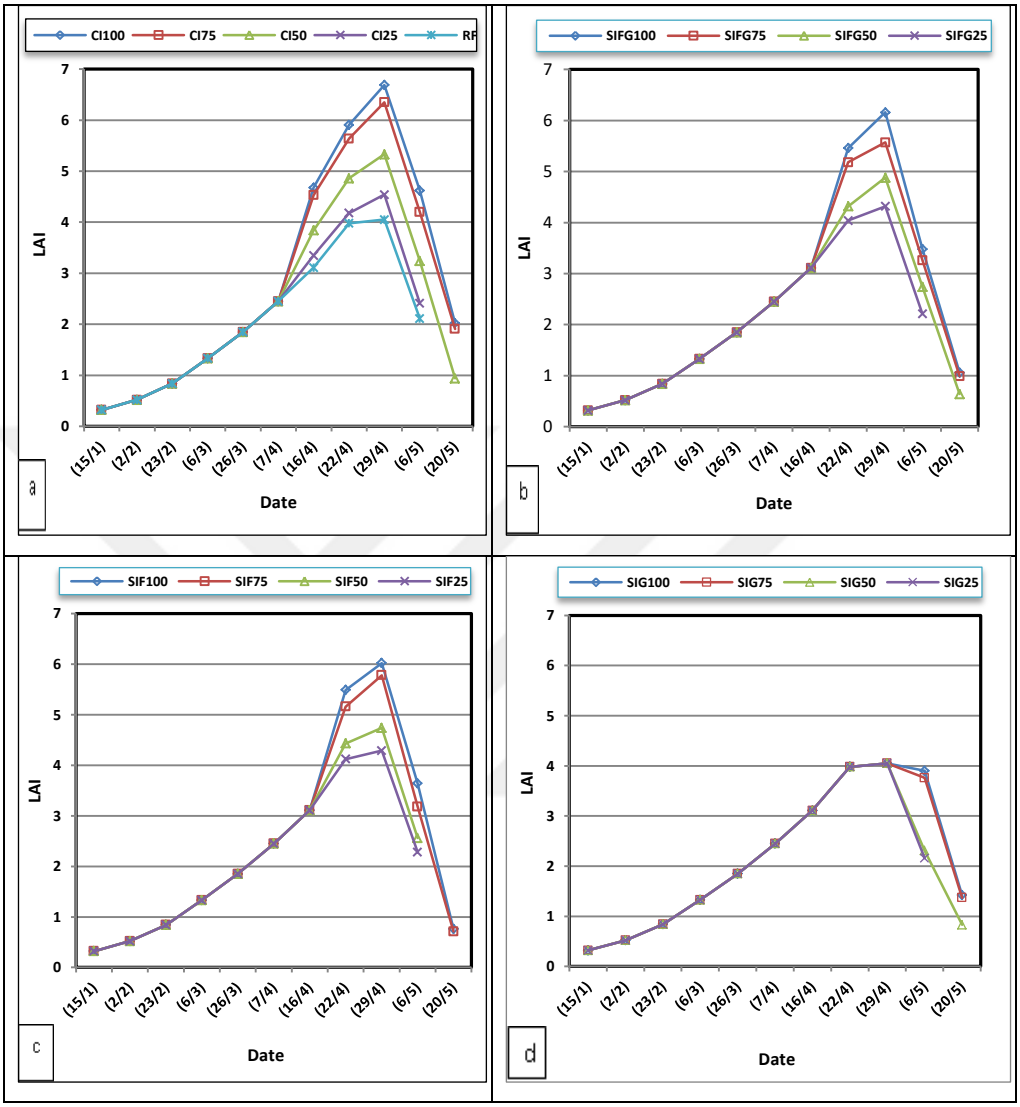

Figure 4.11. The relation between conventional, supplemental irrigation strategies under different irrigation levels on Leaf Area Index (LAI) during the 2015 season

4.2.3. Grain and Biomass Yield

4.2.3.1. Grain Yield

In reference to the statistical analysis in Table 4, it noted significant effects between interactions of irrigation levels and irrigation strategies on grain yield production and the grain yield reflected strongly high sensitivity to water stress

conditions where full conventional irrigation treatment achieved the highest grain yield 5868 and 8258 kg/ha during both dry and wet growing seasons, similar results were reported by Sezen and Yazar (2006) in the Mediterranean region. It was observed CI_{100} dominated significantly on all treatments in an experiment in the first season and second year (except CI_{75} treatment of 2015), this results demonstrate that applying the optimum crop water requirements improve the plant growth rate and photosynthesis processes consequently producing more grain yield.

Data regarding irrigation scheduling of growth stages, it noticed stopping irrigation during grain filling stage (SIF strategy) decreased the wheat yield to 29 and 17% in dry and wet experimental year in comparison with conventional irrigation strategy, however stopping water applied in flowering stage (SIG strategy) decreased yield to 20 and 10% compared to conventional irrigation, and it was observed irrigation in grain filling stage increased grain yield by 12 and 7% compared to irrigation at flowering stage during the first and second seasons, respectively.

As for water regimes, $SIFG_{100}$ and SIF_{100} resulted in water saving about 10.7 and 45.9%, in the first year and this percentage reached 13.0 and 61.2% in the second year respectively, in comparison with CI_{100}. Rain-fed treatment (control) resulted in decreased yields rated 49.2, 39.8 and 46.6% as compared to full supplemental irrigation treatments ($SIFG_{100}$, SIF_{100} and SIG_{100}) respectively, in the dry season, whereas these values decreased to 25.4, 16.3 and 22.3% respectively in the wet season due to the relative increase of soil moisture in the field in the beginning of season.

In related to moderate irrigation levels, results showed that deficit irrigation (CI_{75}) overtopped significantly on all treatments of supplemental irrigation on the same level with average 5466 and 8096.7 kg/ha in the 2014 and 2015 growing seasons respectively. As a result of the present study, it showed no significant decreases between CI_{50}, $SIFG_{50}$, SIF_{75} and SIF_{100} in the first season. In case of

second season, it was observed also insignificant effect between all interactions of 100 and 75% irrigation regimes under the same strategy of CI, SIF and SIFG.

The increase of grain yield with conventional irrigation strategies due to providing water with optimal requirements of wheat in season, whereas the relative reduction of yield under supplemental irrigation strategies (SIF and SIG) compared to conventional irrigation strategy can be explained by the occurrence water stress during flowering and grain filling stages which crop sensitivity to water stress increases. These results are in agreement with Tari (2016) who concluded that water deficit should be applied during the milk grain stage to minimize yield losses of wheat. Our results also confirm the findings of Rao et al. (2012), who reported that treatments under the higher deficit irrigation reduced grain yield markedly comparison with well-watered treatments.

4.2.3.2. Biomass Yield at Harvesting

Biomass production (kg/ha) of winter wheat is the total biomass including stems, leaves and spikes (without grains), this yield influenced significantly by deficit and supplemental irrigation during the both years study. The greatest above-ground dry matter yield at harvesting was produced with full conventional irrigation, followed by conventional deficit irrigation (CI_{75}) and then full supplemental irrigation $SIFG_{100}$ (except $SIFG_{100}$ in the second year which was greater than CI_{75}) with no significant effect between CI_{100} and CI_{75} in the first year and between full treatments of CI and SIFG strategies in the second year that recorded decrease in biomass yield in CI_{75} treatment about 7.6 and 8.7% and the corresponding decrease in $SIFG_{100}$ amounted to 11.2 and 2.8% in comparison with full conventional irrigation in the first and the second experimental year, respectively (Table 4). The three mentioned treatments overtopped significantly on all rest experimental units (except $SIFG_{75}$ in the second year). As expected the lowest value was seen in rain-fed treatment (control) for each year.

In relation to full SI, the water applied at the grain filling stage increased total biomass yield by 9.7 and 3.8% as compared to irrigation at the flowering stage during the cropping season of 2014 and 2015, respectively. The biomass yield was influenced by interaction of supplemental irrigation and crop growth stage. Compared with irrigation at flowering and grain filling stages, wheat irrigated in flowering stage resulted in a significant decrease in biomass by 23.5 and 12.5% in the 2014 and 2015 respectively, whereas the corresponding decrease in biomass yield of wheat irrigated during grain filling stage became insignificant and reduced by 16.0 and 9.1% in the same experimental years. The results confirmed the findings of Zhang et al. (2006) who concluded that the biomass yield production varies based on the level and period of the water deficit.

Moreover the followed treatments ($SIG_{25,50}$, $SIFG_{25}$, $SIF_{25,50}$ and RF) were appeared with lower significant differences with average in growing season 2014 (8083, 8667, 9458, 7500, 8333 and 7417 kg/ha) respectively, however the produced biomass in the next year comparatively was higher that achieved 15450, 15950, 15800, 15367, 15742 and 15333.3 kg/ha respectively without significant effect between the mentioned treatments except $SIFG_{25}$ in the first season. Apparently, the results of study indicated that water deficit affected on biomass production for both years depending on water deficit quantity where an increase of ET from 399.9 to 528.8 mm in SIF_{75} and from 421.59 to 570.6 mm in $SIFG_{75}$ in the 2014 and 2015 cropping seasons caused increasing total biomass recorded 35.5 and 31.8% respectively, that increase in wet season refers to high rainfalls led to increase in moisture content consequently the efficiency of vegetative growth and total biomass became higher.

It was noticed that decreasing irrigation requirement from 194 mm in SIG_{75} to 142 mm in SIG_{50} in 2014 season and from 108 to 72 mm in 2015 season led to remarkable differences in biomass yield that equaled to 1750 and 1050 kg/ha, respectively. However, the corresponding differences between CI_{75} and CI_{50} of biomass production were 2416 and 1492 kg/ha during 2014 and 2015 cropping

seasons, respectively. The reason for increased biomass yield under the full conventional strategy and full supplemental strategy ($SIFG_{100}$) might be due to the capability of those treatments to maintaining the soil moisture for longer period which makes the roots spread in the larger area and further depth in soil and it is reflected in increasing of green production, these results are in general agreement with the findings of Zhang et al. (2006); Padhi et al. (2010); Tari (2016).

4.2.3.3. Harvest Index

The efficiency of wheat to transfer biomass dry matter into grain or economic yield is determined using its harvest index. Results regarding the effect of supplemental and conventional irrigation on harvest index were shown in Table 4. On the whole, the HI range in the first year seemed larger owing to increasing the grain yield range more than second year, however the HI values of 2015 year were relatively higher resulted in high increase of grain yield for all treatments coupled with 2014 year.

The results indicated that when the deficit irrigation increases, the harvest index values appears higher where in year 2015 the water stress of rain-fed treatment decreased HI to minimum significant difference with average 0.37, and the maximum effect was recorded in deficit conventional irrigation CI_{75} treatment. The results confirmed the findings of Kang et al. (2002). Related to the first year data, the harvest index ranged between 0.33 to 0.45 under (CI_{50}, RF) and SIG_{50} treatments respectively, that happened due to the relative increase in grains yield compared to biomass yield. In both years the HI of $SIFG_{100}$ treatment revealed lower significantly compared to other full supplemental irrigation treatments SIF and SIG that was mainly due to increased total biomass compared to grain yield. Regardless of significant degree, the low deficit irrigation regimes (100 and 75%) showed the best HI values (except $SIFG_{100}$) compared to irrigation regime 25 and 50% (except $SIFG_{50}$ and CI_{50} treatments) in the second year study. Moreover, except $SIFG_{100}$ treatment in the first year, it were not noted any significant

differences between all full irrigation strategies (CI, SIFG, SIF and SIG) in harvest index in both years of study. The obtained data pertaining to supplemental irrigation and its scheduling growth stages at flowering and grain filling stages, it was observed the moderate deficit irrigation levels ($SIF_{50,75}$ and $SIG_{50,75}$) were relatively higher than other treatments in HI in the 2014 growing season. Apparently, the harvest index of winter wheat achieved its maximum value under deficit irrigation (75%) for each strategy with average amounted 0.42, 0.41, 0.41 and 0.43 in SIG, SIF, SIFG and CI respectively in the 2015 cropping season, that means the appropriate irrigation and controlled soil water content can increase harvest index (Zhange et al., 1998; Sezen and Yazar, 2006; Bandyopadhyay et al., 2010). As stated above, harvest index was good an indicator of wheat crop to determine the best irrigation regime depending on the relative production of biomass and grain yield.

Table 4.4. The effect of interaction between the irrigation strategies and irrigation levels on grain, biomass yield and harvest index in 2014 and 2015 cropping seasons

Season	2014			2015		
Treatment	grain yield (kg/ha)	Biomass (kg/ha)	HI	grain yield (kg/ha)	Biomass (kg/ha)	HI
$SIFG_{100}$	4910.0^{c*}	14500^{b}	0.34^{f}	7675.0^{b}	19958^{a}	0.38^{def}
$SIFG_{75}$	4518.0^{de}	12333^{cd}	0.37^{def}	7495.8^{bc}	18108^{bc}	0.41^{abc}
$SIFG_{50}$	4182.0^{g}	11917^{cde}	0.35^{ef}	6375^{g}	16575^{def}	0.38^{def}
$SIFG_{25}$	3793.0^{hi}	9458^{gh}	0.40^{bcd}	6004.2^{hi}	15800^{ef}	0.38^{def}
CI_{100}	5868.0^{a}	16333^{a}	0.36^{def}	8258.3^{a}	20550^{a}	0.40^{bcde}
CI_{75}	5466.0^{b}	15083^{ab}	0.36^{def}	8096.7^{a}	18750^{b}	0.43^{a}
CI_{50}	4181.0^{g}	12667^{c}	0.33^{f}	7258.3^{d}	17258^{cd}	0.42^{ab}
CI_{25}	3803.0^{hi}	11250^{def}	0.34^{f}	6533.3^{g}	16400^{def}	0.39^{bcde}
SIF_{100}	4138.0^{g}	11083^{def}	0.37^{def}	6841.7^{f}	17458^{cd}	0.39^{cdef}
SIF_{75}	4211.0^{fg}	10583^{efg}	0.39^{cde}	6791.7^{f}	16417^{def}	0.41^{abc}
SIF_{50}	3649.0^{i}	8333^{hi}	0.44^{ab}	5987.5^{i}	15742^{f}	0.38^{def}
SIF_{25}	2705.0^{k}	7500^{i}	0.36^{def}	5745.0^{j}	15367^{f}	0.37^{f}
SIG_{100}	4670.0^{d}	12167^{cd}	0.38^{cde}	7366.7^{cd}	18125^{bc}	0.40^{bcde}
SIG_{75}	4380.0^{ef}	10417^{fg}	0.42^{abc}	7066.7^{e}	17000^{cde}	0.42^{ab}
SIG_{50}	3875.0^{h}	8667^{hi}	0.45^{a}	6182.5^{h}	15950^{ef}	0.38^{def}
SIG_{25}	3159.0^{j}	8083^{i}	0.39^{cde}	5923.3^{ij}	15450^{f}	0.38^{def}
RF	2491.0^{l}	7417^{i}	0.33^{f}	5723.3^{j}	15333^{f}	0.37^{f}

*The similar letters – treatments have no significant differences

4.2.4. Yield Components

In general, it was noticed high decrease in yield components and growth parameters value of flowering strategy that returns to reduce in soil moisture content during the sensitivity stage to irrigation (grain filling stage) and accordingly it occurred this decrease in yield components parameters (Table 5).

4.2.4.1. 1000 Grain-Weight

Weight of 1000 grain is one of the most effective factor on yield under irrigated and unirrigated conditions that reflects a degree of grains filling and its influence on production data. The full supplemental irrigation SIFG increased 1000 grain-weight significantly by 41.6% against an increase of 21.3% under full supplemental irrigation SIF in comparison with rain-fed treatment in a dry year, however, those increases amounted to 19.8 and 11.5% respectively during the second year. The results are in line with the findings of Pierre et al. (2008) who reported that water stress reduced yield and yield components, and the 1000 grain weight was significantly influenced by supplemental irrigation compared to rain-fed treatment.

The response of 1000 grain-weight to conventional and supplemental irrigation differed depending on deficit irrigation regime and its application period in wheat growth stage that applying irrigation more in heading, flowering and grain filling stages with moderate water deficit irrigation (CI_{75}) increased weight of 1000 grain significantly by 15.5 and 12.0% in year 2014 compared with irrigation in flowering stage and grain filling stage, respectively. However, these increases decreased in the second year with averages 15 and 6.6%, respectively. In both growing seasons of 2014 and 2015, the deficit irrigation 75% of SIFG strategy resulted in decreased 1000 grain weight but insignificantly by 6.2 and 5.4% lower than those in CI_{75} treatments.

It was found that the full supplemental irrigation ($SIFG_{100}$) and full conventional irrigation treatments dominated significantly with an average of 49.0

and 51.6 g on full supplemental irrigation (SIF_{100}) with 42.0 g in the first experimental year, however the full irrigation treatments CI_{100} and $SIFG_{100}$ increased this parameter by 11.6 and 7.3% over the SIF_{100} treatment during the second season, whereas the full supplemental irrigation (SIG_{100}) amounted to 45.2 and 49.8 g during both growing seasons of 2014 and 2015 (Table 5).

The results confirmed the effect on the 1000 grain weight production sensitivity to irrigation at the grain filling stage, which is reflected by irrigation treatments of SIG_{100} and $SIFG_{100}$ for increasing 1000 grain weight in comparison with SIF_{100} treatment. These results are in conformation with Aown et al. (2012) who stated that the 1000-grain weight and grain yield were proved to be sensitive to drought at both stages (flowering and grain filling), however drought stress at grain filling reduced these two parameters to a greater extent (38.5 and 56.5%) over well watered treatment, respectively.

In general, the significant range of dry year was larger than wet year, where in year of 2014 the water deficit regimes 100 and 75% surpassed significantly on 25 and 50% irrigation regimes for all irrigation strategies (except SIG_{50} treatment), meanwhile in the second season, the mentioned high irrigation levels prevailed on low irrigation regimes only under conventional and SIFG irrigation strategies. In the growing season of 2014 the irrigation strategies under low irrigation levels (CI_{25}, $SIFG_{25}$, $SIF_{50,25}$ and SIG_{25}) and rain-fed achieved the lowest significant difference with average (38.3, 37.1, 36.1, 34.4, 35.6 and 34.6 g) respectively in 1000 grain yield. In this respect, statistically, the significant effect was lower in the second trail year, that the treatments decreased the 1000 grain-weight until its minimum significant difference were not only for treatments located under severe water deficit conditions such as RF, SIG_{25}, $SIF_{25,50}$, $SIFG_{25}$ and CI_{25} (as year of 2014) but also included treatments with moderate water deficit as SIF_{75},SIG_{50} and $SIFG_{50}$ treatments. As a result of the present study, it was observed that a strong positive relation between yield and yield component (1000 grain-weight) increased with increasing water deficit magnitudes. Hence, the decrease in grain yield

reached 57.5 and 30.6% for rain-fed compared to full conventional irrigation resulted in the decrease in thousand grain-weight that amounted to 32.9 and 19.6% in both dry and wet season respectively, that means the capability of irrigation to raise the soil water content in the root zone and stimulate the wheat growth and photosynthesis rate reflected in increasing the grain yield production.

Table 4.5. The effect of interaction between the irrigation strategies and irrigation levels on yield components (weight of 1000 grains and number of grains/spike) in 2014 and 2015 cropping seasons

Season	2014		2015	
Treatment	1000 grain-weight	No. of grains/spike	1000 grain-weight	No. of grains/spike
$SIFG_{100}$	49.0^{ab*}	60.8^{ab}	50.8^{abc}	62.6^{ab}
$SIFG_{75}$	45.2^{bc}	54.5^{cde}	48.5^{bcd}	61.1^{ab}
$SIFG_{50}$	40.5^{def}	39.7^{h}	45.2^{efg}	52.8^{cde}
$SIFG_{25}$	37.1^{fgh}	31.1^{i}	43.3^{g}	45.2^{f}
CI_{100}	51.6^{a}	62.4^{a}	52.8^{a}	64.4^{a}
CI_{75}	48.2^{ab}	59.7^{abc}	51.3^{ab}	63.1^{a}
CI_{50}	41.4^{cde}	41.5^{gh}	47.9^{cde}	55.6^{bcd}
CI_{25}	38.3^{efgh}	31.6^{i}	44.4^{fg}	46.4^{ef}
SIF_{100}	42.0^{cde}	49.6^{ef}	47.3^{def}	61.2^{ab}
SIF_{75}	41.7^{cde}	45.7^{fg}	44.6^{fg}	58.7^{abc}
SIF_{50}	36.1^{gh}	34.1^{i}	43.1^{g}	48.3^{ef}
SIF_{25}	34.4^{h}	32.4^{i}	42.7^{g}	44.8^{f}
SIG_{100}	45.2^{bc}	55.6^{bcd}	49.8^{abcd}	62.1^{ab}
SIG_{75}	43.0^{cd}	52.9^{de}	48.1^{cde}	60.4^{ab}
SIG_{50}	39.4^{defg}	39.9^{h}	44.9^{efg}	51.1^{def}
SIG_{25}	35.6^{gh}	28.6^{i}	43.0^{g}	45.1^{f}
RF	34.6^{h}	28.4^{i}	42.4^{g}	44.6^{f}

*The similar letters – treatments have no significant differences

4.2.4.2. Number of Grains/Spike

It is noticed that the increasing of irrigation water to the optimal value led to increasing in no grains/spike as that data was steady with 1000 grain weight. The supplemental irrigation levels 75 and 100% in flowering stage of year 2014 overtopped significantly with 45.7 and 49.6 on low irrigation levels 25 and 50% amounted 32.4 and 34.1. In year of 2015, the findings also statistically were

significant for irrigation treatments SIF_{100} and SIF_{75} with average (61.19 and 58.7) over the low irrigation regime of 50 and 25% which achieved 48.3 and 44.8. The full supplemental irrigation $SIFG_{100}$ dominated significantly with average 60.8 on the other levels 25, 50 and 75% with values 31.1, 39.7 and 54.5 in the first trail year, meanwhile in the second season it was no significant effect between interactions of $SIFG_{100}$ and $SIFG_{75}$ but the full supplemental irrigation led to significant increase with value 62.6 over the other irrigation regimes of 50 and 25% which amounted 52.8 and 45.2 in number of grains per spike whereas the rain-fed treatment gave the least significant difference value 28.4 and 44.6 in the 2014 and 2015 growing seasons in no grains/spike.

The effect of drought in grain filling stage of SIF_{100} treatment decreased significantly the grains number per spike to 20.5 and 18.4% in comparison with full conventional irrigation and full irrigation of SIFG respectively, whereas occurring drought at flowering stage of SIG_{100} reduced it to 10.8% compared to CI_{100} in the first experimental year. During 2015 growing season the values of full irrigation treatments revealed statistically with insignificant difference where the SIF_{100} decreased the number of grains per spike to 2.2, 5.0 and 1.5% in comparison with other full irrigation strategy SIFG, CI and SIG respectively.

The yield component of grains number per spike influenced by irrigation strategy and irrigation regime, the results indicated that the highest range of grains number per spike under conventional strategy graded from 62.4 to 31.6 and from 64.4 to 46.4 followed by SIFG irrigation strategy which varied from 60.8 to 31.1 and from 62.6 to 45.2 during crop season of 2014 and 2015 respectively. in short, the range of grains number per spike between the highest value (CI_{100}) and lowest value (RF) decreased from 54.4 to 30.7% correspond to dry and wet seasons respectively where it observed slight difference between the maximum values of CI in both years recorded 3.1% whereas the difference for minimum values of rain-fed treatments during 2014 and 2015 seasons were markedly higher (36.3) that resulted in reducing the rainfall from 418.8 to 250.6 mm in the wet and dry growing

seasons, these results are in line with finding of (Ashraf, 1998; Villegas et al., 2001; Bukhat, 2005), who reported that increase in grain yield ton/ha was result of the increase in yield components as 1000 grain-weight and number of grains per spike. The results of study indicated that an increase of moderate water deficit from 50 to 75% led to obvious significant enhancement in grains number/spike by 25.3% in year of 2014 and by 17.7% in the next year correspond to supplemental irrigation treatments at flowering stage, against an increase of 13.43% in grain yield in the first season and 11.8% in the second growing season.

4.2.5. The Relationships between Grain Yield, Biomass, 1000 Grain-Weight and Leaf Area Index

The highest determination coefficients between biomass and grain yield were R^2 = 0.93 and 0.83 and thousand grain yield 0.80 and 0.77 in conventional strategy during the first and second year, respectively. The lowest R^2 values corresponded to the lowest applied water irrigation (SIF strategy) which recorded R^2 as 0.75 and 0.70 for biomass and were 0.53 and 0.28 for 1000 grain weight in growing season of 2014 and 2015, respectively (Figure 12). The slope of biomass relation ranged between 0.44 (CI strategy in 2015) and 0.21 (SIFG strategy in 2014) whereas the range varied from 0.19 (CI strategy) to 0.10 (SIF strategy) for 1000 grain-weight in 2015. The biomass and 1000 grain-weight correlated positively and significantly (at the 0.01 probability level) with grain yield, the linear relationship reflects the effect of yield components (biomass and 1000 grain-weight) on developing high wheat grain yield under Mediterranean conditions. Similar results were reported by Tari (2016) who found positive linear relationship between biomass and wheat grain yield (R^2=0.90 and 0.91) with slope (0.46 and 0.49) in the first and second growing seasons. Ahmadizadeh et al. (2011) reported that wheat grain yield showed positive and significant correlation with 1000 grain weight under normal and stress conditions, these results also are in agreement with

other studies by Huang et al. (2005); Zhang et al. (2006) who stated increasing grain yield was noted with increasing biomass yield.

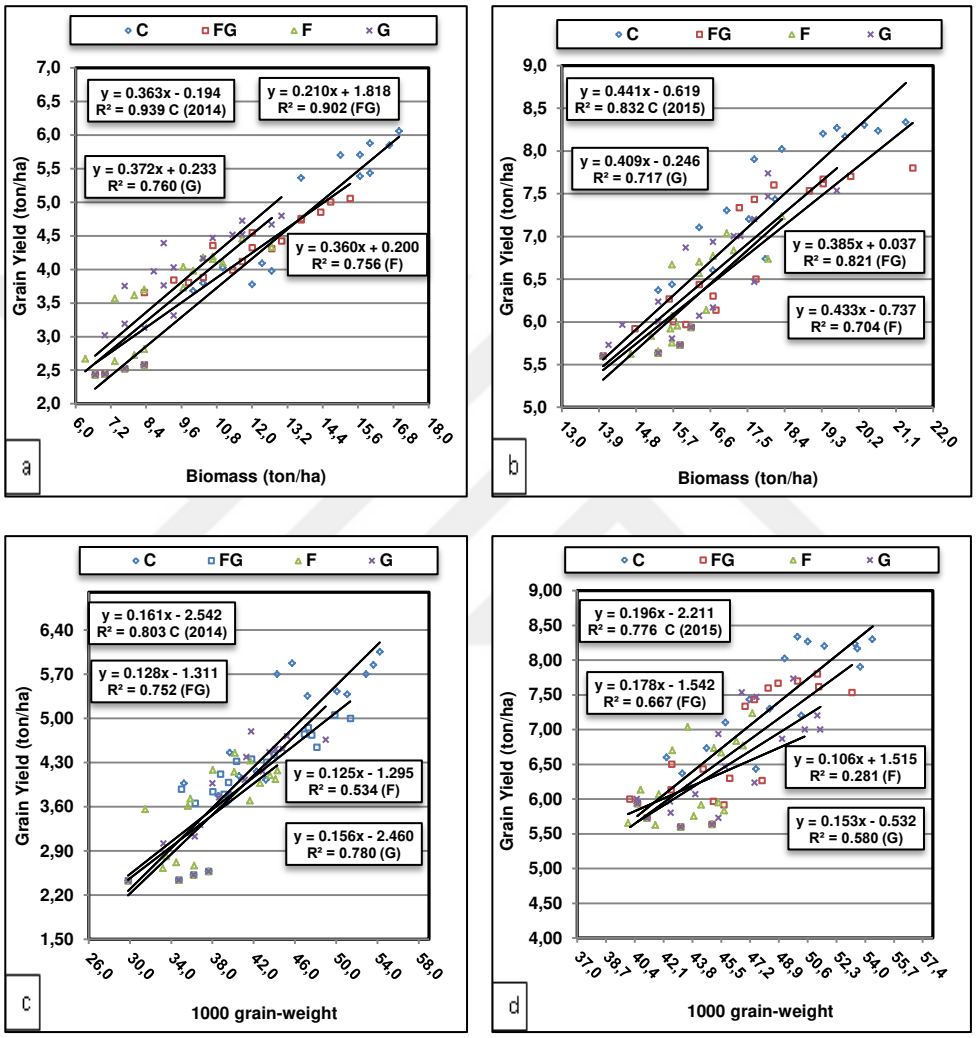

Figure 4.12. The relation between grain yield and parameters of biomass and 1000 grain-weight in both experimental years 2014 and 2015

The coefficient of determination between LAI and grain yield changed depending on growth stage and irrigation strategy that it were higher in SIFG and CI strategy resulting in R^2 = 0.90 and 0.87 in the first and second experimental

years, and dropped to minimum values in SIG strategy 0.61 and 0.44 in the 2014 and 2015 growing seasons (Figure 13). The results showed Linear and positive relationship between the LAI and grain yield was found in both years, the regression slope averaged from 0.91 in CI strategy to 1.62 in SIG strategy in the first trail year. The findings agree with studies by Kumari et al. (2013) who reported that yield results reveal positive relation between LAI and wheat yield with LAI regression slope 0.68 and R^2 (0.53). Regression coefficients were R^2 = 0.93, 0.87 and 0.86 for normal irrigation, light stress and severe stress respectively (Hasanpour et al., 2012). Gupta et al. (2001) reported positive correlations of leaf water potential and leaf area with grain yield at boot and anthesis stage.

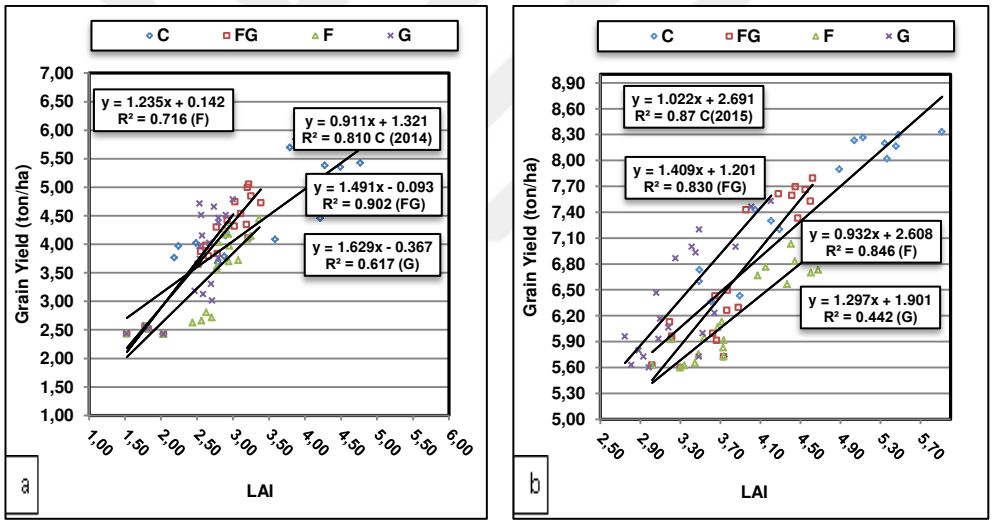

Figure 4.13. The relations between grain yield and LAI of first and second growing seasons

4.3. Physiological Parameters

4.3.1. Crop Water Stress Index (CWSI)

4.3.1.1. Evaluation of Upper and Lower CWSI Baselines

The objectives of CWSI study are to develop the upper and lower baselines equations which can be used to determine the feasibility of using the CWSI to schedule irrigation at different growth stages of winter wheat in Çukurova region, and to assess the relationships between CWSI and wheat yield under different SI and CI strategies.

In theory, CWSI should progress from zero for non-stressed plants transpiring at potential rates, to one for severely stressed plants that are not transpiring (Idso et al., 1981). Diurnal measurements were taken 5 times in 2014 growing season (conventional irrigation): at tillering stage 95 DAP, heading stage 122 DAP, flowering stage 136 DAP and grain filling stage 152 and 165 DAP, however under SIF and SIFG strategies 3 times at 136, 152 and 165 DAP, and in SIG strategy on 152 and 165 DAP at grain filling stage. In the year 2015 CWSI components were carried out 5 times: at heading stage 127 DAP, flowering stage 134 DAP and grain filling stage 139, 149 and 156 DAP in conventional strategy, whereas it measured 4 times in SIFG and SIF strategies at 134, 139, 149 and 156 DAP, and performed on 139, 149 and 156 DAP in grain filling irrigation strategy, Figures 15 and 16.

The CWSI values were averaged for the entire season that started from 24th February on 95 DAP until 5th May and from 13th April on 127 DAP to 12th May for conventional irrigation in the first and second crop season, respectively. The difference of T_c-T_a in the RF was positive while it was either positive or negative in 25% level treatments, whereas for other irrigation levels were negative in both study years, these findings are in agreement with Jackson et al. (1977). Hence canopy temperature and CWSI can be used as indicator for soil water content and water stress of winter wheat.

The lower and upper baselines were derived depend on the local climatic data conditions and using the procedures of Idso et al. (1981). In the first year, the lower and upper baselines developed are expressed by the linear equations: $(T_c-T_a)_{ll}$=-1.2158 VPD+0.4916, and $(T_c–T_a)_{ul}$=0.0411 VPD+2.1297. The VPD values ranged from 1.65 to 2.12 kPa for upper baseline (maximum stress) of RF treatment. During the second season, the non-water-stressed baseline is represented by the following equation $(T_c–T_a)_{ll}$ =-1.107 VPD+0.774, and the fully stressed baseline is expressed by the equation: $(T_c–T_a)_{ul}$ =0.020 VPD+2.078. The VPD values varied from 1.9 to 2.3 kPa for the upper stressed baseline. These results agree with studies reported in the Mediterranean environments where the VPD increases sharply from 1 to values of 2-3 kPa at the end of grain filling stage (Condon et al., 1992; Sato et al., 2006; Zhang et al., 1998). This type of Mediterranean environment is characterized by a low VPD during winter and spring seasons (Idso et al., 1981; Howell et al., 1986) that maximum differences between T_c and T_a (upper limit) which is equal to 2°C in winter wheat.

The coefficient of determination R^2 values for the regression equation of both lower and upper baselines were 0.544 and 0.005 in the first season, and it recorded 0.498 and 0.003 in the second season, respectively. As represented in Figure 14, the intercept and slope obtained of the lower baseline in the first season were 0.4916°C and -1.2158°C and achieved 0.774°C and -1.107°C in the second season respectively, slightly different from published values for wheat by Alderfasi et al. (2001) who reported an intercept of approximately 0.41 and slope -1.5 for non-water stressed baseline. The difference can be attributed to different climatic conditions such as wind speed, VPD, solar radiation and also wheat varieties between the Mediterranean region and Colorado in the United States.

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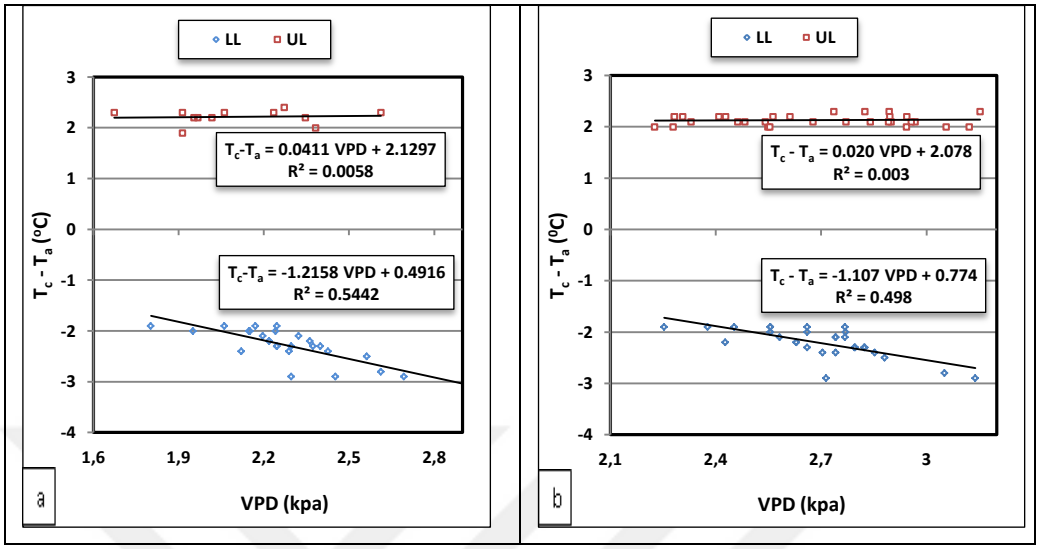

Figure 4.14. Canopy-air temperature (T_c-T_a) versus air vapour pressure deficit (VPD) in well watered and maximally stressed wheat. R^2: determination coefficient in 2014 (a) and 2015 (b).

4.3.1.2. Crop Water Stress Index and Irrigation Scheduling

In this study a few CWSI values in RF and 25% irrigation level and full irrigation were below zero and over 1 respectively, that result reported by several studies (Ca´rcova et al., 1998; Yuan et al., 2004) who suggested this exception (CWSI under zero or over 1) is happened depends on the local weather conditions.

The CWSI measurements T_c-T_a and VPD measurements started at tillering stage after 95 DAP under CI strategy in 2014 growing season where the highest CWSI value was recorded (0.80) in the control treatment (rain-fed) with significant difference over the other treatments and CWSI values were not significantly different between high irrigation levels (CI_{100} and CI_{75}) which had average values of 0.18 and 0.22, respectively. The decreasing soil water content due to no irrigation led to increased CWSI values at heading stage (122 DAP) to 0.90 in rain-fed treatment, it increased under irrigation levels (CI_{100}, CI_{75} and CI_{50}) to 0.26, 0.31 and 0.37, respectively.

The calculations of CWSI during the 2015 year started a little late at the end of heading stage after 127 DAP of conventional strategy due to rainfalls. The range of CWSI values appeared to be lower as compared to a dry year, and there was no significant difference between CI_{25} and RF treatments which resulted in average CWSI values of 0.32 and 0.38. The other irrigation levels (50, 75 and 100%) had lower significant effect of CWSI values and the fully irrigated treatment CI_{100} reflected no water stress and accomplished the smallest CWSI in both experimental years as 0.08. After irrigation process in flowering stage (130 DAP) in the crop season of 2014, CWSI values started declining gradually that ranged (136 DAP) under conventional irrigation from 0.11 to 0.40 for CI_{100} and CI_{25} treatments respectively, with significant difference, and there was no significant difference between all 3 full irrigation treatments CI_{100}, $SIFG_{100}$ and SIF_{100} which recorded the following values 0.11, 0.15 and 0.16 respectively. Furthermore the low irrigation levels CI_{25}, $SIFG_{25}$ and SIF_{25} had higher significant values as compared to full irrigation treatments with average values 0.40, 0.44 and 0.44, respectively. After the first supplemental irrigation (130 DAP) in the 2015 crop season at flowering stage (134 DAP) the CWSI values were low in supplemental irrigation strategies SIFG and SIF where they varied from 0.13 to 0.30 under the first strategy and ranged from 0.10 to 0.28 under second strategy. Relative to conventional irrigation strategy the values started to increase where the range reached (0.17-0.36) for full and 25% irrigation levels respectively. During flowering stage CWSI values between irrigation levels 25 and 50% for all 3 irrigation strategies were not significant, while the low irrigation level (25%) had the greater significant value of CWSI in comparison to high irrigation levels 75 and 100% in CWSI values. The CWSI of conventional irrigation appeared relatively lower in comparison with other strategies SIF and SIFG due to an extra irrigation applied at tillering stage (60 DAP) in conventional irrigation which raised soil moisture early, whereas irrigation under other strategies SIF and SIFG commenced at flowering stage in the first season. The results obtained in 2015 season were in contrast to the 2014

season that the CWSI in conventional strategy were relatively higher than supplemental irrigation strategies SIF and SIFG due to decreasing soil moisture content since the CWSI measurements were taken on 134 DAP, which corresponds 4 days after irrigation in flowering stage on 130 DAP under SIF and SIFG strategies however, CWSI was measured in conventional strategy 18 days later than irrigation was applied on 116 DAP in heading stage. For rain-fed treatment CWSI differed with slight decrease due to rain (5 mm) in 134 DAP in the first year, but the values increased from 0.38 to 0.46 due to no rain in this period of second year. The variations of CWSI are represented in Figures 15 and 16.

The CWSI decreased in 2014 after the irrigation events on 136 DAP for CI, SIF and SIFG strategies and on 165 DAP for CI, SIFG and SIG strategies. In general, the CWSI value after irrigation on 165 DAP in grain filling stage appeared relatively higher as compared to the flowering stage following an irrigation (136 DAP) that refer to weather conditions and increasing canopy temperature, maximum air temperature reached to 28.8, 31.2 and 34.6 ^{o}C for measured CWSI value at 136, 152 and 165 DAP, respectively. Even though the temperatures were high at the end of the second season which reached to 30.8, 32.07 and 36.4^{o}C on 139, 149 and 156 DAP, the CWSI values were relatively lower compared to the first season due to higher soil moisture content because of rains in the beginning of the second growing season.

The results indicated that CWSI values increased with declining soil moisture content on 152 DAP in first year, then decreased on 165 DAP due to irrigation on 154 DAP at grain filling stage for all treatments (except SIF treatments and RF). CWSI values for the full irrigation treatment decreased from 0.22, 0.23 and 0.26 before irrigation to 0.16, 0.18 and 0.23 for CI, SIFG and SIG treatments, respectively. The range of CWSI decreased before irrigation from (0.22 - 0.61) for the treatments CI_{100}-CI_{25} in conventional irrigation to (0.16 - 0.55) after irrigation, respectively, and under SIFG strategy from (0.23 - 0.62) in treatments $SIFG_{100}$-$SIFG_{25}$ to (0.18 - 0.58) respectively, however this reduction under SIG

strategy in treatments SIG_{100}-SIG_{25} ranged from (0.26 - 0.64) to (0.23 - 0.60). The data obtained in the second year were different due to applying different irrigation program where on 139 DAP (watery grain filling stage) the smallest range found in supplemental irrigation at grain filling stage, with range varied from 0.1 to 0.28 for full and 25% irrigation level, followed by conventional irrigation varied from 0.12 to 0.30, however, the CWSI ranges were relatively a little high and close to each other under SIFG and SIF strategies that rated (0.2 - 0.37) in SIFG strategy and (0.18 - 0.40) in SIF strategy for full and 25% irrigation levels respectively. The reason for decreased CWSI values in SIG and CI strategies might be that non-stress conditions prevailed since the crop was irrigated on 138 DAP (SIG strategy) and on 135 DAP (CI strategy), however, irrigation was applied on 130 DAP under SIF and SIFG strategies. These results are in agreement with Gontia and Tiwari (2008) who explained that CWSI values for wheat ranged from zero to 0.96 using different irrigation levels (including rain-fed), Zia et al. (2012) indicated that the CWSI values were between 0.33 and 0.65 depending on irrigation quantity.

In growing season of 2014 CWSI values in SIFG strategy for level 25% during measurements periods (152 and 165 DAP) were greater significantly than the rest of irrigation levels (100, 75 and 50%) with no significant difference between the 3 irrigation levels. In relation to SI in flowering strategy SIF_{25} treatment achieved higher significant effect of CWSI values than in the other 3 irrigation levels (100, 75 and 50%) on 152 and 165 DAP whereas there was no significant difference between irrigation levels $SIF_{50,\ 75}$. In reference to data of CWSI in the second season on 149 and 156 DAP fluctuated mainly depend on irrigation scheduling and canopy temperatures. The fourth CWSI measurements taken on 149 DAP was after one day of irrigation in conventional strategy (148 DAP) so the CWSI range on this date was the smallest in the second experimental year, which recorded 0.07 in full irrigation and 0.27 in 25% irrigation level. Under water stress in the wheat root zone and increasing temperatures, the CWSI values of SIFG and SIG strategies started in increasing (149 DAP) to 0.46 and 0.38 for

25% irrigation levels and to 0.29 and 0.19 in fully irrigated treatments, respectively. After applying irrigation on 153 DAP the measured CWSI values decreased (156 DAP) to 0.10 and 0.13 in fully irrigation treatments of SIFG and SIG strategies, respectively.

It was observed that the CWSI values of irrigation at grain filling stage (SIG) were higher in comparison to SIFG strategy in both years, due to the irrigation during flowering and grain filling stages in SIFG strategy but during only grain filling stage for SIG strategy, consequently the water stress occurring in SIG strategy raised the canopy temperatures much higher than those in SIFG strategy. Data regarding SIF strategy indicated that the CWSI values increased steadily after flowering toward the end of the growing seasons in both years that the range increased during the growing season 2014 from (0.29 - 0.68) in treatments SIF_{100} - SIF_{25} on 152 DAP to (0.34 - 0.72) on 165 DAP, in this respect, the calculated CWSI values in the second cropping season on 139, 149 and 156 DAP increased to 0.40, 0.48 and 0.55 for irrigation level 25% and recorded 0.18, 0.27 and 0.40 for fully irrigated level under this strategy. The reasons for the increased CWSI values in SIF strategy might be increased canopy temperatures at the end of the season and cutting irrigation early (130 DAP) in both growing seasons led plant leaves more dried and senesced, consequently, canopy temperature became higher and resulted in increased CWSI values. Similar results were observed in RF treatment in which the CWSI values were higher than all other treatments throughout the experiment which recorded the highest significant value of 0.9 on 152 DAP and 0.92 on 165 DAP in the first season, and reached to 0.49, 0.55 and 0.62 on 139, 149 and 156 DAP respectively in the second year. The observed increase of CWSI in dry season was greater than wet season due to the effect of drought conditions (rain 251 mm) prevailed from the tillering growth stage until the end of the first season.

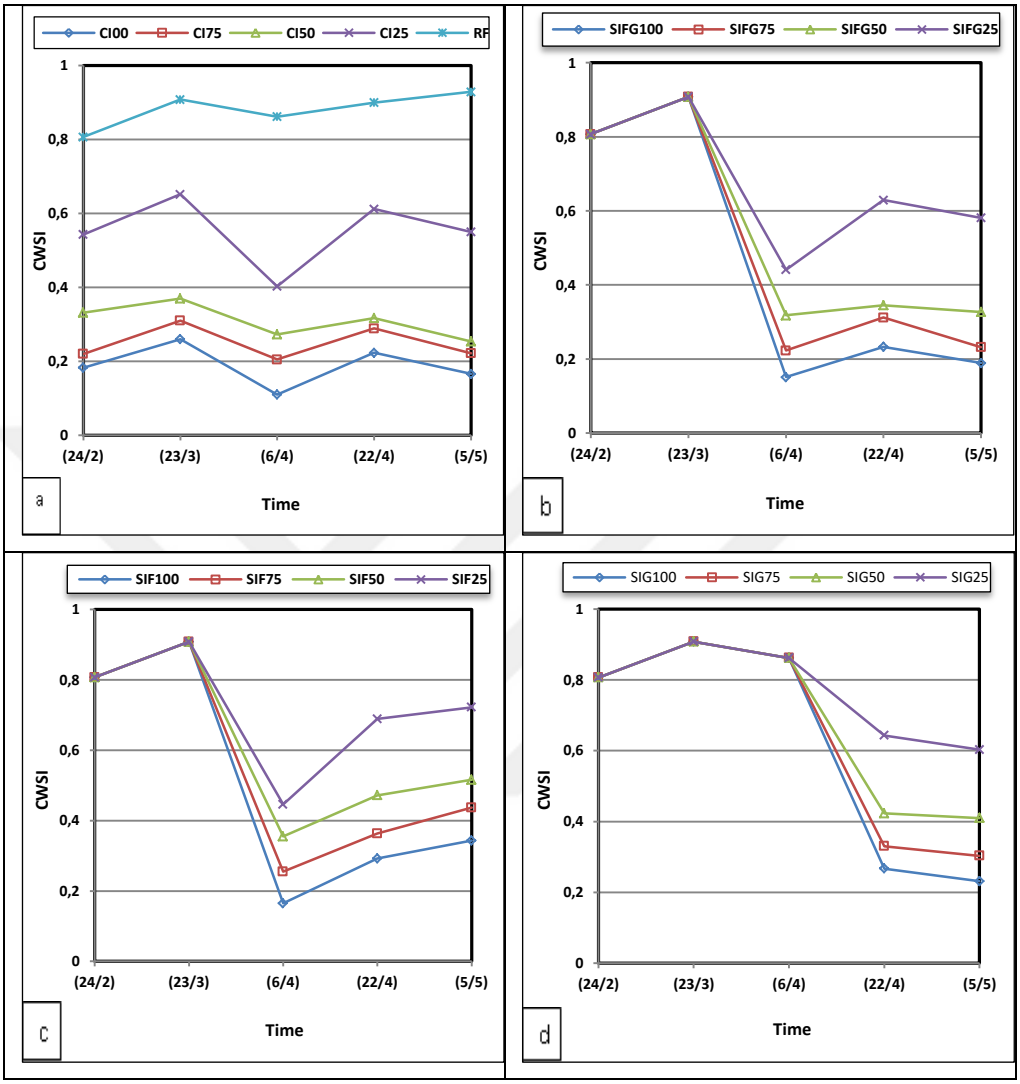

Figure 4.15. Crop Water Stress Index (CWSI) in different irrigation strategies under different irrigation levels during 2014 season

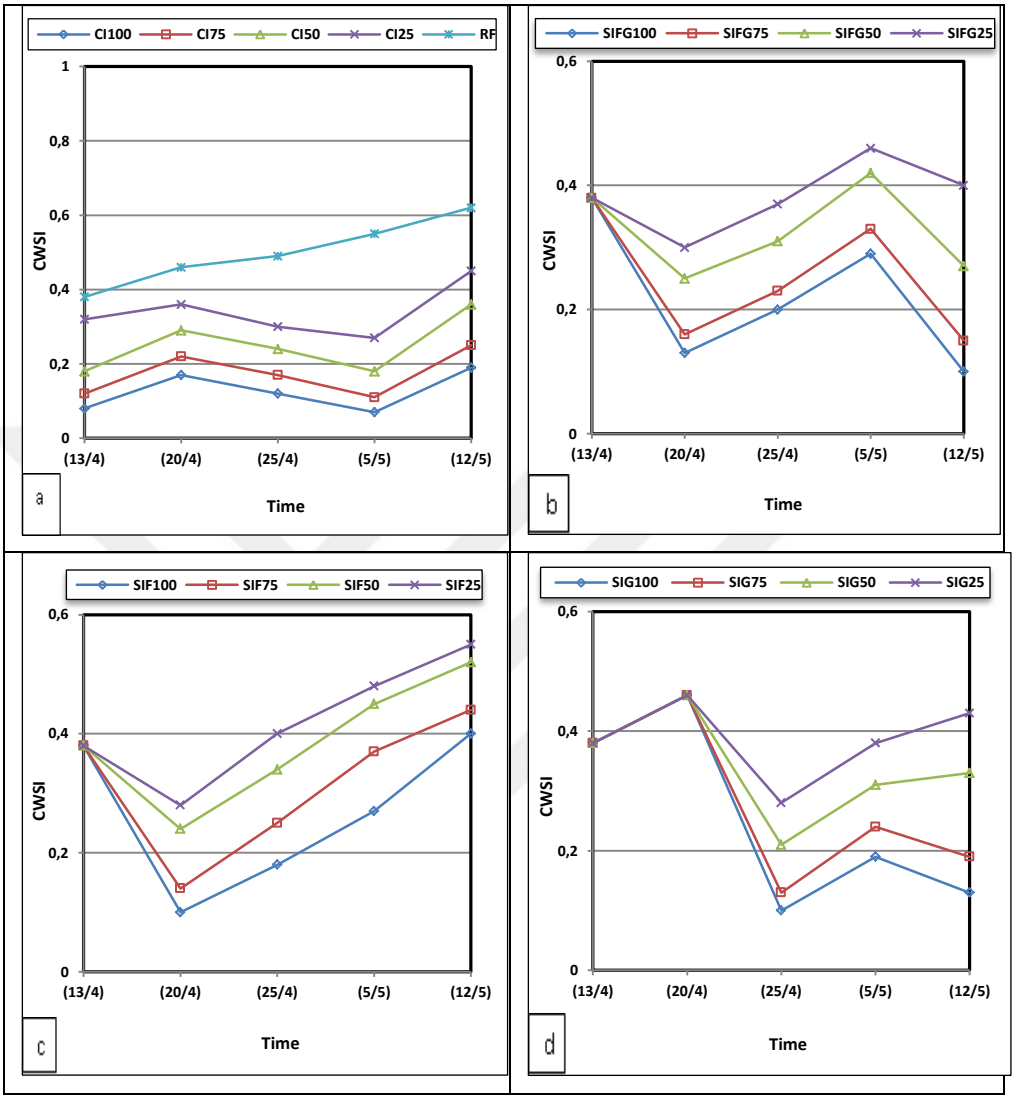

Figure 4.16. Crop Water Stress Index (CWSI) in different irrigation strategies under different irrigation levels during 2015 season

4.3.1.3. Seasonal Crop Water Stress Index Evaluations

The seasonal average of CWSI under non-water-stressed (well-irrigated) treatments were 0.18, 0.24, 0.19, 0.25, 0.26 and 0.24 for $CI_{100,75}$, $SIFG_{100,75}$, F_{100} and SIG_{100} treatments, respectively in dry season and the corresponding CWSI values in wet season 0.12, 0.17, 0.18, 0.21, 0.23 and 0.22 respectively, whereas for

moderately-water-stressed treatments the seasonal CWSI mean amounted 0.3, 0.33, 0.35, 0.31 and 0.41 for CI_{50}, FG_{50}, F_{75} and $G_{75,50}$ treatments, respectively in first growing season, the values became lower in the second year and it gave 0.25, 0.31, 0.30, 0.25 and 0.32 respectively. In relation to stressed treatments and non-irrigated treatment the CWSI of wheat showed its highest values were found as 0.55, 0.44, 0.61, 0.62, 0.55 and 0.88 for CI_{25}, $F_{50,25}$, G_{25} ,FG_{25} and rain-fed treatments in the first year, and the obtained values in the second year for the same treatments were 0.34, 0.38, 0.42, 0.38, 0.38 and 0.5, respectively.

Based on the previous seasonal average CWSI values that ranged from 0.12-0.26 for well-irrigated treatments, it is suggested that winter wheat should be irrigated when the CWSI reach between 0.18-0.26 and between 0.12-0.23 during dry and wet climatic conditions, respectively, in Mediterranean region. However under water scarcity and high price of water cost, the moderately-water-stressed range (0.31-0.41) in dry years and (0.25-0.32) in wet years of CWSI should be preferred as a limited irrigation scheduling strategy under these conditions, therefore an index for irrigation scheduling, CWSI can be used to predict when to irrigate (Irmak et al., 2000; Kacira et al., 2002), but it cannot provide information how much to irrigate as the general case for plant-based irrigation scheduling methods.

4.3.1.4. The Relationships between CWSI, Grain Yield, Leaf Water Potential and Available Water

The relationships between CWSI (as the independent variable) and grain yield (as the dependent variable) were represented in Figure 17a. In general, the CWSI correlated significantly ($p<0.01$) and negatively with grain yield. A similar negative relation was reported by Wang et al. (2005) who pointed out that grain yield of wheat declined with increasing CWSI values. For the growing seasons, the relationship between CWSI and grain yield had close determination coefficients that recorded R^2=0.81 and 0.80 in years of 2014 and 2015, respectively. These

results confirmed the findings of Zia et al. (2012) who reported the linear relationship between CWSI and yield in pre- and post-anthesis of wheat recorded R^2=0.78 and 0.81. The good correlation of simple linear equation can be improved by predicting higher yield quantity under several CWSI levels in irrigated and drought stress conditions.

As for the relation between CWSI and leaf water potential (Ψ_l), CWSI was considered as independent variable thus leaf water potential was graphed as a function of crop water stress index (Figure. 17b). The Ψ_l-CWSI relation was significant and the regression coefficient of these parameters was (R^2=0.61) in 2014 and 0.69 in the 2015 growing season. These findings are in line with the findings of Howell et al. (1986) who found the corresponding leaf water potential values were correlated to CWSI depending on the crop phenology, and this phenological response in Ψ_l may be due to differences in water relations between wheat flag leaves and canopy leaves. In the present study, the leaf water potential negatively correlated with CWSI, which means that the CWSI increases as the water content decreases in leaves. The results are in agreement with Wang et al. (2005) who stated the CWSI increased with decreasing Ψ_l when wheat was under water stress.

The determination coefficient for the relation between Ψ_l and grain yield was achieved in R^2=0.81 and 0.76 in both years of 2014 and 2015, respectively (Figure 17c). The linear relationship between Ψ_l and grain yield was positive and the regression slope ranged between 0.57 in the second season and 0.61 in the first season, the same relation was also found by Xue et al. (2006) who stated when the leaf water potential decreased, the wheat grain yield also decreased.

In this study, we considered the available water percentage as the independent variable and CWSI as the dependent variable. The relationships between crop water stress index and available water are presented in Figure 17d. The simple regression equation showed determination coefficient of 0.59 in the first year and 0.67 in the second year. Additionally, the effect of available water on

CWSI revealed a strong and significant correlation between those parameters but negatively. A similar negative response of CWSI to available water in the soil was obtained for sunflower by Orta et al. (2002) who reported that as percent available soil water decreased, the stomata closed, transpiration rates declined, leaf temperatures and CWSI increased.

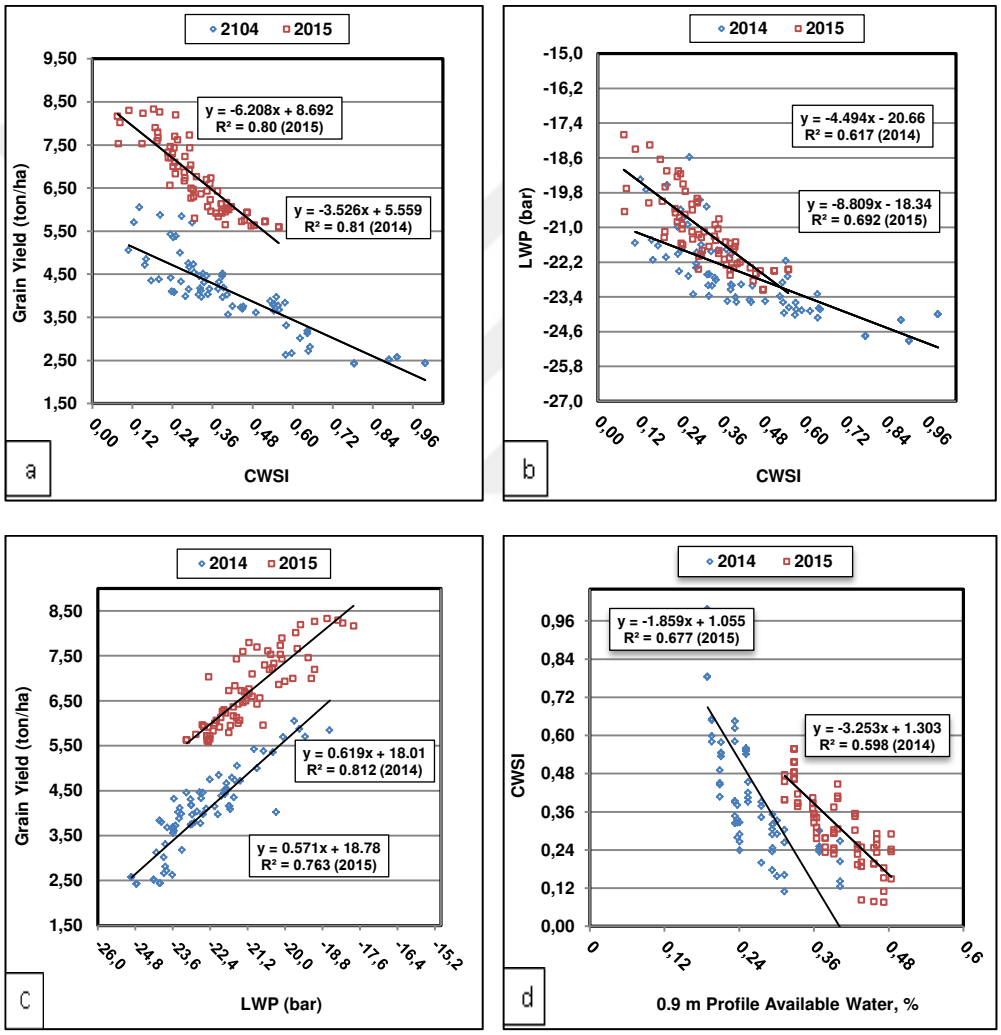

Figure 4.17. The relations between: a)Yield-CWSI b)LWP-CWSI c)Yield-LWP d)CWSI-Available Water / 90 cm soil depth. In 2014 and 2015 growing seasons

4.3.2. Leaf Chlorophyll Content (SPAD value)

The objectives of this part were to evaluate the SPAD chlorophyll meter readings under different supplemental and conventional irrigation strategies as an indicator to plant water stress, and to study its relation (SPAD) to grain yield of wheat. A relationship between grain yield and chlorophyll readings was developed using regression equation.

Significant differences between treatments in chlorophyll content (SPAD units) differed depending on growth stages of heading, flowering, watery and milky grain filling. In year study 2014 on 120 DAP, it was no significant effect between low irrigation levels and rain-fed ($CI_{50,25}$ and RF) due to water stress that treatments reached to flowering stage early and SPAD values of flag leaves were high and dominated significantly on the high irrigation levels CI_{100} and CI_{75} (plants in heading stage) which gave lower significant differences (36.75 and 37.55) respectively. The year study 2015 was wet year, generally the SPAD readings were dissimilar compared to dry year specially in heading (124 DAP) and flowering (133 DAP) where on 124 DAP it showed insignificant differences between the most irrigation treatments of conventional strategy CI_{75}, CI_{50}, CI_{25} and RF that occurred due to the plant treatments probably were not suffered from different water stress conditions and there was no big difference in growth stages periods like first year (Figures 18 and 19). Full irrigation was higher in SPAD value than RF treatment with significant increase amounted 7.8%.

After 133 DAP control treatment (RF) in crop season of 2014 arrived to watering grain stage and reached its maximum SPAD (48.43) with highest significant differences on rest treatments, and there was no significant for irrigation levels (50, 25%) under supplemental irrigation strategies SIF and SIFG, whereas CI_{75} appeared with lowest significant difference (SPAD=41.18) and the treatment was still in flowering stage. In this respect, the SPAD readings in growing season 2015 at 133 DAP continued to increase which achieved 49.5 in CI_{100} and 44 unit in CI_{25}, and there was no significant effect between level (75 and 50%) but level 75%

prevailed significantly on level 25% and RF. Relative to supplemental irrigation strategies, the SPAD values of SIF and SIFG treatments were close to each other and without significant differences under the same irrigation level. Furthermore the range of SPAD between the highest and lowest irrigation level generally revealed low that ranged (45.6-43.2) in SIFG strategy and rated (46.6-43.5) in SIF strategy.

Throughout the first season, SPAD values increased after 133 DAP onward for treatments SIG_{100}, CI_{100} and CI_{75} and reached its maximum on 147 DAP in milky grain stage with highest significant difference on rest treatments amounted 49.36, 50.82 and 50.30 respectively. After that started declining in chlorophyll content during senescence of flag leaf almost linearly until its minimum values at 167 DAP in dough maturity stage amounted 28.05, 33.46 and 30.30 respectively. Depend on the study data, it noticed the SPAD readings in the second year relatively were a little higher and the differences between treatments and strategies were lower refer to the effect of increasing the soil moisture of roots zone during each growth stage in the season compared to the dry year. The SPAD units in the second season achieved its maximum values on 149 DAP (milky grain stage) which the highest values recorded 53.9, 53.4, 55.3 and 55.6 in $SIFG_{100}$, SIF_{100}, CI_{75} and CI_{100} treatments respectively, after that the chlorophyll content steadily decreased toward the end of the season that gave on (165 DAP) 31.2, 23.7, 38.5 and 41.5 respectively. It observed in the field, morphological relationship between leaf greenness, leaf thickness and APAD values where in flowering stage the flag leaf greenness was lighter and with advancing the growth stage until watery and milky grain filling stages the flag leaf became more thicker and the greenness color (chlorophyll content) became more darker, thus the SPAD readings reached to its maximum values in this stages compared to other crop growth stage.

In addition the supplemental irrigation treatments $SIFG_{100,75}$ overtopped significantly on treatments $SIF_{100,75}$ on 147 DAP in the first year, however the irrigation treatments $CI_{25,50}$, $SIF_{75,100}$ and $SIG_{25,50}$ recorded its maximum SPAD values on 140 DAP with average 47.87, 47.5, 46.85, 47.97, 45.38 and 45.22

respectively. Data regarding 2015 season indicated that the SPAD readings were higher in treatments SIFG (100 and 75%) by (4.05 and 1.1 %) than SIG (100 and 75%) on 149 DAP, but lower by (6.2 and 10.9%) for the same treatments on 157 DAP due to the influence of irrigation scheduling where it noted indirect effect of irrigation on SPAD values by accelerating growth stages and improving the biological plant yield, consequently decrease or increase the chlorophyll content. Additionally in the first year drought stress under RF treatment decreased flag leaf chlorophyll by 23.2% compared to full conventional irrigation on DAP=147 where leaf chlorophyll ranged from 50.82 SPAD unit for CI_{100} to about 39.01 SPAD unit for RF treatment, in the next year, the CI_{100} overtopped significantly on RF by 13.4% on 149 DAP where the resulting range was between 55.6 and 49 for full irrigation and rain-fed treatments. Related to final measurement of SPAD (165 DAP), the lowest SPAD readings were under SIF strategy and the highest values under CI strategy that reflects the plants leaves still less greenness (less chlorophyll content) in SIF strategy due to the plants just irrigated one time in 130 DAP, this is agreement with the conclusion of (Yang et al., 2001; Dulai et al., 2006; Liu et al., 2006; Richardson and Berlyn, 2001; Sulok et al., 2012; Bahavar et al., 2009; Ahmdi and Sio-si Mardeh, 2004; Ninou et al., 2013) who reported drought decreases photosynthesis in wheat and increases senescence by enhancing chlorophyll degradation and nitrogen loss.

Generally well watered plants showed healthier leaves growth than that of the water stressed plants. It is worth of a mention at this time that the positive effects on the well-watered plants leaf growth can be very favorable to the plant's photosynthesis, furthermore water deficit decreased the chlorophyll content (SPAD value) in wheat and it reduction was significant at lower irrigation rates. Increasing SPAD values under low irrigation levels early refer to occurring water stress that led to develop (or advance plants in age) growth stages faster compared to high irrigation levels treatments.

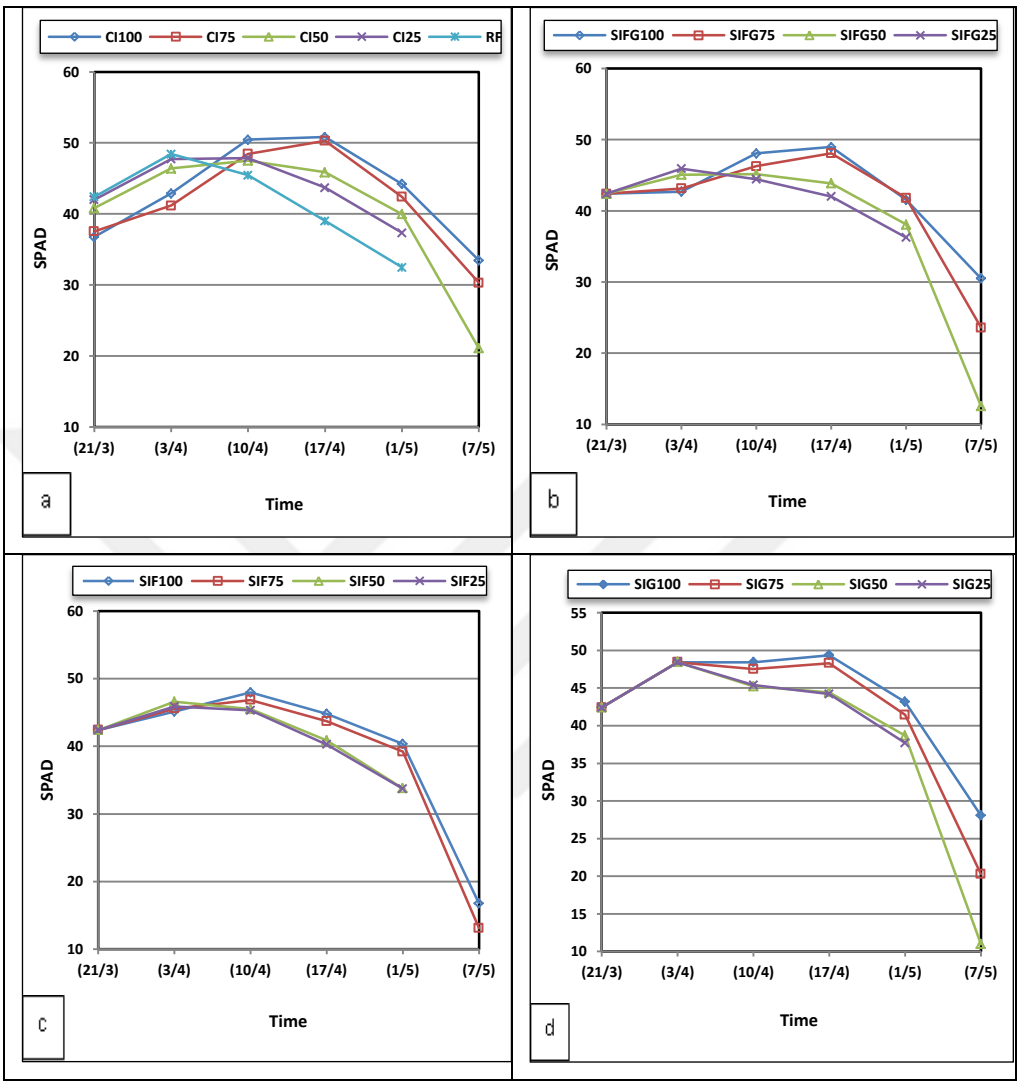

Figure 4.18. The relation between irrigation strategies under different irrigation levels and Leaf Chlorophyll Content (SPAD) during 2014 season

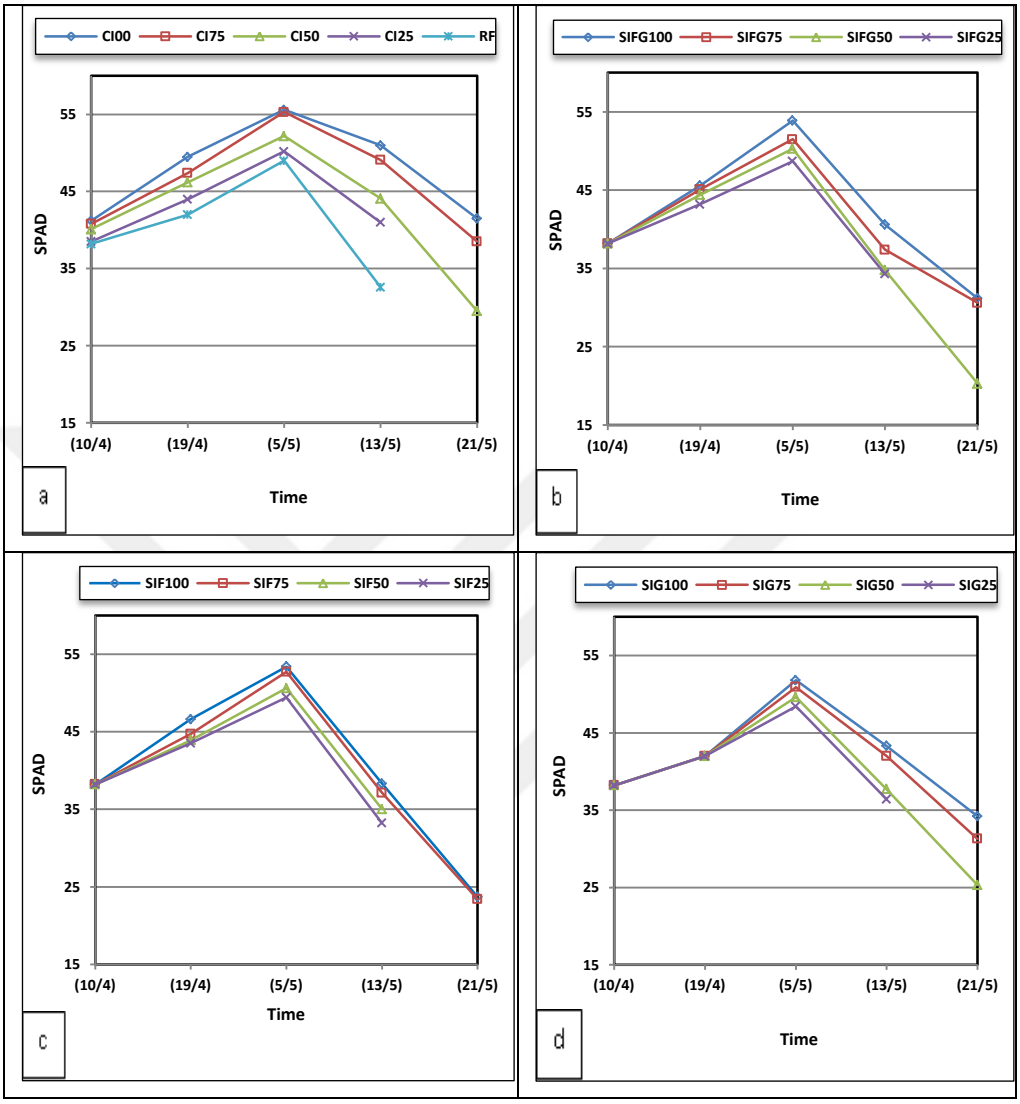

Figure 4.19. The relation between irrigation strategies under different irrigation levels and Leaf Chlorophyll Content (SPAD) during 2015 season

4.3.3. Leaf Stomatal Conductance (mmol/m^{2}s)

The target of this work was to study crop response to stomatal conductance in optimal and in water-stress conditions under supplemental irrigation in Mediterranean region during wheat growth stages.

Photosynthesis is one of the main physiological processes affected by water stress and stomatal conductance provides as primary indicator of photosynthesis production. Significant varietal reductions in stomatal conductance g_s was found both at flowering and early grain filling (watery grain filling) stages changed depending on alternation of drying and wetting soil (soil water deficit), where g_s was higher in the well-watered plants of all strategy as compared to that under water deficit conditions.

The g_s measurements process under conventional irrigation strategy started at heading stage 120 and 122 DAP in the 2014 and 2015 growing season, data represented in Figures 20 and 21. The analysis of variance showed small significant impact between treatments that full and deficit irrigation levels (75%) dominated significantly on control (rain-fed) in the first year and there was no significance between levels 50, 25 and RF, whereas the three high irrigation level (100, 75 and 50%) showed significant increase on RF in the second year. The maximum values of leaf stomatal conductance in this period were observed in CI_{100} and CI_{75} treatments about (140.73 and 139.18 mmol/m^2s) in year 2014 and it achieved 354.55 and 348.22 mmol/m^2s in 2015. The minimum value was obtained under RF with average 91.72 and 192.75 mmol/m^2s in both crop seasons of 2014 and 2015 respectively, in the same period (heading) of 2015 season g_s values seemed higher due to the effect of rain and increasing the soil moisture in the beginning of the season, however the g_s measurements in growing season 2014 revealed with lower values because of taking readings before irrigation, drought stress caused a large decline in the stomatal conductance, it appears to be a possible physiological mechanism which water stress can affect growth and productivity of crops.

The measurements of g_s were made on 132 DAP corresponding to 3 days after SI application at flowering stage in first year, the measured values in the second season at flowering stage done on 132 DAP (2 days after the first SI of SIF and SIFG strategies, and 2 days before the second irrigation of conventional

strategy) that reflected high g_s values under SIFG and SIF strategies in comparison with conventional strategy, and it were not appeared significant effects of conductance values between full supplemental irrigation (flowering - flowering and grain filling) and full conventional irrigation treatments in 2014 season but in the next year both full supplemental treatments $SIFG_{100}$ and SIF_{100} prevailed significantly on full conventional irrigation treatments. In growing season 2014 the 75% irrigation level revealed with lower significant effect averaged (187.15, 161.41 and 165.14 mmol/m^2s) respectively compared with full irrigation level that amounted (223.64, 206.32 and 202.14 mmol/m^2s) which correspond to CI, SIFG and SIF treatments respectively. Throughout the 2015 season, the conductance values were found 226.25, 304.27, and 295.6 mmol/m^2s for 75% irrigation level and accomplished 236.55, 327.37 and 321.65 mmol/m^2s for full irrigation levels under the previously mentioned treatments. Furthermore, the results in both years coincided where supplemental irrigation strategy at flowering - flowering and grain filling stages have no significant at the same four irrigation levels for both irrigation strategy. Additionally, supplemental irrigation treatments $SIF_{75,100}$ and $SIFG_{75,100}$ dominated significantly on irrigation treatments $SIF_{25,50}$ and $SIFG_{25,50}$ in stomatal conductance values. Hence the stomatal closure was the earliest response to drought and dominant limitation to photosynthesis at moderate to severity drought, it is also believed that stomatal responses are often closely linked to soil moisture content than to leaf water status.

After 142 DAP, g_s values during the first season started decreasing gradually for all treatments (except high irrigation levels of conventional strategy $CI_{100,75 \text{ and } 50}$). In the same stage (watery grain filling) on 140 DAP, g_s measured in the 2015 season, and it noticed the g_s range increased under conventional strategy and reduced under SIF and SIFG strategies that refer to increasing the moisture in roots zone in conventional treatments which measured 5 days after irrigation whereas conductance values measured 10 days after first SI irrigation. Although the g_s values of SIG strategy measured earlier (2 days after irrigation) than conventional

strategy but conductance values were lower that refer to irrigate SIG treatment late in the end of the season (watery grain filling) compared to conventional irrigation treatment which started irrigation in 116 DAP. The full conventional irrigation treatment overtopped significantly on all three full supplemental irrigation treatments in the first year, however there was no significant differences between CI_{100} and SIG_{100} in the second year, water deficit decreased g_s values and the reduction of (78.6 ,63.6 and 60.1%) in stomatal conductance occurred due to water stress conditions in rain-fed treatment as compared to full irrigated treatments (CI_{100}, $SIFG_{100}$ and SIG_{100}) in the crop season of 2014 and it achieved 52.8, 46.1 and 49.9% respectively in crop season 2015. The results are in general agreement with (Ahmadi & Sio-se Mardeh, 2005) who reported that there is a strong link between stomatal conductance and photosynthesis in which leaf dehydration can lead to turgid loss of guard cells causing passive stomatal closure which reduce stomatal conductance and consequently the supply of CO_2 to fixation site is reduced. However, the ability of stomata to remain open in rain-fed conditions was closely linked to their greater capacity as compared with irrigated. Similar results were reported by El-Hafid et al. (1998). Additionally, after first irrigation of SIG strategy in growing season 2014 (exactly at watery grain stage) stomatal conductance ranged from 126.53 to 51.15 mmol/m^2s for SIG_{100} and SIG_{25} treatments respectively, on the other hand it was no significant between the three supplemental irrigation strategies under 25, 50% and rain-fed. In related to 2015 season, irrigation levels 25 and 50% for conventional and supplemental strategies achieved significant effect on rain-fed treatment.

The reduction of g_s continued rapidly and steadily (sharp decline) after grain milky stage 155 and 150 DAP in the 2014 and 2015 growing seasons for all treatments, it was observed that g_s decreased with age of leaves and the conductance values were lower after the third SI (at grain filling stage) than after the first (at flowering stage), supplemental irrigation at flowering recorded rate from 68.07 to 41.97 mmol/m^2s for SIF_{100} and SIF_{25} throughout the 2014 season and

the obtained values ranged from 143.52 to 103.32 mmol/m^2s, respectively in the growing season 2015, this can be explained by the relationship between soil and plant water status, the rapid decline in g_s values under this strategy refer to lengthen the dry period consequently the leaves senesced early compared with other strategies. The results confirmed the findings of (Sato et al., 2006; Ahmed et al., 2010; Olszewski et al., 2009) who found significant decreases in g_s by increasing drought stress. Thus present findings clearly showed that water scarcity affects stomatal behavior which imbalance the photosynthesis that results into minimum assimilates production.

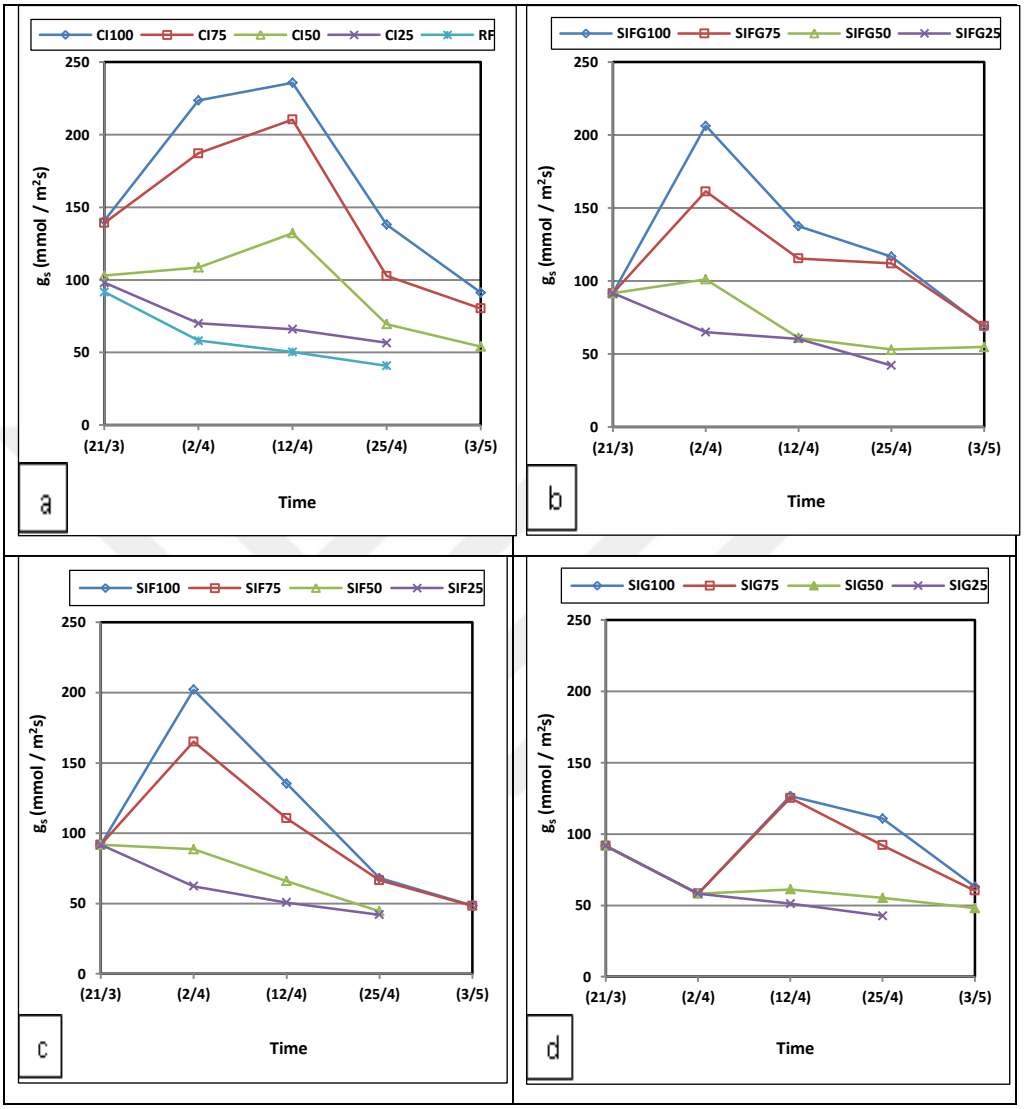

Figure 4.20. The relation between irrigation strategies under different irrigation levels and leaf stomatal conductance (g_s) during 2014 season.

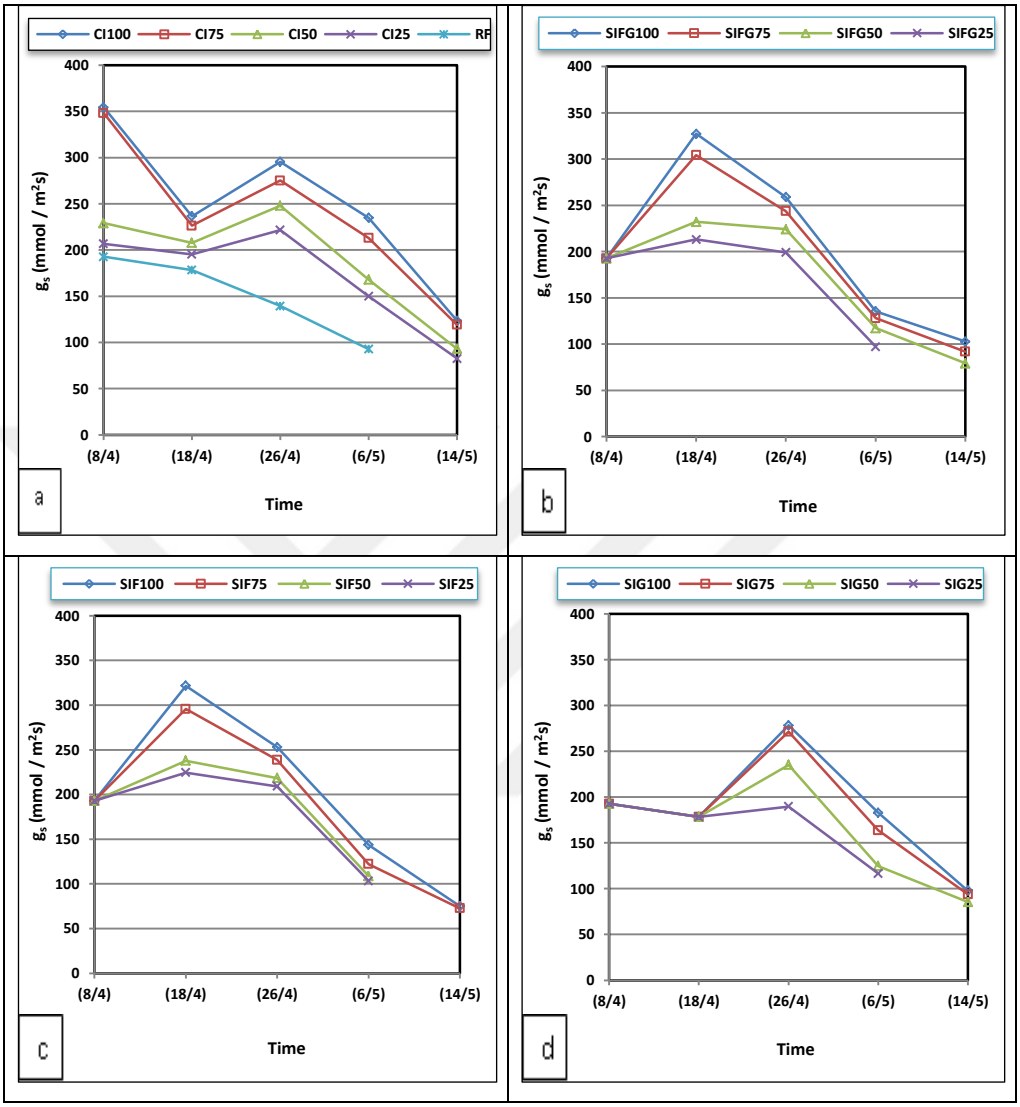

Figure 4.21. The relation between irrigation strategies under different irrigation levels and leaf stomatal conductance (g_s) during 2015 season.

4.3.3.1. The Relation between Yield, Soil Plants Analysis Development (SPAD) and Leaf Stomatal Conductance

The regression coefficient between SPAD (as an index of leaf chlorophyll content) and grain yield recorded 0.53 and 0.79 in growing seasons of 2014 and 2015 (Figure 22). In general, the maximum yield was related to the highest SPAD

value and applied water (CI_{100} treatment). The results are in line with finding of Danda and Behl (2004), that reported a four unit increase in SPAD as relative water content decreased from 94 to 87%, furthermore there are many studies showed the decrease in leaf chlorophyll under drought stress conditions (Ashraf et al., 1994; Sairam et al., 1997).

The regression equation recorded (slope = 0.31, r = 0.73) in the first season and s = 0.26, r = 0.89 in the next year. The results agree with Lopez-Bellido et al. (2004), who found slope regression between wheat yield and SPAD achieved 0.31, however this slope by Monostori et al. (2016) recorded 0.11, 0.17 and 0.21 with R^2 (0.61, 0.18 and 0.46) respectively in different growing seasons of wheat.

In this study, a significant and positive linear relationship of grain yield with flag leaf SPAD values was observed that based on growth stage, irrigation scheduling and environmental conditions. These findings are in agreement with Bavec and Bavec (2001), who reported significant relationships between SPAD readings and grain yield were reported at the heading stage, and in the middle of the grain-filling period (Jiang et al., 2004) in winter wheat. Additionally, In many studies, leaf chlorophyll value measured by SPAD chlorophyll meter was found closely related to grain yield (Blackmer and Schepers, 1995; Maiti et al., 2004; Islam et al., 2014).

The relation between leaf stomatal conductance (g_s) and grain yield of winter wheat was represented in Figure 22. The regression coefficient differed depend on water stress conditions in both growing seasons that in dry year was higher (R^2 = 0.70) as compared to wet year (R^2 = 0.67), similar results were reported by Wang et al. (2005), who found the correlation coefficient of stomatal conductance, photosynthesis and transpiration rate (at 10, 20 and 30 days after anthesis) were higher under drought stress than well watered at various growth stage of wheat.

In present study, grain yield correlated positively and significantly with flag leaf stomatal conductance in two years study that leaf stomatal conductance can be used as an indicator to develop high-yielding wheat under water-limited

environments. The results agree with many studies of (Gillon and Yakir, 2000; Miyashita et al., 2005; Franks et al., 2009; Zlatev, 2004; Ahmadi and Sio-se Mardeh, 2005) who stated that significant and positive correlation was observed between g_s and yield that g_s can improve crop photosynthesis, consequently increase the crop yield.

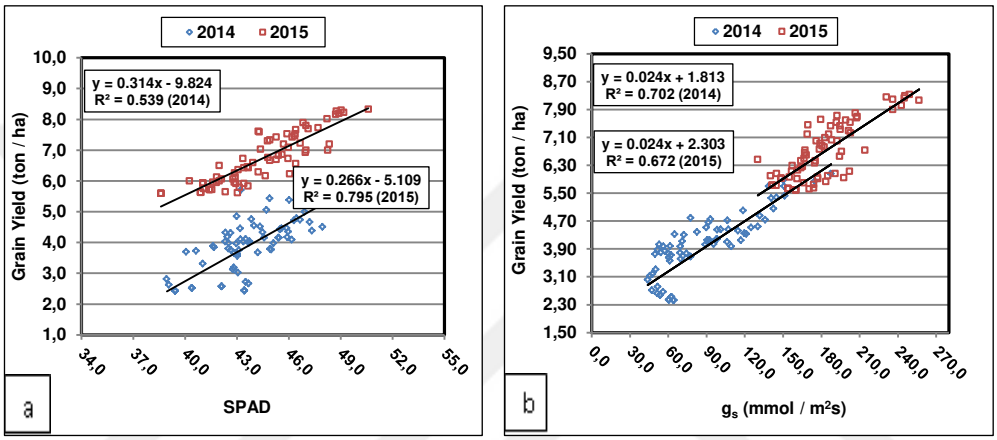

Figure 4.22. The relation between wheat yield and: a) SPAD readings b) leaf stomatal conductance g_s during both growing seasons

4.3.4. Midday Leaf Water Potential of Wheat

The target of this part was to investigate the relationship between wheat growth stage and leaf water potential during the drying soil and rewatering schedule.

In the reference to the statistical data in Table 6, the midday of leaf water potential (Ψ_l) measurements started in post-anthesis stage (watery grain filling stage) that occurred after 139 and 142 DAP in two study years (2014 and 2015). The results revealed clear differences between irrigation levels and strategies in the first growing season where the full conventional irrigation and all three full supplemental irrigation treatments ($SIFG_{100}$, SIF_{100} and SIG_{100}) overtopped on the control (rain-fed) treatment with significant increase (less negative values)

amounted to 31.2, 12.9, 12.3 and 14%, respectively. However these values in the second year revealed higher with slight difference compared to first year which recorded as 32.8, 11.3, 13 and 22.3%, respectively, corresponding to the above mentioned treatments. Ψ_1 values in the second season were higher compared with the first season, consequently the difference between full irrigation treatments and RF seemed higher (Table 6). The results reflect ability of dry condition to decrease Ψ_1 values that might have occurred due to increased respiration and decreased transpiration resulting from stomatal closure. Our results are in line with findings of Siddique et al. (2000) who reported that exposure of wheat to drought led to noticeable decrease in leaf water potential.

Furthermore, In the first season, full conventional irrigation treatment resulted in significantly higher Ψ_1 than those in the three full supplemental irrigation treatments due to higher soil water content in root zone in the conventional strategy. On the other hand, there was no significant difference between full supplemental irrigation treatments. The results showed that Ψ_1 affected by irrigation regime in year of 2015 where Ψ_1 values in the full supplemental irrigation SIFG were lower as compared with full conventional and full grain filling treatments by 16.1 and 8.9%, respectively.

For the lower irrigation levels which plants located under severe drought stress, there was not any significant difference between rain-fed treatment (control) and $SIG_{25,}$ $SIFG_{25}$ in the first season. However Ψ_1 in the control treatment (RF) decreased significantly (negative significant) in comparison to other lower irrigation levels of CI_{25} and SIF_{25}. Similarly, the Ψ_1 value differed depends on water deficit in the second growing season where CI_{25} dominated significantly on the driest treatments $SIFG_{25}$, SIF_{25} and RF and it was no significant effect between DI_{25} and SIG_{25} treatments.

In relation to Ψ_1 values under moderate irrigation levels (75% and 50%), the supplemental irrigation strategy SIG were higher in comparison with other supplemental irrigation treatments SIF and SIFG with average -20.9 and -21.72 bar

in the dry season and achieved -17.85 and -20.25 bar in the wet season, respectively. The reduction in Ψ_l values under irrigation strategy SIG is due to the measurements made 2 and 4 days after irrigation in the first and second year, respectively, whereas under other supplemental irrigation strategies SIF and SIFG measurements were taken at first 10 and 12 days (under more severe water stress) in the first and second growing seasons, respectively. Therefore, Ψ_l values of wheat steadily decreased with increasing days of drying (or after irrigation), the results are in line with the finding of Liang et al. (2002); Waraich and Ahmed (2010).

Leaf water potential had decreasing trend with time and fluctuated depending on drying and rewatering alternated of soil water content, and with developing growth stages that observed at milky grain filling stage (157 and 158 DAP during 2014 and 2015 cropping seasons) Ψ_l became more lower (more negative) which ranged in 2014 growing season from -20.67 to -25.4 bar for full conventional irrigation and rain-fed treatments, whereas this range at watery filling stage varied from -17.9 to -23.5 bar under the same treatments. As for second year, the Ψ_l values ranged from -20.15 to -23.7 bar in milky stage, and from -16.3 to -21.65 bar in watery grain filling stage corresponding to full conventional and rain-fed treatments, respectively.

In general, the results indicated that Ψ_l values at milky grain stage under full irrigation treatments CI, SIFG, SIF and SIG, respectively were higher 22.8, 14.0, 5.3 and 11.3% in the first year, and to 17.6, 9.7, 3.2 and 9.9% in the second year as compared with rain-fed conditions. This relatively decreasing range of Ψ_l in milky grain filling stage was due to decreasing soil water content under deficit irrigation treatments (level 25%) and rain-fed, another reason, plant leaves started to senescence with the progress of growth stages. These results confirmed the findings of Matić (2008); Ali et al. (2014), they found midday Ψ_l ranged for (CI_{100} and RF) from -14.22 to -17.78 bar at flowering and from -18 to -24.03 bar at grain filling stage and dropped linearly with decreasing irrigation levels from 100% ET_c to 60% ET_c. Data obtained from the both seasons coincided that deficit irrigation

levels 75% and 100% dominated significantly on irrigation level 25% and rain-fed for all irrigation strategies (except SIF strategy) in Ψ_1 values measured.

Regarding the supplemental irrigation under flowering average Ψ_1 was the lowest (more negative values) compared with other strategies, where average Ψ_1 was -24.12 bar in the SIF_{100} and -20.67, -22.27 and -22.81 bar, respectively, in other full irrigation strategies CI, SIFG and SIG in the first season. In the second year, Ψ_1 in SIF_{100} treatment (-22.95 bar) was lower by 12.2, 5.8 and 6.1% which corresponds to the treatments CI_{100}, $SIFG_{100}$ and SIG_{100}, respectively. The decrease in Ψ_1 under SIF strategy due to prolonging drought spell which was just irrigated once at flowering stage (130 DAP), whereas other strategies were irrigated during flowering and grain filling stages. Additionally in both cropping seasons of 2014 and 2015 in milky grain stage no significant effect was noticed between the four irrigation levels of SIF strategy due to the soil moisture content differences between those irrigation levels became low and semi constant because of stopping irrigation during long period, these findings are in agreement with conclusion of Puri and Swamy (2001); Jiang et al. (2013).

In general, the Ψ_1 values in the dry year appeared to be lower (more negative values) as compared to the wet year that refers to increased soil drought conditions until high-stress level and decreased Ψ_1 values. In addition, it was also noticed that the Ψ_1 value influenced by the growth stage of wheat where it was lower in the advanced growth stages of wheat that due to the effect of physiological factors such as reduced photosynthetic rate, chlorophyll content and other processes. Consequently the plant leaves start to senescence and drying toward the end of the season.

The variations in Ψ_1 for winter wheat at different supplemental and conventional irrigation fluctuated depend on soil-plant relation that decreasing soil moisture. Ψ_1 value can be applied as an indicator of water stress for monitoring the irrigation scheduling during the growth stages of wheat.

Table 4.6. The effect of interaction between the irrigation strategies and irrigation levels on Leaf Water Potential (Ψ_l) during 2014 and 2015 seasons

Treatment	2014		2015	
	09/04	27/04	28/04	14/05
$SIFG_{25}$	-22.64^{hi}	-24.8^{fg}	-21.05^{fgh}	-23.1^{fg}
$SIFG_{50}$	-22.39^{gh}	-24.23^{ef}	-20.65^{efg}	-22.7^{defg}
$SIFG_{75}$	-21.28^{def}	-22.63^{bcd}	-20.05^{de}	-21.85^{bcd}
$SIFG_{100}$	-20.8^{cde}	-22.27^{bc}	-19.45^{cd}	-21.6^{bc}
CI_{25}	-21.54^{defg}	-24.21^{ef}	-19.95^{cde}	-22.75^{defg}
CI_{50}	-20.11^{c}	-23.11^{cd}	-19.1^{c}	-22.05^{bcde}
CI_{75}	-18.88^{b}	-22.17^{b}	-17.85^{b}	-21.3^{b}
CI_{100}	-17.9^{a}	-20.67^{a}	-16.3^{a}	-20.15^{a}
SIF_{25}	-22.44^{gh}	-25.10^{fg}	-21.2^{gh}	-23.55^{g}
SIF_{50}	-22.18^{fgh}	-24.92^{fg}	-20.75^{efgh}	-23.5^{g}
SIF_{75}	-21.73^{efgh}	-24.25^{f}	-19.95^{cde}	-23.07^{fg}
SIF_{100}	-20.91^{cde}	-24.12^{ef}	-19.15^{c}	-22.95^{efg}
SIG_{25}	-22.6^{hi}	-24.92^{fg}	-20.85^{efgh}	-23.2^{fg}
SIG_{50}	-21.72^{efgh}	-24.45^{fg}	-20.25^{def}	-22.45^{cdef}
SIG_{75}	-20.9^{cde}	-23.32^{de}	-17.85^{b}	-21.75^{bcd}
SIG_{100}	-20.6^{cd}	-22.81^{bcd}	-17.7^{b}	-21.55^{bc}
RF	-23.5^{i}	-25.4^{g}	-21.65^{h}	-23.7^{g}

The similar letters-treatments have no significant differences

4.4. Grain Quality Characteristics

The purpose of this part is to determine the effect of conventional and supplemental irrigation applied during different growing stages on bread-making properties in order to increase wheat quality under Mediterranean conditions, another objective is to study correlation of different quality parameters and grain yield.

4.4.1. Protein Ratio

Protein content is of prime importance in wheat quality and wheat flour, it affects on finished product attributes, such as texture and appearance. Low protein content is desired for crisp or tender products, such as snacks or cakes. High protein content is desired for products with chewy texture, such as pan bread and hearth bread.

With reference to statistical analysis data in Table 7, the full supplemental irrigation treatment SIF_{100} resulted in significant increase in protein content amounted to 21.7 and 14.7% in comparison to the full irrigation treatments CI_{100} and $SIFG_{100}$, respectively, in the first trail year, and 17.8 and 6.4% in the second year. This means that applying irrigation just once early at flowering stage influenced wheat protein more than irrigating twice (at flowering and grain filling) and three times at different growth stages (heading, flowering and grain filling). Therefore, these results reveal that the environmental factors such as water stress and high temperatures during grain filling period have important effect on grain protein accumulation and bread quality. Similar results were reported by Aslani et al. (2013) who stated that water stress in the post-anthesis (grain filling period) was found to affect quality parameters where an increase in protein content and sedimentation volume, consistent with a decrease in grain yield.

In the first experimental year, the water applied in grain filling stage increased significantly the protein ratio by 4.3% compared to full conventional strategy. In this respect, supplemental irrigation in grain filling stage decreased the protein content by 14.2% compared with applying supplemental irrigation at flowering stage. In the second year, application of SI in grain filling stage caused significant increase in protein content about 5% over the conventional strategy, while the SI at grain filling resulted in a 10.6% reduction in protein content in comparison to that of supplemental irrigation at flowering stage. These results were in contrast to the findings of Tari (2016) who found irrigation applied in the milky stage increased the protein ratios, and the highest protein ratios and gluten contents were obtained under the moisture conditions of the DDA treatment (full irrigation treatment at milk stage) in Central Anatolia conditions.

The effect of water stress on grain protein quality was depends on irrigation water level and timing of using water. Furthermore, when the water deficit occurred during growth stages an increase in protein content obtained. Throughout the growing season of 2014, the protein ratio level was raised by decreasing in

irrigation that an increase 16.9% of protein resulted in reducing of full irrigation (276 mm) to 25% level (97 mm) at conventional strategy and reached to 14% under the same levels (100-25%) at flowering and grain filling stage strategy. Data obtained from 2015 season presented that the effect of deficit irrigation quantity from full conventional irrigation (187.63 mm) to CI_{25} (46.91 mm) on increasing protein content was noticeable by 19.4%, whilst the irrigation difference between full and 25% deficit irrigation treatments increased protein ratio to 12% under flowering and grain filling strategy. On the other hand, it were not appeared significant effect in protein quality between moderate deficit irrigation levels 75 and 50% in the same strategy (except supplemental irrigation at grain filling stage) during cropping season 2014, whereas in the next season at the same strategy, deficit irrigation (75 and 50%) affected significantly protein ratio for all irrigation strategies.

For the lower irrigation level 25%, slight but not significant differences were observed under CI, SIFG and SIG strategy whereas SIF_{25} dominated significantly on the previous treatments during first season. Similar to first cropping season, protein content did not influenced significantly by lower deficit irrigation 25% in the second season.

On the whole, in the current study the dry year resulting high water stress that made protein values richer than wet year. Furthermore, Irrigation strategies had significantly different effects on protein content of wheat grain. An inverse relation between protein content and irrigation water was observed and the highest value of protein ratio (15.9%) was found in rain-fed treatment which resulted in significant superiority to the other treatments in the crop season of 2014. The similar trend of protein ratio to water regime was observed in the second season that the rain-fed treatment achieved the maximum significant value of protein content with an average 14.5%. Based on this given data, the drier conditions in the first year helped to improve the protein quality as compared with wetter conditions in the second season. However the lowest protein content was obtained in full

conventional irrigation treatment (high consumptive use) with an average of 11.5 and 11.2% in two years study of 2014 and 2015, respectively. In addition, yield obtained in rain-fed treatment in cropping season of 2014 was 57.5% lower than in full conventional irrigation treatment but protein percentage was 38.2% higher than full conventional treatment. However the corresponding values were comparatively lower in the second year, in which the water stress under rain-fed treatment reduced the grain yield to 30.6% of full irrigated treatment of conventional strategy and it increased protein content by 29.4% over the full conventional irrigation. It can be concluded that the negative relationship between grain protein content and yield production, also between irrigation quantity and protein content was found. These findings are in line with findings of Saint-Pierre et al. (2008); Naseri et al. (2010); Seleiman et al. (2011); Noorka and Sliva (2012).

Finally, the treatment $SIFG_{75}$ overtopped significantly on CI_{100}, CI_{75}, $SIG_{100,75}$ and $SIFG_{100}$ in protein ratio (except $SIFG_{100}$ in 2015) and this interaction treatment $SIFG_{75}$ decreased the yield by 23 and 9.2% in the first and second cropping year compared to full conventional irrigation but increased the protein ratio to 14.7 and 14.2% during both growing seasons 2014 and 2015. Based on these results the $SIFG_{75}$ coalition considered economically the best for yield and acceptable protein quality. Thus it could be concluded under dry conditions years in Mediterranean area in order to obtain suitable bread making quality combined with high yield production, supplemental irrigation at flowering and grain filling (with 194 mm) could be recommended.

4.4.2. Wet Gluten Content

Gluten content is a very important trait for the assessment of flour quality, the unique properties of endospermic protein are called gluten. The wet gluten content was affected by both the magnitude of water deficit and the growing stage. The wet gluten content obtained from supplemental irrigation just once at grain filling stage (SIG_{100}) was higher than the irrigating 3 times in full conventional

irrigation treatment by 14 and 11% in the 2014 and 2015 seasons, respectively, and wet gluten content values were lower by 2.5 and 2.2% than supplemental irrigation at flowering and grain filling ($SIFG_{100}$) in 2014 and 2015 cropping seasons. Furthermore, one extra irrigation in the heading growth stage at conventional strategy (CI_{100}) decreased wet gluten by 14.5% in comparison with irrigation in flowering and grain filling stages ($SIFG_{100}$) in the first cropping season (Table 7). Data regarding the second season showed that reduction percent of wet gluten content under conventional irrigation in comparison with irrigation at flowering and grain filling stages was lower (11.9%). These findings suggest that wet gluten responded well to different water stress in the dry and wet seasons. These results are in conformation with Mary et al. (2001); Ozturk and Aydin (2004) who stated that the water stress increased wet gluten content relative to the fully irrigated treatment.

In the first trail year, it were not revealed significant effects between $SIF_{100,75}$ and $SIFG_{75}$ in gluten concentration, however these treatments overtopped significantly on the other treatments in the same deficit irrigation levels as $CI_{75,100}$, $SIG_{75,100}$ and $SIFG_{100}$. In general, the significant range of wet gluten values revealed smaller in the second experimental year. The fully irrigated treatment of SIG and SIFG strategies appeared with non significant differences, whereas the irrigation treatments $SIF_{100,75}$ prevailed significantly on the other high irrigation treatments except $SIFG_{75}$. The significant difference of gluten concentration between the highest (SIF_{25}) and lowest (SIF_{100}) value was small compared with other irrigation strategies with average amounted 4.6 and 3.4% in both years of 2014 and 2015, whereas this range recorded 8.15 and 5.87% in the first year study and achieved 9.1 and 6.8% during the second year correspond to conventional and supplemental irrigation in grain filling stage respectively.

In relation to lower deficit irrigation levels 25 and 50% in the growing season of 2014, the treatments CI_{50} and $SIFG_{50}$ had minimum significant values of wet gluten 32.13 and 32.40%, respectively and $SIF_{50,25}$ resulted in the maximum

significant values with average of 36.30 and 36.70%, respectively. Compared with the second season results for the same water regime (levels 50 and 25%), the lower wet gluten concentration (28.9%) was just observed under one treatment (CI_{50}), and as expected the higher wet gluten content was observed in treatment SIF_{25} (33.9%) which corresponds to the lowest irrigation quantity.

The lowest and highest wet gluten content were related to applied water quantity. The full conventional irrigation treatment achieved the lowest gluten content with decrease 34.1 and 32.1% in the first and second experimental years in comparison with the lowest consumptive use treatment (rainf-ed treatment). The results are in agreement with the conclusion of Erekul et al. (2012) who reported the wet gluten contents without irrigation were found significantly higher than the values obtained from the irrigation treatments.

In both growing seasons of 2014 and 2015, it was observed under supplemental irrigation in flowering stage, the extreme water stress occurred in post-anthesis stage made SIF strategy to give the highest gluten percentage compared with the other three irrigation strategies.

The results illustrated that using single irrigation at flowering stage not only saved irrigation water about 45.9 and 39.4% compared with CI_{100} and SIG_{100}, but also increased the gluten content to 24.4 and 9.0% throughout the 2014 growing season. In related to second season results when the water stress happened in grain filling stage (SIF strategy), accordingly the saved irrigation water amounts up to 61.2 and 49.5% in comparison that of full conventional irrigation and fully irrigated at grain filling, in addition to wet gluten elevated by 29.2 and 16.4% compared to the mentioned previously treatments respectively. Hence it appeared the effect of water stress generally occurs in grain development stage under Mediterranean area caused a high aggregation level of gluten content that was reflected in improving the wet gluten technological quality character.

4.4.3. Sedimentation Value (mm/l)

The sedimentation values under the different treatments are provided in Table 7. Negative relationship was found between sedimentation value and water stress. Hot weather (higher than 30^{o}C) under Mediterranean conditions during the grain filling period caused an increase 24.4 and 28.1% of sedimentation volume during the first and second seasons for supplemental irrigation strategy SIF_{100} higher than supplemental irrigation in grain filling stage (SIG_{100}). Furthermore, in the first trail year the irrigation applied just in flowering growth stage increased sedimentation volume to 16.5 and 35.5% in comparison with irrigation at flowering and grain filling stage and conventional irrigation. Based on statistical analysis in the second experimental season of the study, the severe water stress in SIF strategy with only single irrigation elevated sedimentation content significantly higher than the values obtained in the first season which reached to 21.1 and 38.4% over the irrigation at SIFG and conventional strategy, respectively. This relative increase return to minimum values of sedimentation where these values in the second year were lower and relatively the sedimentation ranges were larger as compared to first cropping season. The results are in line with findings of Gooding et al. (2003), found that the effect of drought stress imposed during grain development on sedimentation volume was dependent on the timing of stress application, that restricting moisture between the first and the 14th day during grain reduced sedimentation volume relative to water stress applied.

The current results revealed that the water applied in the flowering and grain filling stage elevated sedimentation volume by 6.7 and 16.2% in the first experimental year and by 5.7 and 14.2% in the year study of 2015 higher than irrigation in grain filling stage and irrigation in heading, flowering and grain filling stage (conventional irrigation) that means for raising the wheat sedimentation value and improving the bread quality, supplemental irrigation SIFG could be applied under Mediterranean region.

Refer to high irrigation levels of growing season 2014, no significant effects were found between CI_{75} and $SIFG_{100}$, also between $SIFG_{75}$ and SIF_{100} in sedimentation value, whereas observed significant differences between the other treatments under the mentioned irrigation levels. In crop season of 2015, the results indicated that the response of sedimentation content to high deficit irrigation levels was greater than previous year study, where it noted significance between all 8 treatments of high irrigation regimes except $SIFG_{100}$ and CI_{75} treatments.

As shown in Table 7, in the first year study the sedimentation volume for supplemental irrigation in grain filling stage ranged between 46.5 mm/l for irrigation level 25% to 33.43 mm/l for level 100%, however this range was varied from 41.6 mm/l for irrigation level 100% to 50.7 mm/l for level 25% under supplemental irrigation in flowering stage. In relation to year study of 2015, the combined effect of interaction between supplemental irrigation strategy and deficit irrigation regime reduced the sedimentation value of winter wheat from 41.8 to 29.5 mm/l under SIG strategy and from 43.8 to 37.8 mm/l in SIF strategy which correspond to deficit irrigation 25% and fully irrigated levels respectively, this results reflect the effect of good management of supplemental and deficit irrigation using single irrigation in sensitive time of growing (flowering or grain filling stage) to achieve high sedimentation values, consequently improving the bread-making properties.

The occurrence of water stress in winter season allowed a good sedimentation quality where the highest sedimentation volume was found in the grains grown under rain-fed, followed by supplemental irrigation in flowering stage level 25%, the lowest value was observed in full conventional irrigation with a decrease about 42.2% (in dry season) and reduced to 38.5% (in wet season) lower than rain-fed. This is in agreement with the conclusion of Erekul et al. (2012); Kiliç and Yağbasanlar (2010) who reported the sedimentation values changed depend on supplemental irrigation doses and limited water elevated grain quality by increasing sedimentation volume unit.

In general, the findings showed negative response between the quality parameters: protein ratio, wet gluten content and sedimentation volume, and water scarcity depend on the applied water quantity and which stage the stress occurred.

Table 4.7. The effect of interaction between the irrigation strategies and irrigation levels on grains quality properties of wheat in 2014 and 2015 seasons

Season	2014			2015		
Treatment	Protein ratio (%)	Wet gluten content (%)	Sedimentation value (mm/l)	Protein ratio (%)	Wet gluten content (%)	Sedimentation value (mm/l)
$SIFG_{100}$	12.20^{gh}	30.20^{gh}	35.7^{g}	12.40^{gh}	26.8^{gh}	31.2^{i}
$SIFG_{75}$	13.20^{e}	32.05^{e}	42.05^{e}	12.8^{fg}	29.6^{ef}	35^{g}
$SIFG_{50}$	13.25^{e}	32.40^{e}	43.10^{de}	13.90^{bcd}	30.3^{ed}	40.4^{de}
$SIFG_{25}$	14.2^{cd}	35.10^{c}	49.70^{b}	14.1^{ab}	33.1^{bc}	41.1^{cd}
CI_{100}	11.5^{i}	25.8^{i}	30.7^{i}	11.2^{j}	23.6^{i}	27.3^{k}
CI_{75}	12.65^{fg}	30.75^{fg}	36.00^{g}	12^{hi}	27.5^{g}	31.7^{i}
CI_{50}	13.10^{ef}	32.13^{e}	41.90^{e}	13.5^{cde}	28.9^{f}	36.8^{f}
CI_{25}	13.85^{d}	33.95^{d}	45.90^{c}	13.90^{bcd}	32.7^{c}	39.2^{e}
SIF_{100}	14.00^{d}	32.10^{e}	41.60^{e}	13.2^{ef}	30.5^{ed}	37.8^{f}
SIF_{75}	14.55^{bc}	32.60^{e}	44.80^{cd}	13.4^{de}	31.1^{d}	39.5^{e}
SIF_{50}	14.70^{bc}	36.30^{b}	49.20^{b}	14^{abc}	33.2^{bc}	43.1^{b}
SIF_{25}	14.86^{b}	36.70^{b}	50.7^{b}	14.2^{ab}	33.9^{ab}	43.8^{ab}
SIG_{100}	12.00^{h}	29.43^{h}	33.43^{h}	11.8^{i}	26.2^{h}	29.5^{j}
SIG_{75}	12.65^{fg}	31.05^{f}	39.15^{f}	12.3^{h}	28.6^{f}	32.9^{h}
SIG_{50}	13.83^{d}	33.93^{d}	44.90^{cd}	13.8^{bcd}	31.3^{d}	39.6^{e}
SIG_{25}	14.25^{cd}	35.30^{c}	46.50^{c}	14.10^{ab}	33^{bc}	41.8^{c}
RF	15.90^{a}	39.20^{a}	53.2^{a}	14.50^{a}	34.8^{a}	44.4^{a}

The similar letters - treatments have no significant differences

4.4.4. The Relations between Yield, Available Water and Grain Quality Characteristics

The relationships between grain yield and available water in 0.9 m soil depth and grain quality were presented in Figure 23. Under water stress conditions of dry year, the grain quality properties (protein ratio, wet gluten and sedimentation value) showed high regression coefficient with grain yield that recorded R^2=0.81, 0.89 and 0.85, however the corresponding values in the next year were 0.74, 0.81 and 0.84 respectively. The results are in confirmation with Aslani et al. (2013) who found that water stress in the post-anthesis (grain filling period) caused an increase

in protein content and sedimentation volume, consistent with a decrease in grain yield, 1000 grains weight, bread volume and wet gluten were observed when a terminal water stress happened. In relation to the response of grain yield to grain quality in this study, linear relationship of wheat grain yield and quality parameters were recorded highly negative and significant correlations. Similar findings were stated by Oury and Godlin (2007), who reported the protein contents, gluten quality and contents have significantly negative correlations with grain yield and thousand kernel weights under normal and stress conditions. It is known that yield reduction that generally occurs under water stress conditions is generally associated with an increase in protein content (Rharrabti et al., 2003a; Garrido-Lestache et al., 2005; Guttieri et al., 2005; Dupont et al., 2006; Pompa et al., 2009).

With reference to effect of available water in 0.9 m soil depth (as independent variable) on grain quality characteristics (as dependent variable), it was observed that when the available water in root zone decreases the wheat grain properties increases and the total yield decreases. The winter wheat quality parameters correlated significantly and negatively with available water in soil and this correlation was relatively higher in dry year (R^2= 0.76 and 0.80) compared to wet year (R^2= 0.73 and 0.79) for protein and wet gluten values, respectively. The statistical data expressed that grain quality responded well to applied water in root zone of wheat. The results were in agreement with Kanani et al. (2013) who reported that the effect of drought stress on gluten percentage was significant and increased in drought stress compared to normal condition. Ozturk and Aydin (2004) also confirmed present results and reported water stress increased grain protein, sedimentation volume, and wet gluten content relative to the fully irrigated treatment in winter bread wheat.

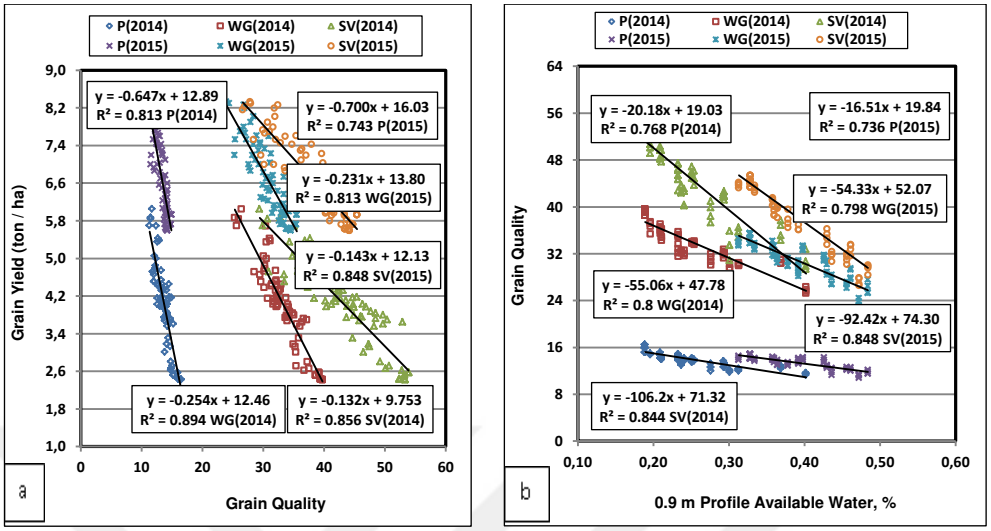

Figure 4.23. The relations between: a) grain yield and grain quality b) grain quality and available water in 0.9 m soil depth.

4.5. Economical Analysis

A few studies examined the appropriate conventional and supplemental irrigation dose and analyzed the economic return to determine the most economic irrigation system alternative. Hence the purpose of this part of the study is to evaluate and compare the economic feasibility of agriculture with conventional and supplemental irrigation (SI) strategies in the Mediterranean region in order to maximize the net benefit from optimal wheat production (no maximizing yield) and optimize SI amount especially under limited water and land resources.

The results obtained by the economical evaluation discussed separately for first and second wheat season due to the evaluation was under different climatic conditions during both years.

The wheat sales price was calculated integrating selling price of seeds and side products together which equaled 0.33 $/kg and the net income from one hectare of land for CI_{100} amounted to 601.12 $ in 2014 growing season. Data regarding 2015 was slightly greater in selling price per kg to 0.34 $ whereas the net income increased to 1236.17 $ due to increased the production yield. Prices in

dollars were determined according to Turkish Central Bank's exchange rates of 2.2 TL in 2014 and 2.4 TL in 2015. The total costs, gross income and net income of wheat under different irrigation strategies for the experimental years were presented in Tables 8 and 9.

The total costs in $/ha for full conventional irrigation were divided as following: irrigation labor cost 1.2%, water cost 4.1%, crop production 64.7% and yearly cost of irrigation system 30% in the first year. On the other hand, during 2015 season the corresponding percentages were 2.4, 27.3, 69.4 and 0.8%, respectively, for water cost, yearly cost of irrigation system, crop production and irrigation labor. The total costs of wheat production increased steadily with increasing applied water quantity from 25% to 100% irrigation level under each strategy where the highest value was recorded under CI_{100} from the 1335.32 $/ha in 2014 to 1571.66 $/ha in 2015 and the lowest value in rain-fed treatment as 863.6 and 1091.37 $/ha in 2014 and 2015, respectively. This increase in production costs for CI_{100} compared to RF treatment due to cost of irrigation labor, water cost and yearly cost of irrigation system in CI_{100}.

All the variable costs are fixed except irrigation cost because the experiment has different irrigation levels and to study the effect of irrigation strategies on net income.

Table 4.8. Total production costs and net income for wheat under different irrigation strategies during 2014 in Adana (Turkey)

Treatments	irrigation water (mm) (1)	irrigation water (m^3/ha) (2)	irrigation duration for the irrigation season (h)(3)	labor cost for irrigation ($/h) (4)	Total cost for irrigation labor ($) (5)	water price ($/$m^3$) (6)	water cost ($/ha) (7)	crop production costs ($/ha) (8)
CI_{100}	275.83	2758.3	11.03	1.5	16.55	0.02	55.17	863.6
CI_{75}	216.15	2161.5	8.65	1.5	12.97	0.02	43.23	863.6
CI_{50}	156.47	1564.7	6.26	1.5	9.39	0.02	31.29	863.6
CI_{25}	96.78	967.8	3.87	1.5	5.81	0.02	19.36	863.6
RF	.		.	.	.		.	863.6
$SIFG_{100}$	246.38	2463.8	9.86	1.5	14.78	0.02	49.28	863.6
$SIFG_{75}$	194.06	1940.6	7.76	1.5	11.64	0.02	38.81	863.6
$SIFG_{50}$	141.74	1417.4	5.67	1.5	8.50	0.02	28.35	863.6
$SIFG_{25}$	89.42	894.2	3.58	1.5	5.37	0.02	17.88	863.6
SIF_{100}	149.15	1491.5	5.97	1.5	8.95	0.02	29.83	863.6
SIF_{75}	121.14	1211.4	4.85	1.5	7.27	0.02	24.23	863.6
SIF_{50}	93.13	931.3	3.73	1.5	5.59	0.02	18.63	863.6
SIF_{25}	65.11	651.1	2.60	1.5	3.91	0.02	13.02	863.6
SIG_{100}	246.59	2465.9	9.86	1.5	14.80	0.02	49.32	863.6
SIG_{75}	194.22	1942.2	7.77	1.5	11.65	0.02	38.84	863.6
SIG_{50}	141.85	1418.5	5.67	1.5	8.51	0.02	28.37	863.6
SIG_{25}	89.47	894.7	3.58	1.5	5.37	0.02	17.89	863.6

Treatments	irrigation system cost for 1 ha ($/ha) (9)	yearly cost for the irrigation system ($/ha) (9/10 years) (10)	total cost for 1 year ($/ha) (11)	yield (kg/ha) (12)	wheat sales price ($/kg) (13)	gross income per ha. ($/ha/ year) (14)	net income ($/ha/year) (15)
CI_{100}	4000	400	1335.32	5868	0.33	1936.44	601.12
CI_{75}	4000	400	1319.80	5466	0.33	1803.78	483.98
CI_{50}	4000	400	1304.28	4181	0.33	1379.73	75.45
CI_{25}	4000	400	1288.76	3803	0.33	1254.99	-33.77
RF	.	.	863.6	2490	0.33	821.7	-41.90
$SIFG_{100}$	4000	400	1327.66	4910	0.33	1620.3	292.64
$SIFG_{75}$	4000	400	1314.06	4518	0.33	1490.94	176.88
$SIFG_{50}$	4000	400	1300.45	4182	0.33	1380.06	79.61
$SIFG_{25}$	4000	400	1286.85	3793	0.33	1251.69	-35.16
SIF_{100}	4000	400	1302.38	4138	0.33	1365.54	63.16
SIF_{75}	4000	400	1295.10	4211	0.33	1389.63	94.53
SIF_{50}	4000	400	1287.81	3649	0.33	1204.17	-83.64
SIF_{25}	4000	400	1280.53	2705	0.33	892.65	-387.88
SIG_{100}	4000	400	1327.71	4670	0.33	1541.1	213.39
SIG_{75}	4000	400	1314.10	4380	0.33	1445.4	131.30
SIG_{50}	4000	400	1300.48	3875	0.33	1278.75	-21.73
SIG_{25}	4000	400	1286.86	3159	0.33	1042.47	-244.39

Table 4.9. Total production costs and net income for wheat under different irrigation strategies during 2015 in Adana (Turkey)

Treatments	irrigation water (mm) (1)	irrigation water (m^3/ha) (2)	irrigation duration for irrigation season (h)(3)	labor cost for irrigation($/h) (4)	Total cost for irrigation labor ($)(5)	water price ($/$m^3$) (6)	water cost ($/ha) (7)	crop production costs ($/ha) (8)
CI_{100}	187.64	1876.4	7.51	1.7	12.76	0.02	37.53	1091.37
CI_{75}	140.73	1407.3	5.63	1.7	9.57	0.02	28.15	1091.37
CI_{50}	93.82	938.2	3.75	1.7	6.38	0.02	18.76	1091.37
CI_{25}	46.91	469.1	1.88	1.7	3.19	0.02	9.38	1091.37
RF	.		.	.	.		.	1091.37
$SIFG_{100}$	163.11	1631.1	6.52	1.7	11.09	0.02	32.62	1091.37
$SIFG_{75}$	122.33	1223.3	4.89	1.7	8.32	0.02	24.47	1091.37
$SIFG_{50}$	81.56	815.6	3.26	1.7	5.55	0.02	16.31	1091.37
$SIFG_{25}$	40.78	407.8	1.63	1.7	2.77	0.02	8.16	1091.37
SIF_{100}	72.8	728	2.91	1.7	4.95	0.02	14.56	1091.37
SIF_{75}	54.6	546	2.18	1.7	3.71	0.02	10.92	1091.37
SIF_{50}	36.4	364	1.46	1.7	2.48	0.02	7.28	1091.37
SIF_{25}	18.2	182	0.73	1.7	1.24	0.02	3.64	1091.37
SIG_{100}	144.31	1443.1	5.77	1.7	9.81	0.02	28.86	1091.37
SIG_{75}	108.23	1082.3	4.33	1.7	7.36	0.02	21.65	1091.37
SIG_{50}	72.16	721.6	2.89	1.7	4.91	0.02	14.43	1091.37
SIG_{25}	36.08	360.8	1.44	1.7	2.45	0.02	7.22	1091.37

Treatments	irrigation system cost for 1 ha ($/ha) (9)	yearly cost for irrigation system ($/ha) (9/10 years) (10)	total cost for 1 year ($/ha) (11)	yield (kg/ha) (12)	wheat sales price ($/kg) (13)	gross income per ha. ($/ha/year) (14)	net income ($/ha/year) (15)
CI_{100}	4300	430	1571.66	8258	0.34	2807.83	1236.17
CI_{75}	4300	430	1559.09	8097	0.34	2752.86	1193.78
CI_{50}	4300	430	1546.51	7258	0.34	2467.83	921.32
CI_{25}	4300	430	1533.94	6533	0.34	2221.33	687.39
RF	.	.	1091.37	5723	0.34	1945.93	854.56
$SIFG_{100}$	4300	430	1565.08	7675	0.34	2609.50	1044.42
$SIFG_{75}$	4300	430	1554.15	7496	0.34	2548.58	994.43
$SIFG_{50}$	4300	430	1543.23	6375	0.34	2167.50	624.27
$SIFG_{25}$	4300	430	1532.30	6004	0.34	2041.41	509.12
SIF_{100}	4300	430	1540.88	6842	0.34	2326.16	785.28
SIF_{75}	4300	430	1536.00	6792	0.34	2309.16	773.16
SIF_{50}	4300	430	1531.13	5988	0.34	2035.75	504.62
SIF_{25}	4300	430	1526.25	5745	0.34	1953.30	427.05
SIG_{100}	4300	430	1560.05	7367	0.34	2504.66	944.62
SIG_{75}	4300	430	1550.38	7067	0.34	2402.66	852.29
SIG_{50}	4300	430	1540.71	6183	0.34	2102.05	561.34
SIG_{25}	4300	430	1531.04	5923	0.34	2013.93	482.89

The gross income was estimated using average market price of wheat grain and rest plants in Adana / Turkey, that the gross income per hectare of wheat decreased gradually by decreasing the yield production in both the years of study that ranged in 2014 from 1620.3 $/ha in $SIFG_{100}$ to 1251.69 $/ha in $SIFG_{25}$ and from 1365.54 to 892.65 $/ha in SIF_{100} and SIF_{25}, this rate of gross income was higher during the next year resulted in higher yield that varied from 2326.16 to 1953.3 $/ha for SIF_{100} and SIF_{25} and ranged (2609.5 - 2041.41 $/ha) under full and 25% irrigation level of SIFG strategy, however 821.7 and 1945.93 $/ha were recorded under rain-fed treatment in both dry and wet seasons respectively.

In the growing season 2014, the lower deficit irrigation levels $SIG_{25,50}$, $SIF_{25,50}$, $SIFG_{25}$ and CI_{25} resulted in negative net income amounted -244.39, -21.73, -387.88, -83.64, -35.16 and -33.77 $/ha that means the production costs are greater than the gross return. The lowest negative net income appeared in treatment SIG_{50} as compared to CI_{100} and net income difference between these treatments amounted to 622.86 $/ha. SIG_{50} resulted in water savings of 48.6% and in yield reduction of 34% in comparison to CI_{100}, however the highest negative net income value occurred in SIF_{25} treatment. The reduction in net income value in SIF_{25} amounted to 989 $/ha along with water savings of 76.4% and 53.9% losses in yield (Table 10). Similar results are reported by Ali et al. (2007) that the net return of wheat fluctuated between positive and negative values depending on irrigation quantity and crop production costs. In the second growing season, the net income values for the irrigation strategies were all positive that refers to the gross income values were higher than the production costs. Consequently the reduction in net income appeared lower in the second season in comparison with the first season (except $SIFG_{50,25}$, SIF_{50} and SIG_{50} treatments). The lowest net income generated in SIF_{25} treatment with a reduction of 809.12 $/ha in net income and with water saving of 90.3% and yield reduction of 30.4%, whereas the reduction of net income and water saving of SIG_{50} in 2015 were higher with a value recorded as 674.83 $/ha and 61.5% but yield losses was lower than first year which amounted to 25.1%.

Table 4.10. The relative yield and net income, and water savings for each treatment in the both years of 2014 and 2015

Treatments	2014				2015			
	The loss in net income ($)	The loss in yield (%)	Saving in water (%)	saving in water (m^3)	The loss in net income ($)	The loss in yield (%)	Saving in water (%)	saving in water (m^3)
CI_{100}	0.00	00	00	0.0	00.00	00	00	0.0
CI_{75}	117.14	07	22	596.8	42.40	02	25	469.1
CI_{50}	525.68	29	43	1193.6	314.86	12	50	938.2
CI_{25}	634.90	35	65	1790.5	548.78	21	75	1407.3
RF	643.02	58	100	2758.3	381.61	31	100	1876.4
$SIFG_{100}$	308.48	16	11	294.5	191.76	07	13	245.3
$SIFG_{75}$	424.24	23	30	817.7	241.75	09	35	653.1
$SIFG_{50}$	521.52	29	49	1340.9	611.90	23	57	1060.8
$SIFG_{25}$	636.28	35	68	1864.1	727.06	27	78	1468.6
SIF_{100}	537.96	29	46	1266.8	450.89	17	61	1148.4
SIF_{75}	506.59	28	56	1546.9	463.01	18	71	1330.4
SIF_{50}	684.77	38	66	1827.0	731.55	27	81	1512.4
SIF_{25}	989.00	54	76	2107.2	809.12	30	90	1694.4
SIG_{100}	387.74	20	11	292.4	291.56	11	23	433.3
SIG_{75}	469.82	25	30	816.1	383.89	14	42	794.1
SIG_{50}	622.86	34	49	1339.8	674.83	25	62	1154.8
SIG_{25}	845.52	46	68	1863.6	753.28	28	81	1515.6

Regarding the rain-fed treatment in 2014 season, it generated negative net return but this net return (-41.9 $/ha) was greater than those in deficit supplemental irrigation treatments $SIF_{50,25}$ and SIG_{25} which resulted in net returns of -83.64, -387.88 and -244.39 $/ha, respectively. Generally, similar results were obtained in 2015 growing season with difference that the values of net return of mentioned treatments were positive, the net return of the rain-fed treatment (854.56 $/ha) was higher than all irrigation levels of SIF strategy, which ranged for 25 - 100% irrigation levels from 427.05 to 785.28 $/ha. Furthermore the rain-fed treatment generated greater net income than CI_{25}, $SIFG_{50,25}$ and $SIG_{50,25}$ treatments with net return averages were 687.39, 624.27, 509.12, 561.34 and 482.89 $/ha, respectively. The decrease in net income of abovementioned supplemental irrigation treatments compared to rain-fed treatment caused by the irrigation costs (irrigation labor costs, water cost and yearly cost of irrigation system). Hence, it is recommended that

planting wheat under rain-fed condition is more profitable than applying supplemental irrigation during flowering (level 50% and 25%) and grain filling stage (level 25%) under dry years and using sprinkler system; in wet years, applying supplemental irrigation during flowering, grain filling (level 25% and 50%) and in both stages flowering and grain filling (level 25% and 50%) since these are less profitable than rain-fed conditions.

Regarding the full supplemental strategies in the first year, applying two irrigation during flowering and grain filling stages $SIFG_{100}$ generated the highest net income (292.64 $/ha) followed by two irrigations in grain filling stage SIG_{100} with 213.39 $/ha, then single irrigation in flowering stage SIF_{100} with value of 63.16 $/ha. For moderate level 75% of supplemental irrigation, SIF_{75} revealed with highest loss in net income (506.59 $/ha), however the lowest value was found in $SIFG_{75}$ (424.24 $/ha). Under level 50%, $SIFG_{50}$ produced positive net income but SIG_{50} and SIF_{50} achieved negative net income due to reduction of wheat production. In relation to data of full supplemental irrigation strategies of 2015 year, the maximum and the minimum values of net income were found 1044.42 and 785.28 $/ha which correspond to the treatments SIFG and SIF respectively, and it noticed slight decrease for moderate irrigation level 75% (compared to full supplemental irrigation) of the same treatments which achieved 994.43 and 773.16 $/ha in $SIFG_{75}$ and SIF_{75} respectively. As for lowest water regime (25%), the net income values relatively exhibited higher (compared to dry year) which averaged 509.12, 427.05 and 482.89 $/ha for $SIFG_{25}$, SIF_{25} and SIG_{25} treatments respectively.

The economical analysis of wheat production revealed that generally, the yield increase due to applied irrigation that in turn increase gross income higher than the production costs, consequently increasing net incomes, thus applying the highest irrigation quantity (2758.3 m^3/ha) in CI_{100} achieved the highest yield 5868 kg/ha and net income 601.12 $/ha in dry year. In this respect, the ET of CI_{100} increased from 485 mm in dry year to 645 mm in wet year, consequently the net

income increased to 1236.17 $/ha. These findings are in agreement with the conclusion of Eid et al. (2014) who indicated the net income of wheat changed between -199 and 1289.3 $/ha depending on sprinkler system and irrigation frequency. The full conventional irrigation strategy surpassed the other full supplemental irrigation strategies on net income per hectare with increase amounted to 308.48, 537.96 and 387.74 $/ha for $SIFG_{100}$, SIF_{100} and SIG_{100}, respectively, in 2014 growing season. The reduction in net income during the wet season was lower due to difference in yield production between full irrigation treatments was lower, and the net income reductions were 191.76, 450.89 and 291.56 $/ha for $SIFG_{100}$, SIF_{100} and SIG_{100}, respectively. Regarding water savings, the mentioned full supplemental irrigation treatments resulted in water savings of 294.5 m^3 (10.7%), 1266.8 m^3 (45.9%) and 292.4 m^3 (10.6%) respectively in comparison with CI_{100} in the first year, however water savings in the second year reached to 245.30 m^3 (13.1%), 1148.40 m^3 (61.2%) and 433.30 m^3 (23.1%), respectively. Hence, when the water resources relatively are abundant, the grower will select the strategy that maximizes net income per unit land, thus the treatment C_{100} is the appropriate strategy under these conditions.

In reference to the first growing season, the applied water of full supplemental irrigation SIFG 2463.8 m^3 was close to full supplemental strategy (SIG) 2465.9 m^3 but the $SIFG_{100}$ strategy dominated on SIG_{100} strategy in net income with difference amounted 37.1%, in another season (2015) the $SIFG_{100}$ treatment was 10.5% higher than SIG_{100} treatment in net income, so it is concluded to develop optimal irrigation management for supplemental irrigation strategies, irrigation at flowering and grain filling development stages were more economical to achieve higher grain production and net income of wheat.

In spite of the irrigation quantity of $SIFG_{100}$ strategy (2463.8 m^3) higher than deficit conventional irrigation level 75% (2161.5 m^3) in the first experimental year, the yield and net income of $SIFG_{100}$ were 10.1 and 39.5% lower than CI_{75}. In the second season, the results confirmed the first year where the applied water in

$SIFG_{100}$ treatment (1631.1 m^3) was higher than CI_{75} treatment (1407.30 m^3) but net income and yield were higher by 12.5% and 5.2% for CI_{75} in comparison with $SIFG_{100}$, which refer to using early single irrigation more (at heading stage) under CI_{75} in both years of study. In this respect, the results confirm the appropriate irrigation scheduling can reduces the irrigation water requirements of crop and produces more yield and net financial income of wheat. On the other hand deficit irrigation treatment CI_{75} attained the best economical profits per applied water unit in hectare (after full irrigation) and saved irrigation water by 21.6% and 25.0% with small grain yield loss of 6.9% and 2.0% as compared to full conventional irrigation for crop season 2014 and 2015 respectively, hence it can be concluded that for maximizing yield and net income under limited water resources conditions (exactly when the water is scare or water costs are high), preference should be given to irrigate first with deficit irrigation treatment CI_{75} then full supplemental irrigation in flowering and grain filling stages, moreover the saved water by a reduction in irrigation might be applied to irrigate additional lands, thus raising the net income of wheat production unit, so the results of this study provide database for making irrigation management decisions.

4.5.1. The Relation between Yield and Net Income of Wheat

The regression equation of grain yield against net income was shown in Figure 24. The present results indicated high positive and significant relation between the grain yield and net income that recorded 0.71 and 0.55 in the first and second seasons, respectively. These findings are in line with many studies concluded that deficit irrigation can increase net farm income (English et al., 1990; Martin et al., 1989; Kumar and Khepar, 1980; Fardad and Golkar, 2002; Zhang et al., 2002).

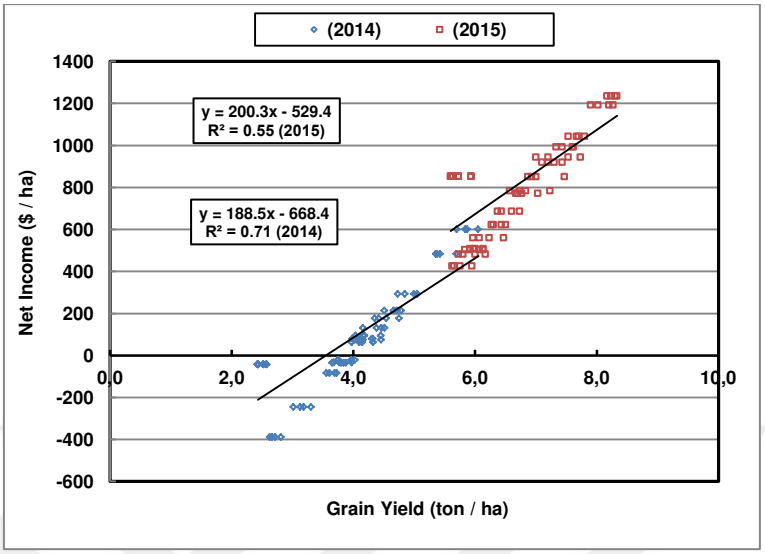

Figure 4.24. The relation between wheat grain yield and net income during the growing seasons

5. CONCLUSIONS

With reference to irrigation scheduling of supplemental irrigation, terminating irrigation at grain filling stage (SIF_{100} strategy) decreased the grain yield to 29 and 17% in dry and wet years as compared to full conventional strategy. However, this decrease reached to 20 and 10% when irrigation was cut off at flowering stage (SIG_{100} strategy), that means irrigation during grain filling stage can increase yield by 12 and 7% as compared to SIF_{100} strategy in both years of 2014 and 2015.

In general, the deficit irrigation level 75% for all supplemental irrigation strategies (SIF_{75},SIG_{75} and $SIFG_{75}$) raised the water use efficiency and irrigation water use efficiency to the greatest values (except IWUE of SIFG treatment in the first year) compared to other levels (25, 50 and 100%) in both years 2014 and 2015, therefore the deficit irrigation level 75% can be considered as the appropriate schedule of irrigation instead of full irrigation under each strategy for maximizing WUE and IWUE which lead to saving more water and achieving the better economic wheat grain yield under supplemental irrigation conditions in regions which facing water scarcity.

The seasonal evapotranspiration affected the biomass production markedly that decreasing ET from 528.8 to 399.9 mm for SIF_{75} and from 570.6 to 421.6 mm for $SIFG_{75}$ in wet and dry seasons led to decreased biomass yield that amounted to 35.5 and 31.8%, respectively. Statistically, the strong positive linear relationships between yield and other parameters such as biomass and 1000 grain-weight reflected the effect of those parameters to increase (or develop) winter wheat production under the Mediterranean region.

The soil water content in advanced growth stages reached below WP for drought stress treatments (25%) of CI and SIFG strategy, and (75, 50 and 25%) of SIF strategy in the dry cropping season, however remained between field capacity and wilting point during the wet growing season. Generally, monitoring SWC of

conventional strategy was carried out depend on plant water requirements instead of winter wheat growth stage in supplemental irrigation strategies.

The greatest harvest index was obtained from CI_{75} (0.43), whereas the lowest value was in RF (0.37) in wet season, however the corresponding highest and lowest values were under SIG_{50} and (CI_{50} and RF) treatments respectively in the dry growing season. The full SIF treatment decreased grains number per spike to 10.3, 12.75 and 6.1% in comparison with other full irrigation strategy SIFG, CI and SIG respectively.

The lowest grain yield was observed under the drought stress treatment (rain-fed) which achieved the minimum of LAI (positive correlation between LAI and grain yield), that RF treatment decreased LAI and grain yield by 49.2 and 57.5% in the first season and by 39.4 and 30.6% in the second season lower than full conventional irrigation treatment.

These results confirmed the wheat was not equally sensitive to water stress during growth stages, where the crop with higher K_y (SIF strategy) suffered a greater yield loss than the other strategies. Thus according to present study supplemental irrigation during grain filing or during both flowering and grain filling more sensitive and effective to increase the yield in comparison with irrigation under SIF strategy. Hence crop response factor can be used for planning the wheat production strategies especially when the water resources are limited.

The lower baselines developed were represented by the equations LL=-1.2158 VPD+0.4916 (R^2=0.54) and LL=-1.107 VPD+0.774 (R^2=0.49) in the first and second growing seasons. Statistically, the grain yield correlated with CWSI in the phenological stages of pre and post-anthesis, that leads to use CWSI as an index for predicting yield of winter wheat, furthermore, the linear equations in wheat growing seasons between CWSI and available water / 90 cm depth: CWSI=-3.25 AW+1.30 (R^2=0.59) and CWSI=-1.85 AW +1.05 (R^2=0.67) can be used to monitor crop water status by observing the increase of canopy temperature with decreasing soil water content. The highest range of grain yield recorded 5868-4138

and 8258-6841 kg/ha for CI_{100} and SIF_{100} in the dry and wet seasons, these yield values correspond to irrigations scheduled at a CWSI value less than 0.26. Based on these results it can be concluded that CWSI is a practical tool for timing the irrigation scheduling.

It was observed in the field that the morphological relationship between leaf greenness, leaf thickness and SPAD values where in flowering stage the flag leaf greenness was lighter and with advancing the growth stage until watery and milky grain filling stages the flag leaf became more thicker and the greenness color (chlorophyll content) became more darker, thus the SPAD readings reached to its maximum values in this stage compared to other crop growth stages.

Based on the study data, it was noticed that the SPAD readings in the second year relatively were a little higher and the differences between treatments and strategies were lower refers to the effect of increasing the soil moisture of roots zone during each growth stage in the wet season compared to the dry year, and the SPAD index values of irrigation treatments differed also depend on growth stage where the flowering, watery and milky grain stages were the most appropriate growing stages to identify differences between treatments as confirmed by SPAD readings.

The differences in stomatal conductance g_s were found in both of flowering and early grain filling (watery grain filling) stages and changed depend on alternation of drying and wetting soil (soil water deficit), where g_s was higher in the well-watered plants of all strategy as compared to water deficit conditions.

The full conventional irrigation treatment overtopped on all three full supplemental irrigation treatments in the first year (142 DAP), however there was no significant differences between CI_{100} and SIG_{100} in the second year (140 DAP) depends on irrigation scheduling system that water drought affects stomatal behavior which imbalance the photosynthesis that led to reduce yield production.

The findings confirmed the effect of applied water on midday flag leaf water potential Ψ_l that high irrigation levels 75 and 100% had significantly higher than

irrigation level 25% and rain-fed for all irrigation strategies (except SIF strategy) during both growing seasons. Additionally, midday Ψ_l decreased depending on drying and wetting cycle of soil water content, and with advancing growth stages that it ranged from -17.9 to -25.4 bar in dry season and -16.3 to -23.7 bar in the wet season, where Ψ_l during the milky grain stage decreased to more negative values as compared to the early stage of watery grain filling.

The treatment $SIFG_{75}$ resulted in the water saving of 33% compared to full conventional irrigation and increased the average protein ratio to 14.5%. Based on these results the $SIFG_{75}$ coalition can be considered economically the best for saving more water and with acceptable protein quality. Thus it could be concluded that under dry conditions in the Mediterranean area in order to obtain suitable bread making quality combined with high saved water, supplemental irrigation at flowering and grain filling level 75% could be recommended.

The results illustrated that using single irrigation at flowering stage not only saved irrigation water about 45.9 and 39.4% compared with CI_{100} and SIG_{100}, but also increased the gluten content to 24.4 and 9.0% in the 2014 growing season. The second season results indicated that when the water stress occurred in grain filling stage (SIF strategy), the saved irrigation water up to 61.2 and 49.5% in comparison that of full conventional irrigation and fully irrigated at grain filling, and increased wet gluten content by 29.2 and 16.4%. Hence it appeared that the effect of water stress which generally occurs during the grain development stage under Mediterranean area caused higher gluten content that was reflected in improving the wet gluten technological quality character.

The occurrence of water stress in winter season allowed a good sedimentation quality where the highest sedimentation volume was found in the grains grown under rain-fed, followed by supplemental irrigation in flowering stage level 25%, and the lowest value was observed in full conventional irrigation with a decrease about 42.2% (in dry season) and reduced to 38.5% (in wet season) lower than rain-fed.

The amount of water applied in full supplemental irrigation $SIFG_{100}$ (2463.8 m^3) in the growing season of 2014 was close to full supplemental strategy SIG_{100} (2465.9 m^3) but the $SIFG_{100}$ strategy dominated SIG_{100} strategy in net income with difference amounted to 37.1%, in the second season (2015) the $SIFG_{100}$ treatment generated 10.5% higher net income than SIG_{100} treatment, thus we concluded that in order to develop optimal irrigation management for supplemental irrigation strategies, irrigating at flowering and grain filling development stages were more economical to achieve higher wheat grain production and net income.

The conventional deficit irrigation treatment CI_{75} generated economical profits just second to CI_{100} per hectare and saved irrigation water by 21.6 and 25.0% with slight grain yield loss of 6.9 and 2.0% as compared to full conventional irrigation for crop season of 2014 and 2015, respectively. Hence it can be concluded that for maximizing yield and net income when the water is scare or water costs are high, preference should be given to irrigate first with deficit irrigation treatment CI_{75} then full supplemental irrigation in flowering and grain filling stages, moreover the saved water by CI_{75} in irrigation might be applied to irrigate additional lands, thus raising the net income of wheat production, so the results of this study provide database for making irrigation management decisions.

The supplemental strategy $SIFG_{75}$ resulted in 30 and 35% water savings and yield reduction of 23 and 9% in comparison to CI_{100} in dry and wet growing seasons, respectively, consequently the full conventional irrigation strategy can be recommended for obtaining greater grain and biomass yields, however, for water saving in drought years, supplemental irrigation SIFG strategy with 75% irrigation level can be recommended for sustainable wheat production in the Mediterranean region.

RESEARCH HIGHLIGHTS

Research Highlights (1)

- Irrigation at grain filling stage increased yield on the average 10.2% as compared to irrigation at flowering stage.
- Compared with CI_{100}, the deficit supplemental irrigation treatment $SIFG_{75}$ resulted in 33% water saving and 16% yield decrease.
- The deficit supplemental irrigation level 75% achieved the highest WUE and IWUE compared to other irrigation levels in each supplemental strategy
- The yield response factor K_y value varied depending on water stress and growth stage where the smallest value was obtained under conventional strategy and greatest value under supplemental irrigation during flowering. Hence crop response factor can be used for planning the wheat production strategies especially when the water resources are limited.
- The deficit irrigation treatment CI_{75} saved water by 23.3% with small grain yield loss 4.35% compared to full conventional irrigation.

Research Highlights (2)

- The highest grain yield was obtained when the irrigation was applied at CWSI less than 0.26
- Midday LWP values can be applied as an indicator for monitoring the irrigation scheduling
- The highest chlorophyll reading of CI_{100} increased by 17.8% over the lowest value in RF where SPAD reached to its maximum value in watery and milky grain stages.
- The higher grain yield was achieved when the seasonal g_s reached to 207.4 mmol/m^2s in CI and to 169.21 mmol/m^2s in SI.

Research Highlights (3)

- Applying Single irrigation in sensitive time of growing (flowering or grain filling stage) improved grain quality higher compared with conventional irrigation.
- Compared with CI_{100}, the deficit supplemental irrigation treatment $SIFG_{75}$ resulted in 14.5% protein ratio increase.
- Using single irrigation at flowering stage saved irrigation water by 53.5 and 44.5% and increased wet gluten content to 26.8 and 12.7% compared with conventional and supplemental irrigation at grain filling stage.
- Lower deficit irrigation treatments generated negative net income in dry season and positive in wet season.
- Two irrigations in flowering and grain filling stages (SIFG) increase net income to 15.4% compared to two irrigations in grain filling stage.
- In spite of the irrigation amount of deficit conventional irrigation (CI_{75}) was less than $SIFG_{100}$ the yield and net income were 26 and 7.65% greater than $SIFG_{100}$.

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CURRICULUM VITAE

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APPENDIX

Appendix 1. Analysis of variance showing the mean squares of water and crop Characteristics in 2014 and 2015 wheat growing seasons

Season	2013/2014			
Studied Parameters	Irrigation strategies (A)(df=3)	Irrigation levels (B)(df=4)	(AxB)(df=12)	CV(%)
WUE (kg/m^3)	0.10665458^{**}	0.15938313^{**}	0.01872229^{**}	3.0
$^{+}$IWUE (Kg/m^3)	0.41651250^{**}	0.15662083^{**}	0.35709167^{**}	8.6
Grain yield (Kg/ha)	3091296.35^{**}	15280193.72^{**}	418579.09^{**}	3.1
Biomass yield (Kg/ha)	54772572.0^{**}	93012542.5^{**}	4236111.9^{**}	8.4
Harvest Index	0.01056115^{**}	0.00795726^{**}	0.00300573^{**}	7.1
Leaf Area Index	2.73408500^{**}	5.94543000^{**}	0.45399750^{ns}	12.4
1000 grain-Weight (g)	95.9238300^{**}	445.515364^{**}	10.333510^{ns}	6.6
Number of grains/spike	163.236460^{**}	2679.38594^{**}	39.452600^{**}	8.8
Season	2014/2015			
WUE (kg/m^3)	0.01830667^{**}	0.03097063^{**}	0.00243896^{**}	1.9
IWUE (Kg/m^3)	1.56725208^{**}	1.65118333^{**}	0.82806875^{**}	12.1
Grain yield (Kg/ha)	3318812.83^{**}	10181436.64^{**}	274051.570^{**}	1.9
Biomass yield (Kg/ha)	10588819.0^{**}	35807352.10^{**}	1306848.80^{*}	4.5
Harvest Index	0.00147693^{**}	0.004512520^{**}	0.00025357^{ns}	3.5
Leaf Area Index	1.40426167^{**}	10.58767313^{**}	0.30064396^{*}	12.6
1000 grain-Weight (g)	38.0945310^{ns}	1136.985156^{**}	5.57890600^{ns}	8.9
Number of grains/spike	47.0241679^{**}	168.2042612^{**}	5.43430120^{ns}	4.4

^{ns} Indicates non significance, * and ** indicate significance at 5 and 1% respectively. $^{+}$ IWUE under irrigation levels (B) (df=3) and under (AxB) (df=9)

Appendix 2. Analysis of variance showing the mean squares of seasonal physiological parameters and grains quality properties in 2014 and 2015 seasons

Season	2013/2014			
Studied Parameters	Irrigation strategies (A)(df=3)	Irrigation levels (B)(df=4)	(A x B) (df=12)	CV (%)
CWSI	0.03809588^{**}	1.14131971^{**}	0.00267446^{ns}	12.3
SPAD units	15.3253333^{**}	56.9745625^{**}	1.7868958^{ns}	3.3
g_s (mmol/m^2s)	4965.28712^{**}	16783.69656^{**}	503.78181^{**}	9.9
Ψ_l(bar)	10.8237413^{**}	26.0743419^{**}	1.2148235^{**}	-1.6
Protein content (%)	7.41145830^{**}	27.05312500^{**}	0.8381250^{**}	2.4
Wet gluten content (%)	30.3521250^{**}	222.4717500^{**}	5.0498333^{**}	1.6
Sedimentation value (mm/l)	143.221125^{**}	756.0793750^{**}	15.803208^{**}	2.8
Season	2014/2015			
CWSI	0.03401667^{**}	0.23182375^{**}	0.00254375^{ns}	11.6
SPAD units	18.7028546^{**}	122.306995^{**}	1.8660817^{ns}	2.2
g_s (mmol/m^2s)	4506.40707^{**}	8880.55390^{**}	875.84545^{**}	5.3
Ψ_l(bar)	8.06022000^{**}	20.5105200^{**}	0.98172000^{**}	-2.1
Protein content (%)	2.54666667^{**}	15.93700000^{**}	0.53166667^{**}	2.4
Wet gluten content (%)	34.6153333^{**}	161.0550000^{**}	5.31366670^{**}	2.3
Sedimentation value (mm/l)	119.666000^{**}	437.5130000^{**}	12.6676670^{**}	2.0

Appendix 3. Measurements scheduling as date and days after planting (DAP) during the 2014 and 2015 cropping seasons

Parameter	Biomass D. M.		LAI		CWSI		SPAD		g_s	
Season	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
Date and days after planting	17/2/2014 (88 DAP)	16/4/2015 (130 DAP)	17/2/2014 (88 DAP)	16/4/2015 (130 DAP)	24/2/2014 (95 DAP)	13/4/2015 (127 DAP)	21/3/2014 (120 DAP)	10/4/2015 (124 DAP)	21/3/2014 (120 DAP)	8/4/2014 (122 DAP)
	6/3/2014 (105 DAP)	22/4/2015 (136 DAP)	5/3/2014 (104 DAP)	22/4/2015 (136 DAP)	23/3/2014 (122 DAP)	20/4/2015 (134 DAP)	3/4/2014 (133 DAP)	19/4/2015 (133 DAP)	2/4/2014 (132 DAP)	18/4/2015 (132 DAP)
	20/3/2014 (119 DAP)	29/4/2015 (144 DAP)	20/3/2014 (119 DAP)	29/4/2015 (143 DAP)	6/4/2014 (136 DAP)	25/4/2015 (139 DAP)	10/4/2014 (140 DAP)	5/5/2015 (149 DAP)	12/4/2014 (142 DAP)	26/4/2015 (140 DAP)
	5/4/2014 (135 DAP)	6/5/2015 (152 DAP)	5/4/2014 (135 DAP)	6/5/2015 (150 DAP)	22/4/2014 (152 DAP)	5/4/2015 (149 DAP)	17/4/2014 (147 DAP)	13/5/2015 (157 DAP)	25/4/2014 (155 DAP)	6/5/2015 (150 DAP)
	18/4/2014 (148 DAP)	20/5/2015 (164 DAP)	18/4/2014 (148 DAP)	20/5/2015 (164 DAP)	5/5/2014 (165 DAP)	12/5/2015 (156 DAP)	1/5/2014 (161 DAP)	21/5/2015 (165 DAP)	3/5/2014 (163 DAP)	14/5/205 (158 DAP)
	30/4/2014 (160 DAP)	9/6/2015 (184 DAP)	30/4/2014 (160 DAP)				7/5/2014 (167 DAP)			
	22/5/2014 (182 DAP)									