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Original Research Article

"Water-use efficiency and ammonium-N source applied of wheat under irrigated and desiccated conditions"

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ABSTRACT

Pot experiment laid out to study the effects of watering, nitrogen fertilization, and their interactions on the growth, dry matter production and water use efficiency of two cultivars(Egyptian Sakha94 cultivated in 2009/2010 season and Turkish Adana99 cultivated in 2010/2011 season) of wheat. The experiment laid out in randomized complete design. Cultivars were grown in pots at the greenhouse of the Faculty of Life and Environmental Science, Shimane University during 2009/2010 and 2010/2011 growing seasons. Two watering levels started after booting stage (well-watered and desiccated) and five nitrogen fertilization levels0.0,0.24,0.48,0.72 and 0.96 g pot^{-1} (0.0,75,150,225,300 kg N h^{-1}) respectively, were designed.Our objective was to determine the effect of nitrogen (N) from ammonium sulfate split-applied at different rates before anthesis on water use efficiency under well-watered and desiccated conditions in the recent Egyptian cultivarSakha94 and Turkish Adana99 used in pots. The results showed that the leaf area, shoot dry matter production at anthesis, total dry matter production, number of spikelet's spike^{-1}, number of spikelet's pot^{-1} ,number of spikes pot^{-1},spad value after sowing to anthesis time, consumptive use and water use efficiency of wheat increased with increasing level of nitrogen under well-watered conditions for both cultivars, but the stomatal conductance and transpiration rate decreased under desiccated conditions. No significantly difference among N levels under desiccated conditions.It was considered that under our experimental condition applied 0.96 g N pot^{-1} (300 kg N ha^{-1}) led to significantly increase in WUE in both cultivars under irrigated and desiccated conditions. However, WUE was significantly higher in desiccated conditions than irrigated conditions in in Sakha94 than Adana99. May the primary cause of increased WUE, decreasing leaf chlorophyll concentration, photosynthesis rate and stomatal conductance (g_s).

Keywords: transpiration rate, water use efficiency, nitrogen, water, Stomatal conductance (g_s).

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1. INTRODUCTION

Wheat (*Tritium aestivum*, L.) is the most important grain crop for bread flour and straw crop for livestock feed in Egypt [1].The recent wheat production of 8.8 million tons [2] in Egypt was not sufficient to keep up with the population growth, and hence yield increases are greatly anticipated [3].Nitrogen (N) is the most effective fertilizer element to increase wheat yield [4]. In the Nile basin in Egypt, N fertilizer is applied to irrigated wheat several times from the sowing to stem elongation stages to realize the maximum economic yield [5].However, the hazards of soil pollution resulting from excessive N application have increased [1].Although urea is a popular N fertilizer, researchers are examining the superiority of ammonium sulfate for improving the efficiency of N use for wheat production (Jones et al. 2007and Hafez et al. 2012). However, the superiority of ammonium sulfate has not been confirmed in recent Egyptian wheat cultivars under irrigated and desiccated conditions.Because of population growth, the per capita share of water has dropped dramatically to less than1000 (˜700) m^3/capita, which, by international standards, is considered the "water poverty limit". The value may even decrease to 584 m^3/capitain the year 2025 [7].In Egypt, production is mainly dependent on Irrigation whereas water shortage and low nutrient availability are the main factors limiting the growth of crops in these areas [8].Fertilizer application has been reported to have a beneficial effect on improving WUE and grain yield of spring wheat [9].Photosynthetic capacity in wheat crop is the primary component of dry matter productivity [10].The final economic yield can be increased by increasing the rate of photosynthesis, by reducing wasteful respiration or by optimizing assimilate partitioning [11].Therefore, important to determine the effect of nitrogen (N) from ammonium sulfate split-applied at different rates before anthesis on water use efficiency under well-watered and desiccated conditions in the recent Egyptian cultivar Sakha94 and Turkish Adana99 used in pots.

2. MATERIAL AND METHODS

2.1. Plant materials and cultivation

Egyptian spring wheat cv. Sakha94 and Turkish cv. Adana99 were grown in pots that the diameter was 20 cm (314 cm^2) and its depth 1 m at the glasshouse of the Faculty of Life and Environmental Science, Shimane University. Sakha94 originated in the Field Crops Department, Agricultural Research Centre, Ministry of Agriculture, Giza, Egypt, and were the new bread wheat cultivars, released in 2005, which have white grains, high tillering, resistance to yellow rust and resistance to leaf rust under irrigated conditions in the Nile delta area [12].Adana99 is popular in the Mediterranean zone in Turkey, respectively. Pots were filled with black soil for rice seedling (andosol; Green soil, Izumo Green Co. Izumo, Japan). Six seeds were sown in a pot on 10December2009/2010 and 30 October 2010/2011. The seedlings were reduced to three plants per pot after establishment. The pots were irrigated with a hand sprayer to maintain near field capacity moisture andcontinued for all pots till booting stage. After booting stage started the irrigation treatments in half pots water irrigation-holding and the irrigation continued in the second half of pots till maturity in non temperature controlled glasshouse in ambient CO_2 concentration.

2.2. N treatments

The andosol was supplied with garden lime, 20 g per pot to adjust the soil pH to 6.6 before sowing. N component ofammonium sulfate was 20.6% and applied at the rate of levels 0.0, 0.24 ,0.48, 0.72 and 0.96 g pot^{-1} (0.0, 75, 150, 225,300 kg N h^{-1}) respectively, three times: 20% before sowing, 50% at tillering and 30% at booting. Superphosphate (P_2O_5) and potassium chloride (K_2O) were applied at the rate of 0.6 g pot^{-1} (300 kg ha^{-1}) before sowing. The experiment was laid out in randomized complete design of two water treatments×five amounts of fertilizer with four replicates in two cultivars.

2.3. Measurements

2.3.1. Plant dry weight, spike and spikelet number

Three above-ground plants per pot were sampled at anthesis. After the leaf area was measured with a leaf area meter, plants were dried in an oven at 80ºC for 48 hr. and weighed. The numbers of spikes and spikelet’s per spike were counted. The relationship between these parameters and the amounts of applied N was curve-fitted by a quadric curve by the least square method, because plant responses to applied N generally should have an optimum or a ceiling point [13].

2.3.2. Transpiration rate, stomatal conductance, water consumptive use and water use efficiency

Chlorophyll concentration of flag leaves was determined with a portable chlorophyll meter (SPAD-502, Soil-Plant Analysis Development (SPAD) Section, Minolta Camera, Osaka, Japan) was used to measure [14].Stomatal conductance (gs)was measured on fully expanded flag leaves from the abaxial surface as mmol H_2O m^{-2} s^{-1} from three plants in each pot with a dynamic diffusion porometer (Delta-T AP4, Delta-T Devices Ltd, Cambridge, UK) during the middle of the day. Two measurements from both adaxial and abaxial surfaces of the leaf were taken. The porometer was calibrated at the start of each measurement session. It measured in the fine days (following weather) every 4 or 7 days from booting till harvest with a porometer. [15].Measurement in the top leave and front (ra) and back side (r_d) of the center of the leaf.

Total leaf conductance (r_l) is $1/r_l = 1/r_a + 1/r_b$

Soil water content (SWC) was measured every 4 days by time domain reflectometry (TDR) from the beginning till the end of the stress period. Readings of soil dielectric constant were converted to a measure of soil water content as described by [16].

SWC=(-619.2BD+631)TDR reading–64.7BD+74.3(H_2O g cm^{-3}) whereas Soil Bulk Density (BD) = 0.9

Water use efficiency (WUE): calculated by this Equation WUE=(DMI/(T_r/VPD)) Where, DMI is dry weight difference between booting and maturity, T_r is the transpiration rate [(PWDn-(n-1)+--+PWD1), and VPD is average vapor pressure deficit at day time between booting and maturity [17].VPD is measured with a humidimeter and logger for 30 min interval [17].Temperature and humidity will be measured and logged with a temperature and humidity sensor and logger before booting [17].

3. RESULTS AND DISCUSSION

3.1. The effect of applied of ammonium-N at booting stage on leaf area, shoot dry matter and Spad value

In both cultivars, leaf area (fig. 1), shoot dry matter (fig. 3) and spad value(fig. 8) increased with the increase in applied N. The rate of increase in the amounts of applied N was greater at 0.96 g pot^{-1} (300 kg ha^{-1}) Nand was highest in Sakha94.There were linear relationships between leaf area (fig. 1), shoot dry matter (fig. 3), spad value (fig. 8) andthe dry weight in each cultivar and N amounts, although theslope of the line and hence the dry weight per pot varied with the cultivar. Therefore, the increase in shoot dry matter by an increase in N amounts before anthesis was accompanied with an increase in leaf area and chlorophyll concentration (Spad value), resulting in shoot dry matter[10].This growth response to N supply became apparent, was mainly due to an N-induced enhancement of leaf and lateral shoot growth [18].Pre-anthesis accumulated N represented 57–92% and 54–129% of total N at maturity at the low and high N levels [19].

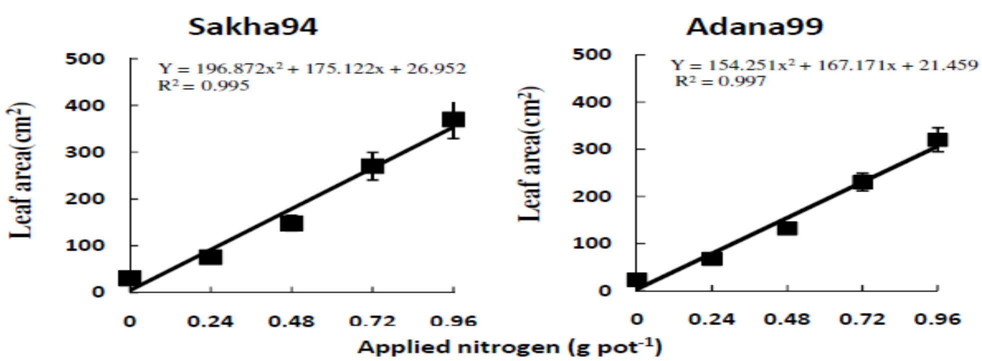

Fig1. Leaf area (cm^2) at anthesis under different amounts of applied nitrogen fertilizer of ammonium sulfate in two (Sakha 94 and Adana99) spring wheat cultivars in 2009-2010 and 2010-2011 season. Each data is mean ± standard error of four replicates. Standard error less than sizes of symbols was omitted for clarify.

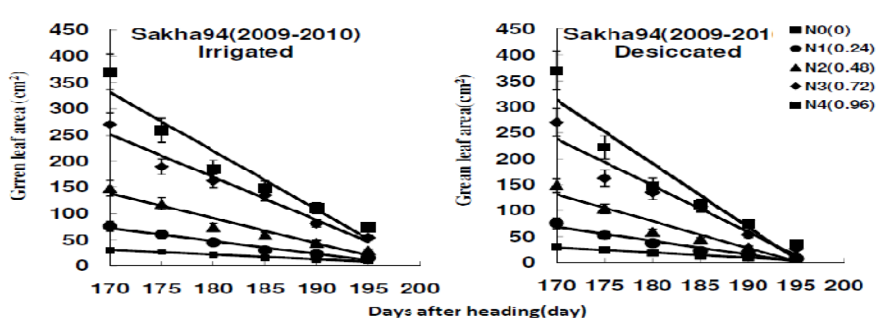

Fig.2. Green leaf area (cm^2) at anthesis under different amounts of applied nitrogen fertilizer of ammonium sulfate in two (Sakha 94 and Adana99) spring wheat cultivars in 2009-2010 and 2010-2011 season. Each data is mean ± standard error of four replicates. Standard error less than sizes of symbols was omitted for clarify.

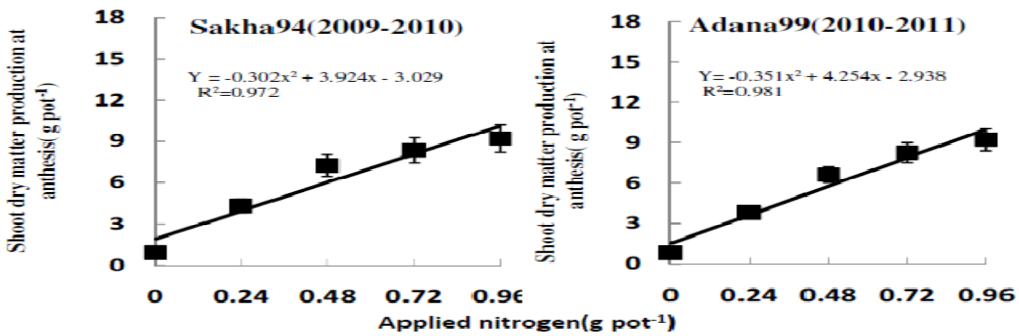

Fig.3. Shoot dry matter production (g pot^{-2}) at anthesis under different amounts of applied nitrogen fertilizer of ammonium sulfate in two (Sakha 94 and Adana99) spring wheat cultivars in 2009-2010 and 2010-2011 season. Each data is mean± standard error of four replicates. Standard error less than sizes of symbols was omitted for clarify.

3.2. The effect of applied of ammonium-N at maturity stage on Number of spikelet's per spike, Number of spikelet's (pot^{-1}), total dry matter and leaf chlorophyll concentration under well watered and desiccated conditions.

In cultivars, Number of total dry matter (fig. 4),spikelet's per spike(fig. 5), Number of spikelet's (pot^{-1}) (fig. 6) and leaf chlorophyll concentration (fig. 9) increased with the increase in applied N in both water treatments but the increase under well-watered conditions was higher than desiccated conditions in all above parameters. The rate of increase in the amounts of applied N was greater at 0.96 g pot^{-1} (300 kg ha^{-1}) N and was highest in Sakha94.There were linear relationships between Number of total dry matter (fig. 4) , spikelet's per spike(fig. 5), Number of spikelet's (pot^{-1}) (fig. 6) and leaf chlorophyll concentration (fig. 9) in each cultivar and N amounts under water treatments, The spikelet number consists of the spike number and spikelet number per spike[10].The difference in spikelet number between the plants treated with the N-fertilizer resulted mainly from the difference in spike number, not from spikelet number per spike, in both cultivars. Thus, the response of spikelet number to applied N was much lower in Adana 99 than in Sakha 94.[1]stated that Sakha94 surpassed the other two varieties in all studied traits except spike length,grain weight per spike and 1000-grains weight whereas Giza 168 surpassed the other two varieties in these traits. Increasing N fertilizerlevels significantly increased all studied traits in both seasons. The maximum grain yield was achieved by 214 kg N/ha.as ammonium sulphate with Sakha94. Yield and its components were increased with increasing soil field capacity from 60 to 100%. [20] noticed that there was a significant effect of the interaction between irrigation and N treatments on growth, and consequently on yields. The increase in spikelet number per plant by N fertilizer was due to an increase in spike number, that is, fertile tiller number as it was previously shown by field experiments [21]. [19]suggested that over high or low post-anthesis soil moisture content could cause the early senescence of flag leaves and decrease kernel weight. Under the same post-anthesis soil moisture content, the SPAD value, and photosynthetic rate increased, indicating that increased N fertilization could postpone the senescence of wheat flag leaves. However, over N application was not favorable to the increase of kernel weight, especially under the condition of post-anthesis soil moisture deficiency.

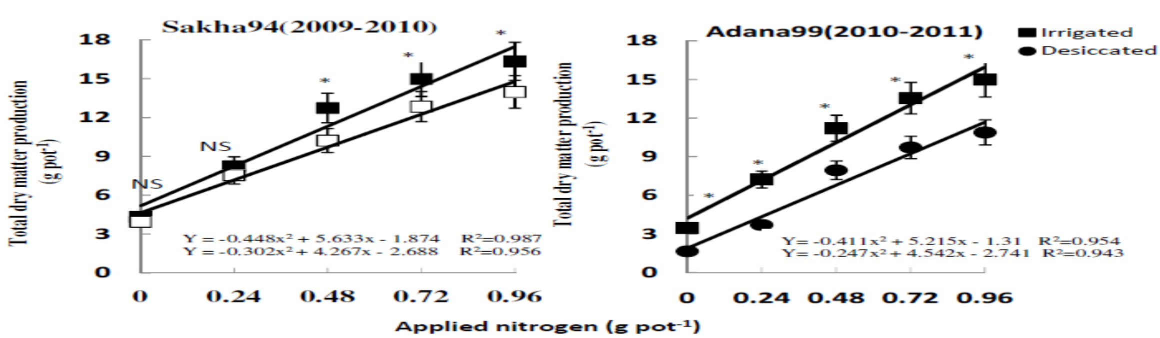

Fig.4. Total dry matter production(g pot^{-2}) after anthesis under different amounts of applied nitrogen fertilizer of ammonium sulfate under irrigated and desiccated conditions in two (Sakha 94 and Adana99) spring wheat cultivars in 2009-2010 and 2010-2011 season. Each data is mean ± standard error of four replicates. Standard error less than sizes of symbols was omitted for clarify.

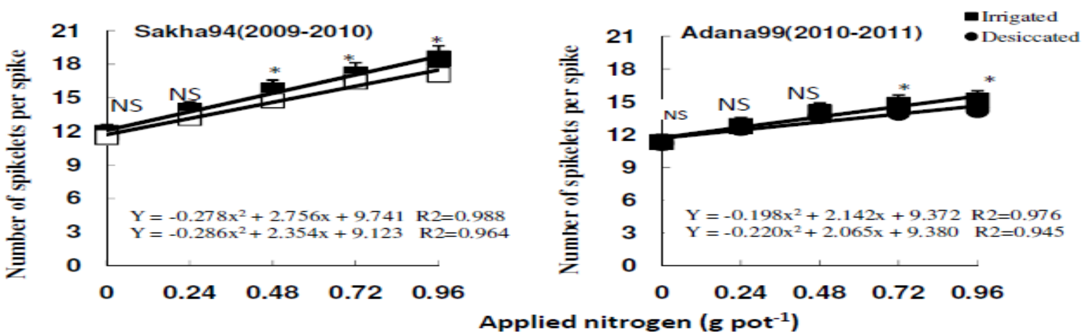

Fig.5. Number of spikelet's per spikeunder different amounts of applied nitrogen fertilizer of ammonium sulfate under irrigated and desiccated conditions in two (Sakha 94 and Adana99) spring wheat cultivars in 2009-2010 and 2010-2011 season. Each data is mean ± standard error of four replicates. Standard error less than sizes of symbols was omitted for clarify.

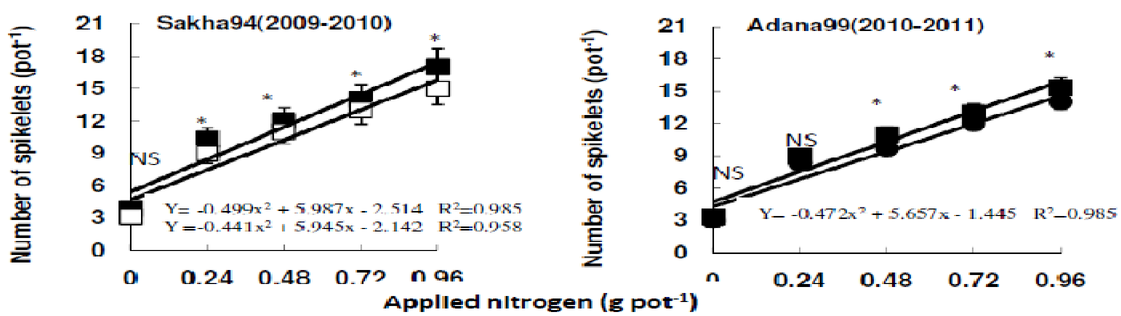

Fig.6. Number of spikelet's (pot^{-1}) under different amounts of applied nitrogen fertilizer of ammonium sulfate under irrigated and desiccated conditions in two (Sakha 94 and Adana99) spring wheat cultivars in 2009-2010 and 2010-2011 season. Each data is mean ± standard error of four replicates. Standard error less than sizes of symbols was omitted for clarify.

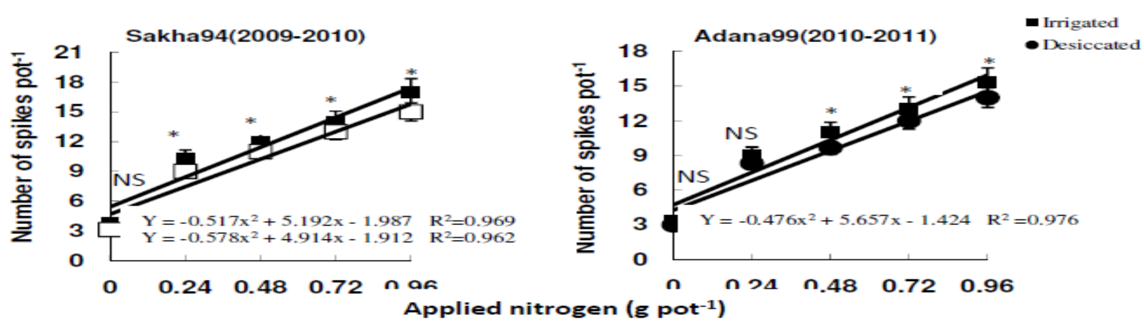

Fig.7. Number of spikes(pot^{-1}) under different amounts of applied nitrogen fertilizer of ammonium sulfate under irrigated and desiccated conditions in two (Sakha 94 and Adana99) spring wheat cultivars in 2009-2010 and 2010-2011 season. Each data is mean ± standard error of four replicates. Standard error less than sizes of symbols was omitted for clarify.

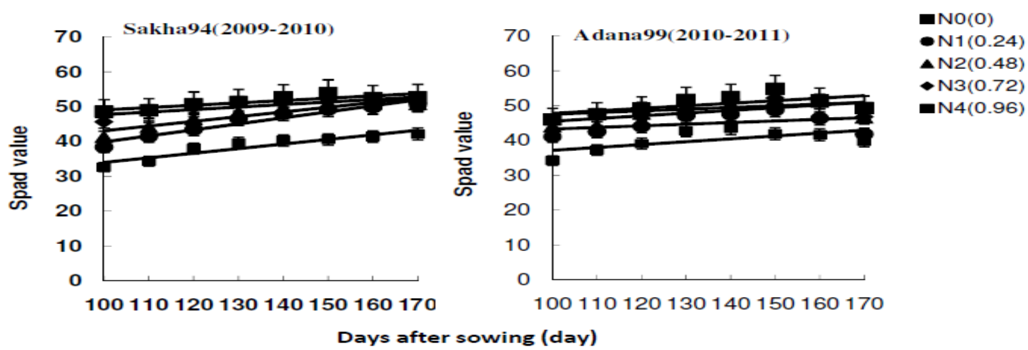

Fig.8.Chlorophyll content (Spad) after days of sowing under different amounts of applied nitrogen fertilizer of ammonium sulfate under irrigated and desiccated conditions in two (Sakha 94 and Adana99) spring wheat cultivars in 2009-2010 and 2010-2011 season. Each data is mean ± standard error of four replicates. Standard error less than sizes of symbols was omitted for clarify.

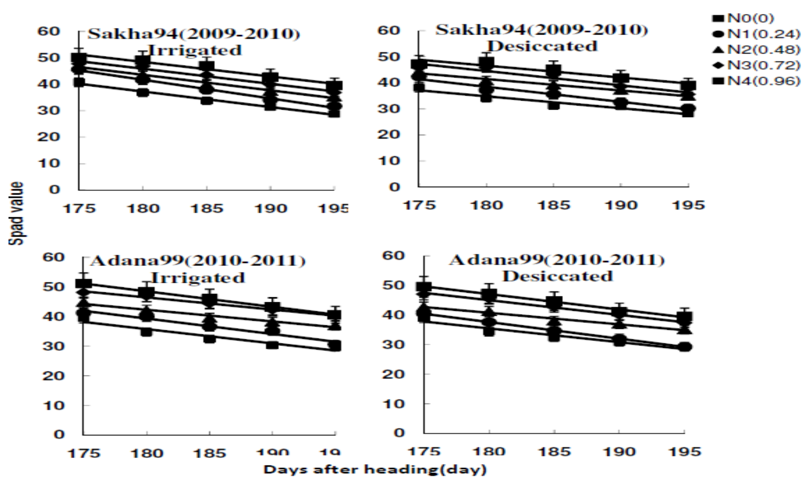

Fig.9. Chlorophyll content (Spad) after days of anthesis under different amounts of applied nitrogen fertilizer of ammonium sulfate under irrigated and desiccated conditions in two (Sakha 94 and Adana99) spring wheat cultivars in 2009-2010 and 2010-2011 season. Each data is mean ± standard error of four replicates. Standard error less than sizes of symbols was omitted for clarify.

3.3. The effect of applied of ammonium-N at maturity stage on green leaf area, leaf chlorophyll concentration after heading,stomatal conductance, transpiration rate, consumptive use and water use efficiency under well watered and desiccated conditions.

3.3.1. Green leaf area and leaf chlorophyll content

In cultivars, measured green leaf area (fig. 2), leaf chlorophyll concentration(fig. 9), stomatal conductance (fig. 10),transpiration rate(fig. 11), consumptive use (fig. 12) and water use efficiency (fig. 13) after heading till maturity time under water treatments and N amounts. The results found that green leaf area and leaf chlorophyll content decreased dramatically after heading time under both well-watered and desiccated conditions. The reduction was higher in Adana 99 under desiccated condition than well-watered-condition. Both green leaf area and leaf chlorophyll concentration were decreased higher in lowest levels of nitrogen than higher one that kept the green leaf for a longer time. When the rate of photosynthesis is low, due to imposed water stress and an increased rateconstant of thermal dissipation of excitation energy and this increase represents a mechanism to down regulate photosynthetic electron transport and match utilization of NADPH and ATP under reduced photosynthesis [22][23]. [24].showed that water deficit remarkably increased the N translocationratio derived from soil and the contributions of N in various vegetative organs to grain N. It is suggestedthat water deficit would weaken the availability of fertilizer N but enhance the remobilization of prestoredN to the grains.

3.3.2. Stomatal conductance

The results of the present study clearly revealed that stomatal conductance (fig. 10) was significantly higher at nitrogen level of 0.96 g pot^{-1} (300 kg ha^{-1}) N ascompared to all other nitrogen treatments in both cultivars under water treatments after heading till maturity but stomatal conductance was significantly decreased under desiccated condition after heading till maturity. Results of present study are also in line with the findings of [25], who reportedincreased stomatal conductance in wheat with N application.The major factor for enhanced productivity is the net CO_2 assimilation rate. CO_2assimilation rate in plants is controlled by stomatal conductance [25].Decrease in stomatalconductance as a result of water deficit could be the main reason of reduced CO_2assimilation rate. These results are in conformity with the findings of [26] who also reported reduction in expansion of leaves and stomatal conductance areason of reduced photosynthetic rate in wheat under water stress. Another reason of this decreased photosynthetic rate may be the decreased leaf water potential and relative water content under water stress due to limited irrigation, which has a pronounced effect on photosynthetic rate. Changes in leaf water potential might be attributable to a change in osmotic pressure, the osmotic component of water potential [27].Results of our experiment are in line with the findings of [28] [29] who reported that N concentration in plants alters water relations of plants under waterstress conditions [30] found that the photosynthetic gas exchange parameters (transpiration rate and stomatal conductance) are remarkably improved by water application and nitrogen nutrition. Water use efficiency (WUE) reduced with increasing number of irrigations and increased with increasing applied nitrogen at all irrigation levels.

3.3.3. Transpiration rate

The effects of water and nitrogen (N) supply on transpiration rate (Tr) at days after heading were examined in both wheat cultivars(fig. 11).The results of the present study clearly revealed that transpiration rate (T_r) was significantly higher at nitrogen level of 0.96 g pot^{-1} (300 kg ha^{-1}) N as compared to all other nitrogen treatments in both cultivars under water treatments after heading till maturity but transpiration rate (T_r) was significantly decreased under desiccated condition after heading till maturity. This may due to low consumptive use and stomata closure led to lower transpiration rate under desiccated condition but under well-watered condition found higher consumptive use and stomata opening let to higher transpiration rate [31].The transpiration rate is dependent on the diffusion resistance provided by the stomatal pores, and also on the humidity gradient between the leaf's internal air spaces and the outside air the effect of different levels of nitrogen on stomatal conductance rate and transpiration rate are recommended the highest dose of nitrogen[32]. [33] revealed a linear relationship between the rate of transpiration and the uptake rates of nitrogen. [33] found that crops took up more nitrogen as canopy transpiration rate increased and Whole-plant transpiration was affected by both fertility and VPD. Increasing VPD increased the evaporative demand experienced by the plants. Thus, they lost more water from their stomata. Increasing N amounts also increased transpiration by increasing leaf area from which water transpired. Transpiration per unit leaf area also showed a higher rate of water loss when plants were exposed to high VPD.

3.3.4. Consumptive use

It can be clearly seen from the data in (fig. 12) that the wheat water consumptive use significantly increased with increase of nitrogen amounts.Eck (1988) found that consumptive use of winter wheat increased with increments of N through 140 kg ha^{-1} on non-stressed treatments while it decreased on stressed treatments. The present study showed that WUE of wheat increased with increase in nitrogen up to 0.96 g pot^{-1} (300 kg ha^{-1}) N in Sakha 94 than Adana99 under water treatments. However, water consumptive use significantly increased under well-watered conditions much more than desiccated conditions in both cultivars. Desiccated conditions was less consumptive use than well-watered conditions because of stomata closure during the water stress whereas [31]stated that irrigationtreatments significantly affected ET after normalizing for vapor pressure deficit (ET/VPD) during the growing season. Supplemental irrigation at 50% and 100% of soil water deficit. The decreased wheat water consumption mainly resulted from the decreased stomata conductance and transpiration rate [34].Stomatal conductance of wheat steadily decreased under desiccated conditions at days after heading in both cultivars[34]. [35]showed that the average seasonal consumptive water use (CU) by wheat increased with every additional irrigation level to a maximum of 328.4 mm and 301.7 mm in the first and second season respectively.

3.3.5. Water use efficiency

WUE (fig. 13) was greater for desiccated treatment and maximum total dry matter production was achieved with well-watered condition. The genetic gains in dry matter yield were associated with increasing in biomass, and spikelet numbers per spike for cultivars released in different years. No significant correlations were found between significant relationships was found between stomatal conductance N-amounts after heading time. Stomatal conductance increased significantly under well-watered condition and decreased dramatically in desiccated conditions after heading to maturity (fig. 10). [36] stated that water use efficiency (WUE) tended to increase with increase in nitrogen from 90 to 150 kg ha^{-1}in wheat.Relationships were apparent between WUE and date of anthesis and total dry matter production at maturity. The positive relationship between total dry matter production and WUE for all the cultivars indicated that using a higher yielding cultivar has the potential to improve WUE and thereby to save water[37]. [38]reported that the water use efficiency of wheat was higher with limited irrigation (One each at crown-root initiation and flowering stage) and decreased with adequate irrigation (One each at crown-root initiation, late tillering , late jointing, flowering and milk stages) condition. This means that production of grain per mm of water used decreased with increase in water supply and the relative increase in the grain yield of wheat has not been in proportion to the increase in consumptive use, thereby resulting in decrease in water use efficiency under adequate irrigation. [39] in Madhya Pradesh reported that maximum water use efficiency of wheat was obtained when one irrigation applied at late jointing stage.[32] found that WUE of winter wheat increasedwith increments of N on non-stressed treatments while it decreased on stressed treatments. The present study showed that WUE of wheat increased with increase in nitrogen up to 0.96 g pot-1 (300 kg ha^{-1}) N in Sakha 94 than Adana99 under water treatments. WUE showed significant increases with increase in nitrogen application and the values were comparable with those reported by many workers for wheat based on total dry matter yield and transpiration rate.

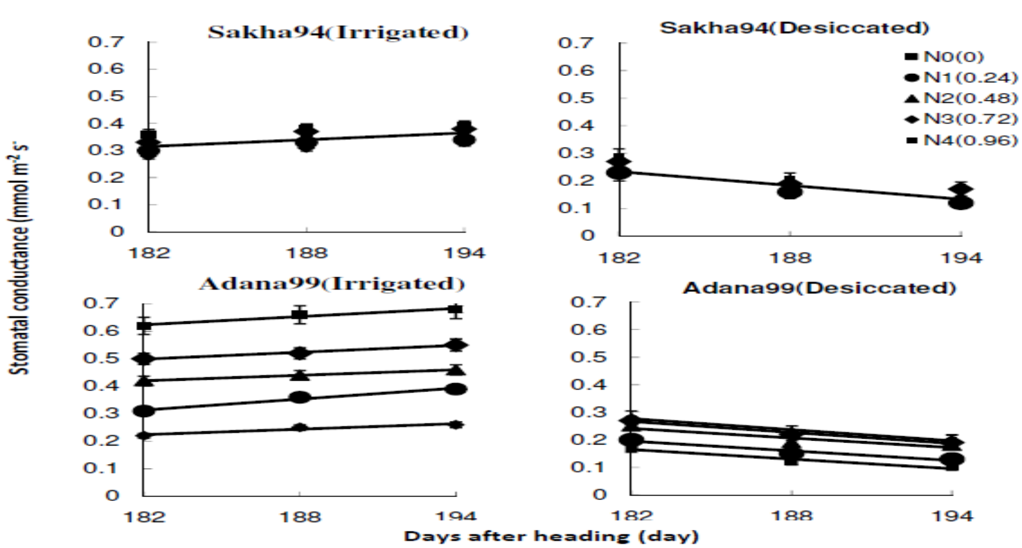

Fig.10. Stomatal conductance(mmol m^{-2} s^{-1}) after days of anthesis under different amounts of applied nitrogen fertilizer of ammonium sulfate under irrigated and desiccated conditions in two (Sakha 94 and Adana99) spring wheat cultivars in 2009-2010 and 2010-2011 season. Each data is mean ± standard error of four replicates. Standard error less than sizes of symbols was omitted for clarify.

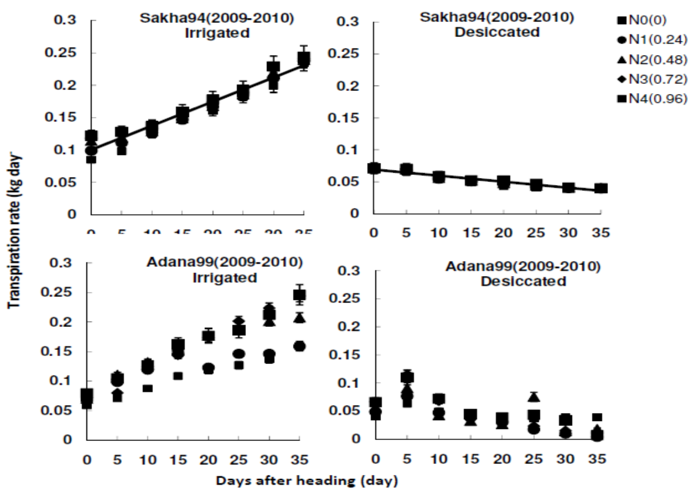

Fig.11. Transpiration rate (kg day^{-1}) after days of anthesis under different amounts of applied nitrogen fertilizer of ammonium sulfate under irrigated and desiccated conditions in two (Sakha 94 and Adana99) spring wheat cultivars in 2009-2010 and 2010-2011 season. Each data is mean ± standard error of four replicates. Standard error less than sizes of symbols was omitted for clarify.

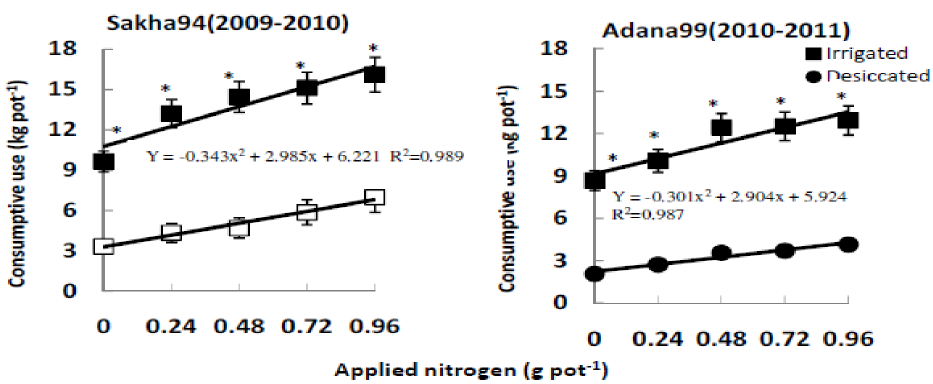

Fig.12. Consumptive use (kg pot^{-1}) under different amounts of applied nitrogen fertilizer of ammonium sulfate under irrigated and desiccated conditions in two (Sakha 94 and Adana99) spring wheat cultivars in 2009-2010 and 2010-2011 season. Each data is mean ± standard error of four replicates. Standard error less than sizes of symbols was omitted for clarify.

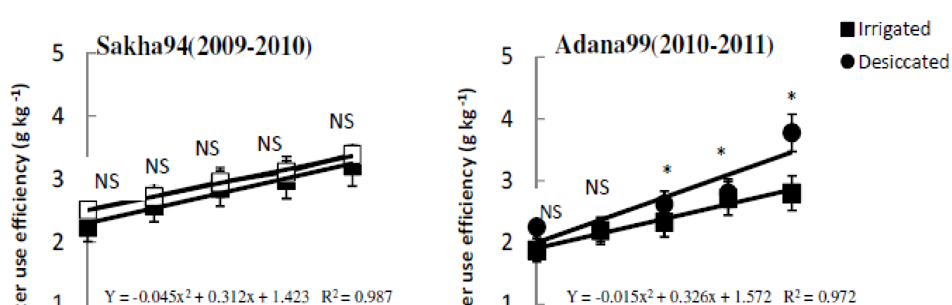

Fig.13. Water use efficiency (g dry matter kg^{-1} water use) under different amounts of applied nitrogen fertilizer of ammonium sulfate under irrigated and desiccated conditions in two (Sakha 94 and Adana99) spring wheat cultivars in 2009-2010 and 2010-2011 season. Each data is mean ± standard error of four replicates. Standard error less than sizes of symbols was omitted for clarify.

4. Conclusion

With respect to water shortage in some regions of the world, it is suggested to optimize efficiencies of consumptive and water use and decrease of transpiration by stomata closure. Physiological water uptake and keeping by plant could be controlled via agronomic practices such as water management, N-fertilization and selecting suitable cultivars.Our results showed that there were significant differences between cultivars in dealing with desiccated conditions as well as spike yield, total dry matter yield and WUE.Our experimental condition demonstrated that applied 0.96 g N pot^{-1} (300 kg N ha^{-1}) led to significantly increase in WUE under irrigated and desiccated conditions in both cultivars. However, WUE was significantly higher in desiccated conditions than irrigated conditions in Sakha94 than Adana99.It was concluded that appropriate N application and post-anthesis desiccated conditions could postpone the plant senescence by keeping green leaf area and increase the spike yield of wheat.It might be recommended that applicationof N and selecting cultivars tolerant tolater season water stress be considered for improving WUE and wheat yields. Also, future studies would need additional effort to consider WUE in pre anthesis periods, whereas many physiological changes occur in these stages.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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