Agr. Nat. Resour. 53 (2019) 205–217

AGRICULTURE AND NATURAL RESOURCES

Journal homepage: http://anres.kasetsart.org

Research article

# Interlaced influence of arbuscular mycorrhiza and water management on mite infestation and kohlrabi production

Alaa F. Mohammed[a,†], Rewaa. S. El shatoury[b,†], Marwa S.Kamel[c,†], Amr K. Mahmoud[d,*]

[a] *Department of Agric.Botany-Faculty of Agricultural-Suez Canal University, Egypt.*

[b] *Department of Horticulture-Faculty of Agricultural-Suez Canal University, Egypt.*

[c] *Department of Plant Protection-Faculty of Agricultural-Suez Canal University, Egypt.*

[d] *Department of Physical and Soil Chemistry-Desert Research Center (DRC), Egypt.*

**Article Info**

**Article history:**
Received 6 October 2018
Revised 6 February 2019
Accepted 7 February 2019
Available online 30 June 2019

**Keywords:**
Arbuscular mycorrhizal,
Irrigation water use efficiency,
Kohlrabi production,
Mite densities,
Water quantities

**Abstract**

An experiment was conducted to assess the influence of arbuscular mycorrhiza and water management on mite infestation and kohlrabi production. This study monitored the influence of three water quantity treatments (Q1, Q2, Q3) with averages of 180 mm, 270 mm and 360 mm, respectively, and two treatments of seed inoculation: 1) seeds inoculated by arbuscular mycorrhizal (AM) and, 2) seeds not inoculated by arbuscular mycorrhizal (Non-AM) on yield production, plant parameters, mite density, canopy temperature, water use and heat use efficiency. The results revealed that the mycorrhizal inoculation increased the yield production with a low amount of water (Q2) by approximately 55% compared to the other treatments with an irrigation water use efficiency of 7.54 kg/m$^3$ and a heat use efficiency of 23.6 kg/ha/°C/d. Moreover, leaf chlorophyll concentration especially with the low amount of water (Q2) was 61%, which was the same as the net irrigation water requirement. The interaction between AM and Q2 was highly significant for mycorrhizal root colonization (71%), and had a positive effect on all plant parameters (plant length, leaf number, root length). Furthermore, predator and soil mites (*Amblyseius swirskii*, *Euseius scutalis*, *Golumna tarsipennata*, *Zygoribatula tritici*) had significant densities with the same interaction treatment. Noticeably, these results encouraged using AM inocula as "bio-enhancers" of plant performance in agricultural systems.

## Introduction

Arbuscular mycorrhizal fungi (AMF) form widespread symbiotic associations with 80% of known land plants,The symbiotic association between the fungi and the plant roots is commonly called arbuscular mycorrhiza (AM) Allen (1996). They play a major role in plant nutrition, growth, water absorption, nutrient cycling and protection from pathogens, and as a result, contribute to ecosystem processes (Allen, 1996; Koricheva et al., 2009). Moreover, in most cases this relationship turns into a positive outcome for both the host plant and the AMF, which is considered a mutualistic relationship (Smith and Read, 2008). In this association, both partners profit from the

† Equal contribution

* Corresponding author.
E-mail address: amr_73@yahoo.com (A.K. Mahmoud)



https://doi.org/10.34044/j.anres.2019.53.3.01

relationship; AMF improve the host plants nutrient status, influencing mineral nutrition, water uptake, growth, disease resistance and irrigation water productivity, whereas in exchange, the host plant provides organic carbon and the substrate necessary for fungal growth and reproduction (Smith and Read, 2008). Recent work has established that AMF can affect on plant fitness (Wilson et al., 2009; Hoffmann et al., 2011).

Furthermore, inoculated plants with arbuscular mycorrhizal maintained a relatively higher water content compared with non-inoculated plants (Colla et al., 2008). Generally, mycorrhizal colonization enables host plants to use water more efficiently and allows them to maintain a lower intercellular carbon dioxide concentration (Evelin et al.,2009). In addition, the mycorrhiza may directly or indirectly also affect other plant-associated organisms such as herbivores feeding on green plant parts (Hoffmann et al., 2009; Koricheva et al., 2009), root feeding insects Gange (2001), predators and mites and cause changes in the plant´s volatile emission (Fontana et al., 2009, Hoffmann et al., 2011; Schausberger et al., 2012), parasitoids (Guerrieri et al., 2004) or even pollinators (Wolfe et al., 2005).

On the other hand; irrigation water management (irrigation system-irrigation scheduling) influences more efficient water use by plants and their developments. Irrigation scheduling involves the definition of the time and amount of water application to a crop according to the management objective Howell (1996). This definition can be based either on soil water balance methods and meteorological data (Nair et al., 2013) or on measurements of plant parameters Passioura(1988). Furthermore, amount of water is critical in making the most efficient use of the irrigation system especially for a drip irrigation system, as excessive irrigation reduces yield, while inadequate irrigation causes water stress and reduces production (Li et al., 2001). The optimum use of irrigation can be characterized as the rooting area, and at the same time, avoiding the leaching of nutrients into deeper soil layers (Kruger et al., 1999).

In addition, (Oloumi et al., 1988) found that water stress can reduce the density of mites and especially the density of females and eggs. Ferree and Hall (1980) showed that low soil moisture did not affect the intensity of mite reproduction. However, there have been different hypotheses about the effects of water stress on mite development and reproduction. Consequently, higher mite densities on leaves cause stomata to remain open for longer periods which allows a greater loss of water, with spider mite densities of 10 mites per leaf and 50 mites per leaf causing a reduction in flower stem length of 17% and 26%, respectively (Landeros et al., 2004).

Consequently, the most useful measure of performance of an irrigation system, in terms of its effect on crop yield, is the water use efficiency (WUE) which evaluates the proportion of the applied water beneficially used by the crops Alghariani (2002). WUE is often defined by the ratio between the crop biomass or grain production and the amount of water consumed by the crop, including rainfall, or irrigation water applied, or crop transpiration (Zhang and Oweis, 1999). Regarding irrigation water productivity, WUE should be used as an indicator of a plant's performance (Luis et al., 2002).

Clearly, the relation among factors of the agricultural system, especially irrigation water, AM, mites and environmental elements, should be controlled to achieve a positive result. Thus, the aim of this study was to monitor the influence of three water quantity treatments with averages of 180 mm, 270 mm and 360 mm, and two treatments of seed inoculation involving either seeds inoculated by arbuscular mycorrhizal (AM) or seeds not inoculated by arbuscular mycorrhizal (Non-AM)) on yield production, plant parameters, mite density, canopy temperature, water use and heat use efficiency and finally, to create a simple mathematical relationship between yield and the factors of the experiments.

## Materials and Methods

The experiment was carried out at a farm of the Faculty of Agriculture, Suez Canal University, Ismailia governorate, Egypt. The study site was established in early February 2018 at 30°37'10.91"N and 32°16'1.33"E. The site was in an arid area with a Mediterranean climate at about 30 m above sea level with an annual rainfall of 29 mm/year. The meteorological data recorded at the local meteorological weather station of average climatic parameters are provided in Table 1 for temperature, relative humidity, wind speed and evapotranspiration . The Penman-Monteith equation was used to calculate reference crop evapotranspiration (ETo) as shown in Equation 1 from Allen et al. (1998):

$$ETo = \frac{0.408\Delta\left(R_n - G\right) + \gamma \frac{900}{T+273} U_2 \left(e_s - e_a\right)}{\Delta + \gamma\left(1 + 0.34U_2\right)} \quad (1)$$

where; ETo is the reference evapotranspiration (measured in millimeters per day), Δ is the slope vapor pressure curve (in kilopascals per degree centigrade), Rn is the net radiation at the crop surface and G is the soil heat flux density (both measured in megajoules per square meter per day), T is the air temperature at 2 m height (in degrees centigrade), $e_s$ is the saturation vapor pressure, $e_a$ is the actual vapor pressure, $e_s$ - $e_a$ is the saturation vapor pressure deficit (all measured in kilopascals), $U_2$ is the wind speed at 2 m height (in meters per second) and γ is the psychometric constant (per degree centigrade).

**Table 1** Climatic characteristics at Ismailian governorate

| Month | Prc | Maximum temperature | Minimum temperature | Humidity | Sun-shine | Wind (at 2 m) | ETo |
|---|---|---|---|---|---|---|---|
| | mm/m | °C | °C | % | h | m/s | mm/d |
| Feb | 0 | 22.7 | 13.5 | 57.8 | 8 | 2.8 | 3.5 |
| March | 0 | 26.9 | 15.2 | 50.3 | 8.7 | 2.8 | 4.8 |
| April | 0 | 28.8 | 19.2 | 48.5 | 10.1 | 2.8 | 6.0 |

Prc = precipitation; ETo = reference evapotranspiration.

The soil at the experimental site had a sandy texture, wand was not saline nor calcareous. The silt and clay content were quite low (3.2% and 1.2%, respectively); thus, both the field capacity and available water were very low (5.6% and 4.5%, respectively) with soil conductivity of 1.37 dS/m. Water samples were analyzed using standard analytical methods for the pH, electrical conductivity and ion composition (American Public Health Association et al., 1992). The average values of the analyzed parameters in the irrigation water are given in Table 2.

The total water applied was calculated using Equation 1. The crop evapotranspiration, net irrigation requirement and total water applied were determined using Equation 2 – 4, respectively, and values in Table 3:

$$ETc = ETo \times KC \quad (2)$$

where, ETc is the crop evapotranspiration and ETo is the reference evapotranspiration (both measured in millimeters per day) and KC is the crop coefficient.

$$IR_n = ETc - P_{eff} \quad (3)$$

where, $IR_n$ is the net irrigation requirement and ETc is the crop evapotranspiration and $P_{eff}$ is the effective rainfall (all measured in millimeters per day).

$$IR_t = IR_n / E_a \quad (4)$$

where, $IR_t$ is the total water applied, (mm/day), $IR_n$ is the net irrigation requirement, (both measured in millimeters per day), and $E_a$ is the overall irrigation efficiency for a modern drip irrigation system (approximately (90%) based on Vermeiren and Jobling (1984) and Phocaides (2007).

Subsequently, the total water applied for kohlrabi was 360 mm using a drip irrigation system (using ground self drip hoses 4L/50 cm/hr at 1.2 bar) with three amounts of water (Q1, Q2, Q3) representing 50%, 75% and 100%, respectively, of the total water applied for kohlrabi.

Seeds of kohlrabi (S.N) were grown in trays for 2 wk before inoculation with mycorrhizal inoculants. The seeds were inoculated with a spore suspension containing three different species (*Glomus intraradices*, *Glomus monosporum*, *Glomus mosseae*) with a concentration of 50 spores/mL. Mycorrhizal inocula were exported from the Microbiological Resource Center, Ain Shams University, Cairo, Egypt. Moreover; the AM inocula were applied at a rate of 10 mL/seedling (containing 500 ± 20 propagules/cell) where the number of spores for each type of AM was about 160 spores. The control treatments were not treated with AM inocula (Non-AM). Seedlings were irrigated regularly in the greenhouse until plants had reached an appropriate size. Seedlings were transplanted to field on 2 February.

*Mite counting*

The kohlrabi crop was cultivated using normal agricultural processes without using any pesticides. Mites were counted weekly based on 10 leaves as a sample randomly collected from all treatments. In addition; leaf samples were collected and placed directly into labelled plastic bags and transported to the laboratory, where they were examined using a stereomicroscope and hand lens. Counting of mites started in the second week of February and continued until the middle of April 2018. Adult stages were counted and recorded of *Amblyseius swirskii* (Athias-Henriot), *Euseius scutalis* (Athias-Henriot), *Golumna tarsipennata* (Grandjean) and *Zygoribatula tritici* (El-Badry and Nasr).

*Thermal image acquisition*

An infrared thermal camera Ti-32 (Fluke Thermography; Germany) was used to take images of the plots using a 320 × 240 pixel microbolometer sensor, sensitive in the spectral range 7.5–13 µm. The canopy height was about 1 m. Images were analyzed using the Ti-32 Pro software (Infrared Solutions; USA); Emissivity for measurements of leaves and plant canopies was set at 0.96 while the transmission correction was 85%. For greater accuracy, the span of the auto-adjusted thermal image was manually set to the level of the displayed image to detect the maximum and minimum temperature of the entire display (Wilcox and Makowski, 2014).

**Table 2** Chemical characteristic for the irrigation water

| pH | EC (dS/m) | Soluble cation (meq/L) | | | | Soluble anion(meq/L) | | | | SAR |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $Ca^{2+}$ | $Mg^{2+}$ | $Na^{+}$ | $K^{+}$ | $CO_3^{2-}$ | $HCO_3^{-}$ | $Cl^{-}$ | $SO_4^{2-}$ | |
| 7.34 | 1.18 | 2.8 | 0.6 | 8.2 | 0.2 | 0 | 2.92 | 6.83 | 2.05 | 6.3 |

EC = electrical conductivity; SAR = sodium adsorption ratio.

**Table 3** Average crop coefficients for kohlrabi

| Parameter | Init | Dev | Mid | Late | Total |
|---|---|---|---|---|---|
| Days | 20 | 30 | 15 | 10 | 75 |
| KC | 0.7 | 1.05 | 1.05 | 0.95 | |

Init = initial; Dev =crop development; Mid = mid-season; Late = late season; KC = crop coefficients.

*Growing degree-days (heat units)*

Growing degree days (GDD) or heat units were calculated using the single sine curve method (Baskerville and Emin, 1969) during the growing season of the kohlrabi crop. This simple linear method requires only daily minimum and maximum air temperatures as shown in Equation 5:

$$GDD = [(T_{max} + T_{min}) /2] - T_{base} \quad (5)$$

where, $T_{max}$ is the daily maximum temperature, $T_{min}$ is the daily minimum temperature and $T_{base}$ is the base temperature (all measured in degrees centigrade).

$T_{base}$ for Kohlrabi, was set as 7°C (Maria et al., 2004; Drost and Johnson, 2010).

Heat use efficiency (HUE) is the ratio of yield to the accumulated growing degree days according to Kingra and Prabhjyot (2012) as shown in Equation 6:

$$HUE = Yield (Ygi) / (AGDD). \quad (6)$$

where, HUE is the heat use efficiency (measured in kilograms per hectare per degree centigrade per day), Ygi is the economic yield (in kilogram per hectare) and AGDD is the accumulated growing degree days (in degrees centigrade per day). Heat units are often used to predict the rate of phonological development of plant species and developmental rates increase approximately linearly as a function of air temperature (Snyder et al., 1999); therefore, a higher or lower the temperature will affect the crop by reducing plant growth and total yield. Consequently, the lower temperature ($T_{base}$) for kohlrabi, was set as 7° C (Maria et al., 2004; Drost and Johnson, 2010).

*Mycorrhizal root colonization*

Collected roots were rinsed carefully to remove soil particles and cut into 1 cm fragments. Root samples were soaked in 10% KOH at 90°C for 30 min and then washed carefully with running tap water. This was followed by neutralization with 1% HCl for 30 min, and then samples were stained with 0.05% Trypan blue for 24 hr at room temperature as described by Brundrett et al. (1984). Finally, the roots were rinsed with water and de-stained in 50% glycerol (Koske and Gemma, 1989). The samples were then mounted on microscope slides and examined under a compound microscope to evaluate the AMF percentage colonization according to Brundrett et al. (1996).

*Proline content*

The free proline content in leaf tissue was measured according to Bates et al. (1973) using acid ninhydrin reagent. Five grams of leaves sample were merged well with 10 mL 3% sulfosalicylic acid, and Whatman No. 1 paper filter was used to filter out the homogenate. Two ml of filtered extract was mixed with 2 mL acid ninhydrin in a test tube; then 2 mL glacial acetic acid was added for 1 hr at 100°C. The reaction in the test tubes was preserved in an ice bath. The mixture was extracted using 4 mL toluene and mixing vigorously before the absorbance was measured at 520 nm in a spectrophotometer. The colored toluene fraction was separated and measured at 520 nm in a spectrophotometer. The proline content measured in milligrams per gram dry weight) in the leaf tissue was calculated using Equation7:

$$Proline = [34.11 \times OD_{520} \times V] / [2 \times f] \quad (7)$$

where, 34.11 is a constant, $OD_{520}$ is the optical density measured at 520 nm, V is the total volume of extract and f is the weight of the leaf sample.

Irrigation water use efficiency was determined using Equation 8 according to Bos (1979):

$$IWUE = [Y_{gi} – Y_{gd}]/ IRR_i \quad (8)$$

where, IUWE is the irrigation water use efficiency (measured in kilograms per cubic meter), $Y_{gi}$ is the economic yield and $Y_{gd}$ is the dry yield which is the crop yield without irrigation (both measured in kilograms per hectare) and $IRR_i$ is the irrigation water applied (in cubic meters per hectare). Often, in most semiarid-to-arid locations, $Y_{gd}$ may be zero

*Leaf chlorophyll concentration*

A SPAD-502 chlorophyll meter (Minolta Co., Ltd.; Japan) was used to measure the chlorophyll content present in plant leaves by measuring the leaf absorbance in the red and near-infrared regions as described by Konica Minolta Optics, (2012). Briefly, the light is emitted by two LEDs with peak wavelengths at 650 nm and 940 nm. These LEDs emit light in sequence from the emitting window to a photodiode detector when the measuring head is closed. When the light passes through the sample leaf in the measuring head, a certain amount transmits through the leaf and the transmitted light strikes the receptor and is converted into electrical signals. With these absorbance values, the SPAD-502 calculates a company-defined SPAD (soil plant analysis development) value by division of the light transmission intensities at 650 nm by 942 nm. This numerical SPAD value specifies the relative content of chlorophyll within the sample leaf.

*Statistical analysis and modeling*

The experimental layout was a spilt plot design with two factors and three replicates. The first factor was seed inoculants as a main plot which was divided into two treatments of seed inoculated by arbuscular mycorrhizae (AM) and seeds not inoculated (Non-AM)]. The second factor was the water quantity as a sub main plot which was divided into three treatments (Q1, Q2 and Q3) with averages of 180 mm, 270 mm and 360 mm, respectively. Data were analyzed using a two way analysis of variance (ANOVA) at a significance level of $p < 0.05$. When the ANOVA was significant at $p < 0.05$, a least

significant difference (LSD) test and Duncan's multiple range test (Duncan, 1955) were used for mean comparisons using the COSTAT 3.03 System software (CoHort; USA).

The simple regression models with predictor variables $X_1 \ldots Xp$ can be described using Equation 9:

$$y = B_0 + B_1X_1 + \ldots\ldots\ldots\ldots + B_pX_p + k \quad (9)$$

where, y is the response or dependent variable and is dependent on other variables $X_{(1..p)}$ which are the independent or predictor variables (also called the regressor variables), $B_0$ is the intercept, $B_{1\text{-}P}$ are the slope parameters and $k$ is the variability of the error and is constant for all values of the regressor.

## Results and Discussion

### *Growth parameters and yield*

Table 4 indicates that there were significant impacts for the amounts of water and AM for all plant parameters—plant length (PL), number of leaves (NL) and root length (RL)—and yield production. However, the Q2 treatment had the highest mean values (38.11cm, 19.85, 29.71cm) for PL, NL and RL, respectively. Thus, the highest value for yield production was observed with Q2 (16,714.28 kg/ha) compared to the other water quantities (Q1, Q3). Moreover, Q3 had a significantly lower yield, (7,797.62 kg/ha), compared to Q1 (11,871.43 kg/ha) which was related to the distribution of the high amount of water under Q3 in the soil (sandy texture) as the drip irrigation was not homogeneous, so that water losses due to percolation below the rooting zone were likely (Maria et al., 2004). Furthermore, AM recorded the highest mean value (14,428.57 kg/ha) for yield compared to Non-AM (9,826.2 kg/ha) Fig. 1. In addition, there were significant differences for AM compared to Non-AM for PL, NL and RL with AM having values of 30cm for PL, 18.27 cm for NL and 27.65 cm RL. These results were related to the fact that arbuscular mycorrhizal-inoculated plants preserved a relatively higher water content compared with non-inoculated plants (Colla et al., 2008; Evelin et al*.,* 2009), which was facilitated by promoting the root hydraulic conductivity at a low water potential (Kapoor et al., 2008). This promoted root conductance which was associated with changes in the morphogenetic characters of roots. Consequently, AM plants had significant improvements in growth parameters and significant increases in leaf number, plant length and root length over the Non-AM treatment as the control (Borde et al., 2011).

**Table 4** Influence of different treatments on mean plant length, number of leaves and root length

| Parameter | Treatment | | | | |
|---|---|---|---|---|---|
| | Q1 | Q2 | Q3 | AM | Non-AM |
| Plant length (cm) | $34.26^{b}$±1.2 | $38.11^{a}$±2.7 | $30.45^{c}$±2.05 | $36.00^{a}$±4.20 | $32.55^{b}$±3.04 |
| $LSD_{0.05}$ | | 1.655 | | 1.796 | |
| Number of leaves | $17.68^{b}$±0.88 | $19.85^{a}$±0.92 | $18.62^{ab}$±2.19 | $18.27^{a}$±1.817 | $19.16^{a}$±1.43 |
| $LSD_{0.05}$ | | 2.0207 | | 1.1495 | |
| Root length (cm) | $24.99^{b}$±3.76 | $29.71^{a}$±6.87 | $20.27^{c}$±2.31 | $27.65^{a}$±6.56 | $22.33^{b}$±4.01 |
| $LSD_{0.05}$ | | 6.072 | | 4.002 | |

$LSD_{0.05}$ = least significant difference; = Q1 = 180mm, Q2 = 270mm, Q3 = 360mm, AM = mycorrhizal inoculant treatment and Non-AM = non-mycorrhizal inoculant treatment

Values (mean ±SD) followed by the same lowercase superscript are not significantly different ($p < 0.05$).

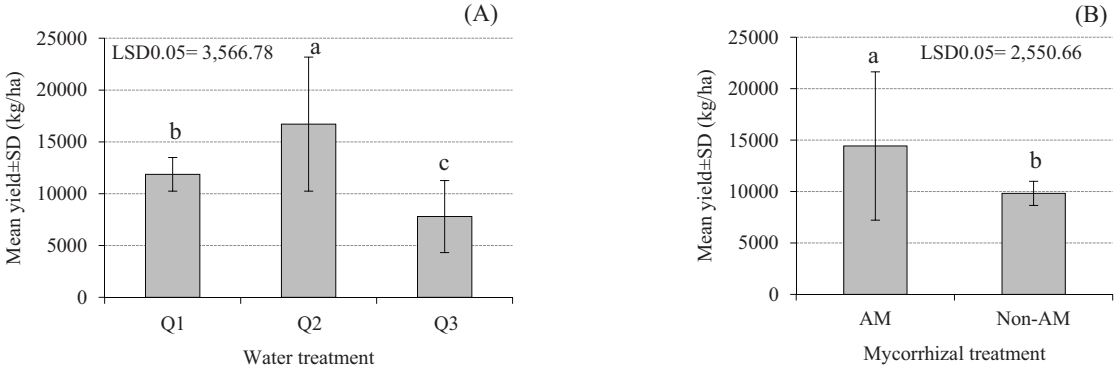


**Fig. 1** Kohlrabi mean yield production as affected by: (A) water treatment; (B) mycorrhizal inoculants, where lowercase letters above columns indicate significant differences at $p < 0.05$, $LSD_{0.05}$ = least significant difference , error bar = ±SD, Q1 = 180mm, Q2 = 270mm, Q3 = 360mm, AM = mycorrhizal inoculant treatment and Non-AM = non-mycorrhizal inoculant treatment.

*Thermal images and canopy temperature*

There were variations in the canopy temperature (CT) related to different treatments (Fig. 2 and Fig. 3). For example, higher values for CT were recorded with Non-AM compared to AM at all levels of water treatment.

On the other hand, CT had a significantly higher value (27.3°C) under Q1 compared to other treatments of Q2 and Q3, which had values not significantly different of 25.4 °C and 24.6°C, respectively. Notably, AM had a significant influence on CT (24.9°C) for kohlrabi compared to the Non-AM (26.6°C), with a reduction in CT of approximately 2°C. and also water treatment Q2. For Q3, the CT reduced approximately 2.6°C. These results of the best water status being detected in AM plants were in agreement with Yu et al (2015) who reported that the canopy temperature was inversely proportional to stomatal conductance.

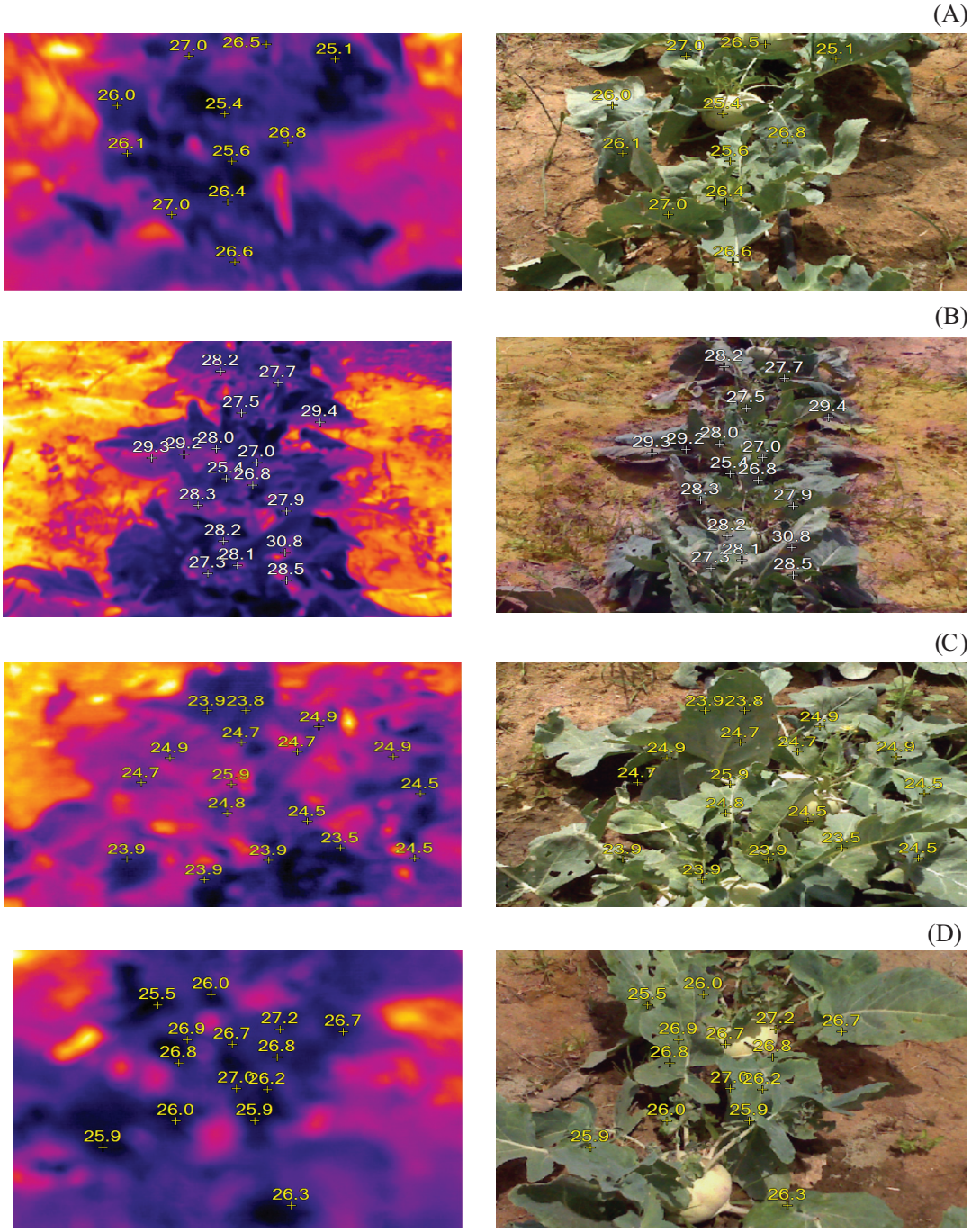


**Fig. 2** Thermal images for kohlrabi canopy under different treatments: (A) AM with water amount Q1; (B) Non-AM with water amount Q1; (C) AM with water amount Q2; (D) Non-AM with water amount Q2, where values indicate degrees centigrade, Q1 = 180 mm, Q2 = 270 mm, Q3 = 360 mm,AM = mycorrhizal inoculant treatment and Non-AM = non-mycorrhizal inoculant treatment.

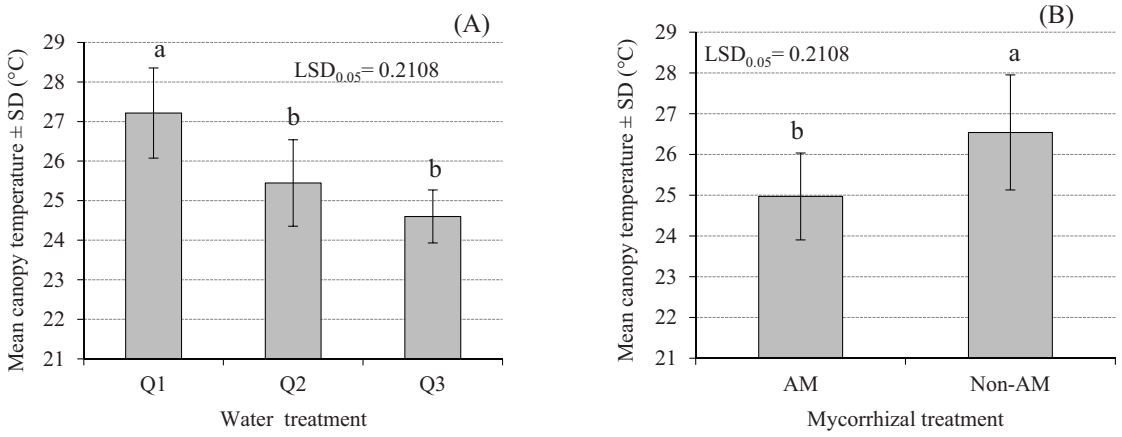


**Fig. 3** Mean canopy temperature as affected by: (A) water quantity treatment; (B) mycorrhizal inoculants treatment, where lowercase letters above columns indicate significant differences at $p < 0.05$, $LSD_{0.05}$ = least significant difference , error bar = ±SD, Q1 = 180 mm, Q2 = 270 mm, Q3 = 360 mm, AM = mycorrhizal inoculant treatment and Non-AM = non-mycorrhizal inoculant treatment.

*Accumulated growing degree days and mites*

Table 5 shows the mean 10 d monthly, real and adjusted temperatures, growing degree days (GDD) and accumulated growing degree days (AGDD) during the kohlrabi growing season. Generally, the total amount of heat units for kohlrabi to develop from one point to another in its life cycle was 958.13°C per season or heat unit. On the other hand, four different types of mites were observed during different stages for kohlrabi, with predator mites being *Amblyseius swirskii* and *Euseius scutalis* and soil mites being *Golumna tarsipennata* and *Zygoribatula tritici*.

The relationship between different predator mites by density and AGDD is shown in Fig. 4. A density 1 mite/cm$^2$ of *Amblyseius swirskii* needed 1,212.05 heat units, 755.68 heat units and 1,545.3 heat units under treatments Q1, Q2 and Q3, respectively, with AM. Nevertheless, the Non-AM treatments for the same density of *A. swirskii* needed more heat units (2,554.3 heat units, 1,355.5 heat units and 1,635.31 heat units under Q1, Q2 and Q3, respectively). With (AM, for the same mite density of *Euseius scutalis*, the required heat densities were 2,020.09 heat units under Q1, 1,593.16 heat units under Q2 and 1,545.37 heat units under Q3 (Fig. 5). However, with the Non-AM treatment, *E. scutalis* needed 5,614.53 heat unit with Q3 for the same unit density. Thus; the mycorrhizal inoculant treatment helped plated mites to utilize lower low heat units to increase their numbers compared to Non-mycorrhizal inoculant treatments which needed higher heat units to increase, especially under water quantity Q3.

Noticeably, Fig. 6 illustrates the relationship between different soil mite densities and AGDD, with Q2 having a low value for heat units (180.4) compared to Q1 and Q3 (216.8 and 256.4, respectively) for a unit density per square centimeter of *Golumna tarsipennata* under (the AM treatment. In contrast, the same mite species under the Non-AM treatment required 330.5 heat units, 191.08 heat units and 320.9 heat units under treatments Q1, Q2 and Q3, respectively, which was much higher than for the AM treatment. In addition, the same unit density of *Zygoribatula tritici* required 162.2 heat units with Q2 but with Q3 and Q1 required approximately 190.9 heat units with the AM treatment, but the heat unit values were higher for the same mite species and density (233.2 heat units, 235.5 heat units and 307.38 heat units for Q1, Q2 and Q3, respectively) under the Non-AM treatment.

**Table 5** Mean 10 d monthly temperatures, growing degree days and accumulated growing degree days during kohlrabi growing season

| Month (in 2018) | Day period | $T_{max}$ (°C) | $T_{min}$ (°C) | GDD (°C) | AGDD (°C d) |
|---|---|---|---|---|---|
| February | 1–10 | 25.25 | 12 | 116.25 | 116.25 |
| | 11–20 | 20.3 | 14.1 | 102 | 218.25 |
| | 21–28 | 23.37 | 14.5 | 95.48 | 313.73 |
| March | 1–10 | 27.5 | 16.1 | 148 | 461.73 |
| | 11–20 | 26.2 | 14.7 | 134.5 | 596.23 |
| | 21–31 | 27 | 15 | 140 | 736.23 |
| April | 1–10 | 25.3 | 17.6 | 101.15 | 837.38 |
| | 11–12 | 28 | 20.5 | 120.75 | 958.13 |

$T_{max}$ = maximum mean 10 d monthly temperature; $T_{min}$ = minimum mean 10 d monthly temperature; GDD = growing degree days; AGDD = accumulated growing degree days

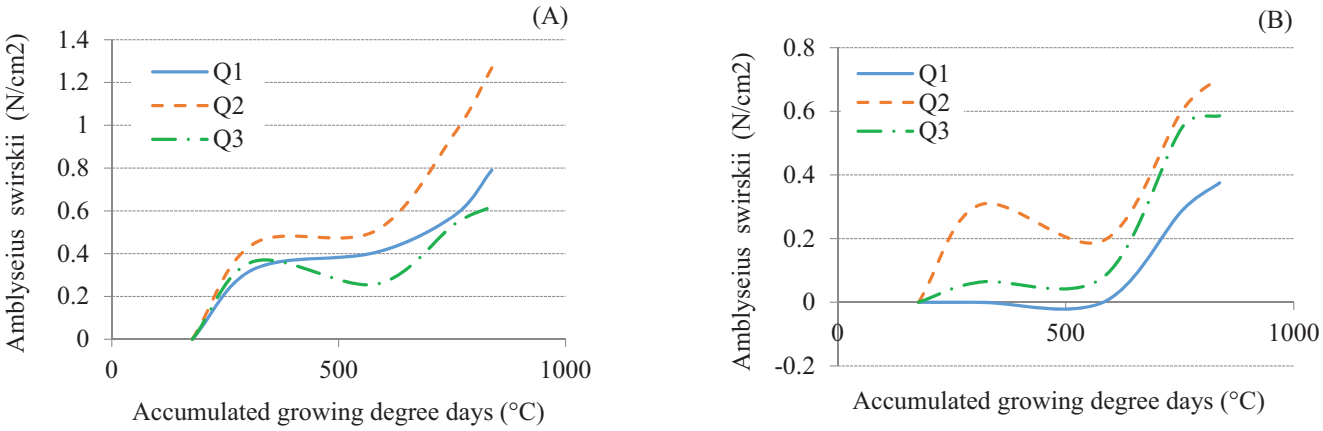


**Fig. 4** Relationship between *Amblyseius swirskii* density and accumulated growing degree days (AGDD) under different treatments: (A) mycorrhizal inoculant treatment; (B) non-mycorrhizal inoculant treatment, where N = number of mites, Q1 = 180 mm, Q2 = 270 mm and Q3 = 360 mm

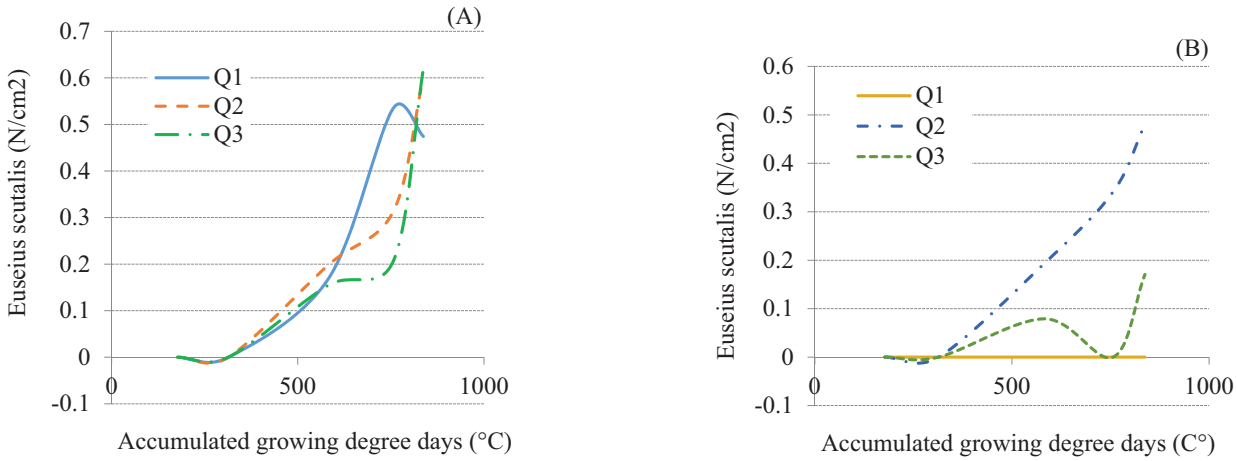


**Fig. 5** Relationship between *Euseius scutalismites* density and accumulation of growing degree days (AGDD) under different treatments: (A) mycorrhizal inoculant treatment; (B) non-mycorrhizal inoculant treatment, where N = number of mites, Q1 = 180 mm, Q2 = 270 mm and Q3 = 360 mm

Finally, the soil mites needed low values of AGDD with the AM treatment compared to the predator mites. Clearly, the AM treatment had a significant influence on mite species especially with a low amount of water (Q2) compared to the Non-AM treatment. These results may have been related to belowground organism-induced changes in the plant chemistry that may have cascaded up and influenced the life history of natural enemies via the nutritional value of their herbivorous prey (Bezemer et al., 2005). The mycorrhizal-induced changes in the volatiles emitted by mite-infested plants did not influence the attraction of the mites to their host plants. Spider mites were reported to randomly choose either of two odors (Guerrieri et al., 2004). On the other hand; the numbers of predator mites increased with AGDD and this may have been related to these mites beginning development when the temperature exceeded their lower developmental threshold or base temperature, with rate of development increasing as the temperature exceeds the base temperature and decreasing as the temperature drops. Thus, insect development is accelerated during warm years and delayed during cooler years. Upper developmental threshold temperatures, above which growth slows or ceases, are seldom used for mites since these thresholds are either not known, or the mites live in habitats where the upper threshold is seldom exceeded. GDD takes into account the average daily temperature by calculating the number of heat units received. Thus, this system can be more accurate than the calendar method for estimating mite development and developing timing management strategies.

*Mycorrhizal root colonization and proline*

The results of mycorrhizal root colonization measured 2 mth after transplanting indicated that both AM and Non-AM plants were colonized by mycorrhizal fungi. It was possible that the presence of vascular arbuscular mycorrhizal (VAM) root colonization in non-mycorrhizal plants might have been due to native mycorrhizae already existing in the soil in the experimental field**.** The VAM structures in inoculated plant roots are shown in Fig. 7.

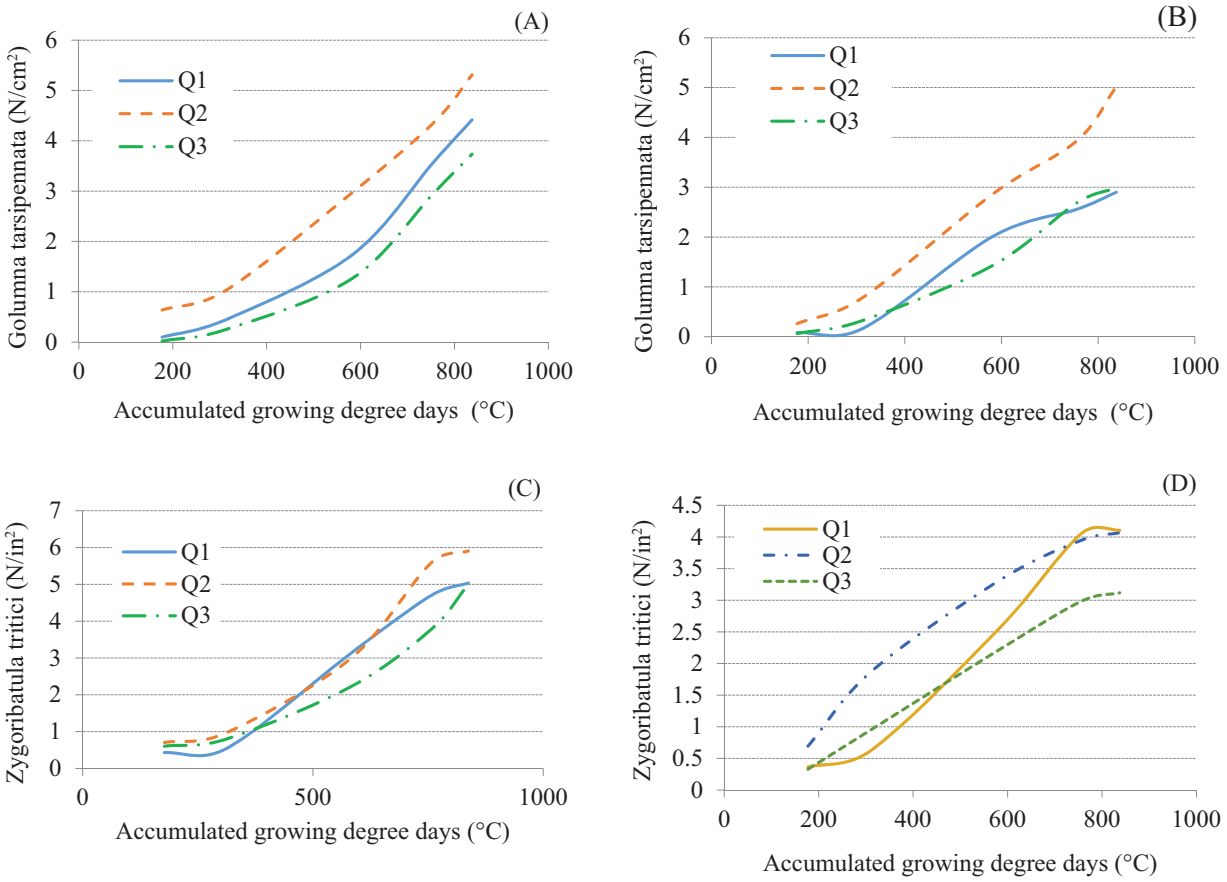


**Fig. 6** Relationship between *Golumna tarsipennata* (A) and (B) and *Zygoribatula tritici* (C) and (D) between density and accumulation of growing degree-days (AGDD) under different treatments (A) and (C) with AM treatment; (B) and (D) with Non-AM treatment, where Q1 = 180 mm, Q2 = 270 mm and Q3 = 360 mm

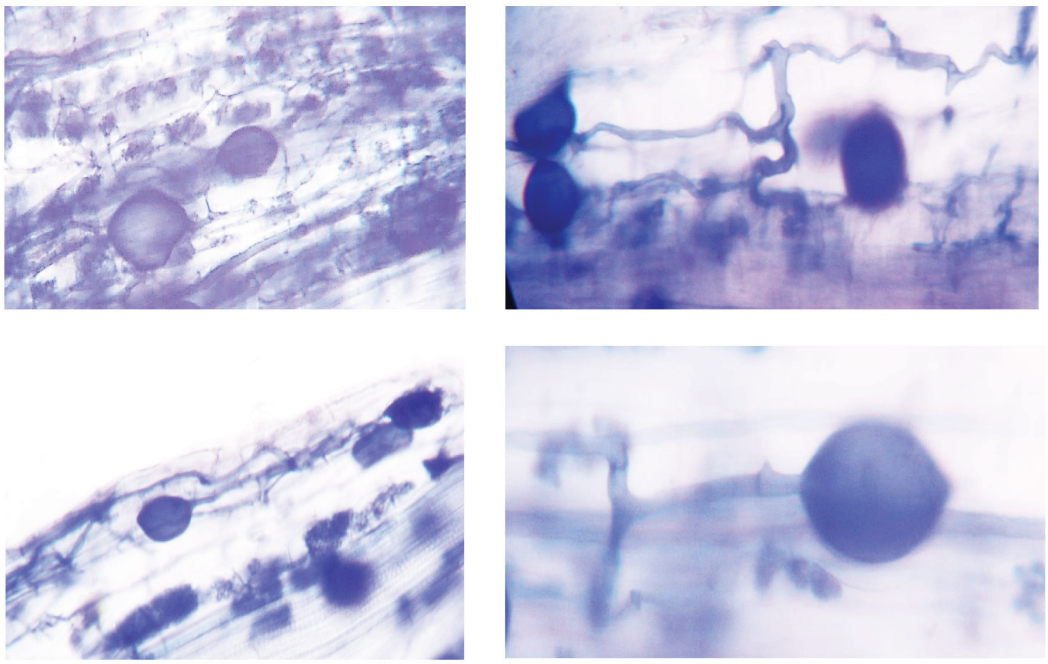

**Fig. 7** Photomicrographs for arbuscular mycorrhizal fungal structures in plant roots after clearing and staining (200×)

**Table 6** Influence of different treatments on mean mycorrhizal root colonization and proline content

| Parameter | Treatment | | | | |
|---|---|---|---|---|---|
| | Q1 | Q2 | Q3 | AM | Non-AM |
| Mycorrhizal root colonization (%) | $31.2^{c} \pm 27.46$ | $43.45^{b} \pm 35.26$ | $48.63^{a} \pm 37.13$ | $71.5^{a} \pm 11.77$ | $10.73^{b} \pm 3.75$ |
| $LSD_{0.05}$ | | 0.6033 | | 1.0484 | |
| Proline(mg/g) | $9.1^{a} \pm 1.83$ | $7.06^{b} \pm 1.49$ | $4.93^{c} \pm 0.86$ | $5.84^{b} \pm 1.49$ | $8.27^{a} \pm 2.28$ |
| $LSD_{0.05}$ | | 0.9636 | | 0.5027 | |

$LSD_{0.05}$ = least significant difference; Q1 = 180 mm, Q2 = 270 mm, Q3 = 360 mm, AM = mycorrhizal inoculant treatment and Non-AM = non-mycorrhizal inoculant treatment Values (mean ±SD) followed by the same lowercase superscript are not significantly different ($p < 0.05$).

The data in Table 6 indicates that there were significant impacts associated with different amounts of water in the AM treatment with regard to mycorrhizal root colonization and the proline contents. For example; mycorrhizal root colonization (71.5%) under the AM treatment was significantly greater than for the Non-AM treatment (10.73%). In addition; the amount of water had a significant influence on mycorrhizal root colonization with the latter having values of 31.2%, 43.45% and 48.63% for Q1, Q2 and Q3, respectively, with the highest value for Q3. The decrease in root mycorrhizal colonization under drought stress compared to well watering was ascribed by Fagbola et al. (2001) to the reduction in spore germination, root exudates and root carbohydrate supply.

In contrast, the proline content was significantly higher for the Non-AM treatment (8.27 mg/g) compared to the AM treatment (5.84 mg/g). Moreover; with the lowest amount of water, Q1 had the highest proline content (9.1 mg/g) compared to Q2 and Q3 (7.06 mg/g and 4.93 mg/g, respectively). Clearly, in the vegetative stage, drought stress increased the proline content about ten-fold, due perhaps to its increasing role because it is osmotic compatible and thus adjusting the osmotic potential which resulted in drought stress avoidance in chickpea, where proline accumulation was believed to play an adaptive role in plant stress tolerance (Verbruggen and Hermans, 2008).

Notably, the proline content in the AM treatment with high water treatment (Q3) decreased by 3.3 mg/g on average compared to the Non-AM with the same water treatment. However, a high proline content (10.8 mg/g) was recorded for Non-AM with the low water treatment (Q1) but with the AM treatment, the value was 7.5 mg/g under the same water treatment. This result could have been related to root colonization by AM inducing major changes in the relative abundance of the major groups of organic solutes (Sheng et al., 2008), such as modifying the composition of carbohydrates (Augé et al., 1987) and inducing the accumulation of specific osmolytes such as proline (Ruiz-Lozano et al., 1995), thus facilitating osmotic adjustment. Mycorrhizal colonization in plants raised the leaf concentrations of soluble sugars, reducing sugars, soluble protein, total organic acids, acetic acid, oxalic acid, malic acid and citric acid, and decreased the concentrations of total free amino acids, proline and formic acid (Ashwani et al., 2015).

*Leaf chlorophyll concentration*

It was observed that the amount of water had a significant influence on the SPAD value especially for Q2 and Q3 compared to Q1 (Fig. 8). For example, the SPAD value for Q2 was significantly higher (61%) than for Q3 (52.7%). In addition, for the AM treatment, the SPAD value was significantly higher (61%) than for the Non-AM treatment (56%). Thus, the AM treatment had a positive impact on the leaf chlorophyll concentration which was in agreement with Zuccarini (2007) who found that the chlorophyll content and total foliar area were mostly enhanced following colonization with mycorrhizal fungi. Furthermore, there was no significant reduction in the leaf chlorophyll concentration by reducing the water quantity from Q3 to Q2. In contrast, the leaf chlorophyll concentration was

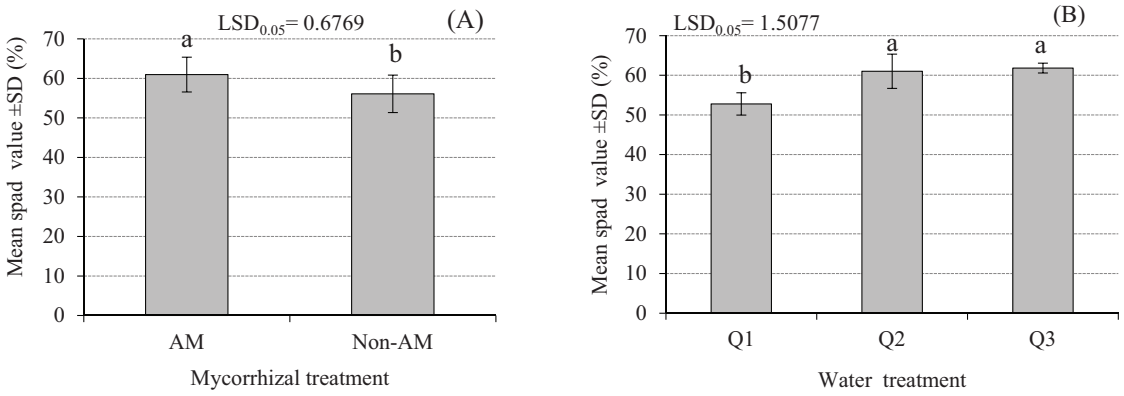


**Fig. 8** Mean SPAD (leaf chlorophyll concentration) value as affected by: (A) mycorrhizal inoculants treatment; (B) water quantity trreatment, where $LSD_{0.05}$ = least significant difference, error bar = ±SD, Q1 = 180 mm, Q2 = 270 mm, Q3 = 360 mm, AM = mycorrhizal inoculant treatment and Non-AM = non-mycorrhizal inoculant treatment

significantly reduced after the kohlrabi was exposed to water stress (Q1) inasmuch as plants respond to drought differently regarding their chlorophyll content because in most plant species, chlorophyll is generally sensitive to drought (Rong-hua et al., 2006). Huang et al. (2011) reported higher chlorophyll contents in the leaves of mycorrhizal plants, confirming that symbiosis plays a key role in modifying photosynthetic and metabolic activities. Campanelli et al. (2012) confirmed that the photosynthetic rate and chlorophyll content were higher in mycorrhizal plants than in non-mycorrhizal plants.

*Irrigation water use efficiency and heat use efficiency*

The most important index for determining optimal water management practices is the irrigation water use efficiency (IWUE) according to (Bos, 1979). The results for IWUE and HUE in the current study are given in Table 7.A lower IWUE value was observed for the treatment Non-AM and Q3, while a higher value was observed for the treatment AM and Q2. Thus, excessive irrigation led to a decrease in the IWUE which in turn may result in higher production and IWUE (Jin et al., 1999). In addition, the IWUE results under treatments were highest with AM (6.67 kg/m$^3$, 7.54 kg/m$^3$ and 2.61 kg/m$^3$ under Q1, Q2 and Q3, respectively). On the other hand, for the Non-AM treatment the IWUE was 5.2 kg/m$^3$ for Q1, 3.58 kg/m$^3$ for Q2 and 2.06 kg/m$^3$ for Q3. Consequently, a decrease in the amount of water by 25% from the total water applied to the kohlrabi crop can result in effective and economical irrigation water with the AM treatment. The heat use efficiency (HUE), which is the efficiency of utilization of heat in terms of dry matter accumulation, depends on the crop type, genetic factors and sowing time and has great practical application (Rao et al., 1999). From Table 7, the HUE data indicate that the highest value was observed under the AM treatment with Q2 (23.6 kg/ha/°C/d). However, the lowest value for HUE was recorded for the Non-AM treatment with Q3 (8.62 kg/ha/°C/d). Generally, the AM treatment had a significant impact on water use and heat use efficiency but with the suitable amount of water (Q2) the AM treatment provide an effective contribution to raising irrigation water unit productivity.

**Table 7** Irrigation water use efficiency and heat use efficiency for kohlrabi as effected by mycorrhizal inoculant and different water quantity treatments

| Treatment | | IWUE (kg/m$^3$) | HUE (kg/ha/°C/day) |
|---|---|---|---|
| (AM) | Q1 | 6.67±0.129 | 13.92±0.271 |
| | Q2 | 7.54±0.195 | 23.6±0.611 |
| | Q3 | 2.61±0.122 | 10.88±0.509 |
| (Non-AM) | Q1 | 5.20±0.262 | 10.83±0.486 |
| | Q2 | 3.58±0.490 | 11.31±0.198 |
| | Q3 | 2.06±0.142 | 8.62±0.515 |

IWUE = irrigation water use efficiency; HUE = heat use efficiency; AM = mycorrhizal inoculant treatment; Non-AM = non-mycorrhizal inoculant treatment. Values are presented as mean ±SD.

*Statistical model*

A model is a schematic representation of the conception of a system or an act of mimicry or a set of equations, which represents the behavior of a system (Murthy, 2003). A crop and plant growth model is a very effective tool for predicting the possible impacts of different factors on crop growth and yield. Crop growth models are useful for solving various practical problems in agriculture. Thus several regression models were developed which utilized some parameters to determine yield production for kohlrabi in the Ismailia governorate in sandy soil.

With (AM) treatment

$$Yield_{(AM)} = -60{,}411.7 + [380.5*(Myco)] + [1{,}346.07*(SPAD)] + [53.7*(LN)] - [11.45*Q]$$

$$R^2 = 0.942$$

With (Non-AM) treatment

$$Yield_{(Non\text{-}AM)} = -9{,}569.5 + [485.108*(Myco)] + [598.8*(SPAD)] - [21.94*(LN)] - [6.32*Q]$$

$$R^2 = 0.89$$

where, Yield is measured in kilograms per hectare, Myco is mycorrhizal root colonization as a percentage (Myco ≤ 71.5%), SPAD is the leaf chlorophyll concentration in percent (SPAD ≤ 60%), LN is the number of leaves (LN < 20) and Q is the total water applied in cubic meters per hectare (Q ≤ 360mm).

Mycorrhizal inoculation improved the performances of kohlrabi plants compared to the non-mycorrhizal treatments, particularly under the different water management regimes. These results should encourage using AM inocula as "bio-enhancers" of plant performance in agricultural systems as the mycorrhizal inoculation could increase yield production under a low water regime by 25% of the total water applied for kohlrabi, which would produce an irrigation water use efficiency of 7.54 kg/m$^3$ and a heat use efficiency of 23.6 kg/ha/°C/d). Moreover, the leaf chlorophyll concentration with the low water regime (Q2) was 61% which is the same value as for the net irrigation water requirement. The interaction between AM and Q2 was highly significant for mycorrhizal roots colonization (71%) and had a positive effect on all plant parameters (plant length, number of leaves, root length). Furthermore predator and soil mites (*Amblyseius swirskii*, *Euseius scutalis*, *Golumna tarsipennata*, *Zygoribatula tritici*) all had significantly densities with the same interaction treatment. Finally, the regression models were produced to estimate the kohlrabi yield under different limiting factors.

$$Yield_{(AM)} = -60{,}411.7 + [380.5*(Myco)] + [1{,}346.07*(SPAD)] + [53.7*(LN)] - [11.45*Q]$$

$$Yield_{(Non\text{-}AM)} = -9{,}569.5 + [485.108*(Myco)] + [598.8*(SPAD)] - [21.94*(LN)] - [6.32*Q]$$ where Q ≤ 360mm, LN ≤ 20, SPAD ≤ 60% and Myco ≤ 71.5%.

## References


Alghariani, S.A. 2002. Future perspectives of irrigation in southern Mediterranean region: policies and management issues. In: Al-Rasheed, M., Singh, V.P., Sheriff, M.M. (Eds.). Proceedings of the International Conference on Water Resources Management in Arid Regions, 23–27 March, Vol. 4. Kuwait. Balkema, Lisse [u.a.], Kuwait, pp. 313–320.

Allen, M.F. 1996. The ecology of arbuscular mycorrhizas: A look back into the 20th Century and a Peek into the 21st. Mycol. Res. 100: 769–782.

Allen, R.G., Smith, M., Raes, D., Pereira, L.S. 1998. Crop evapotranspiration, guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper No.56. Rome, Italy.

American Public Health Association (APHA), American Water Works Association (A.W.W.A.) and Water Pollution Control Federation (W.P.C.F.). 1992. Standard methods of examination of water and wastewater, 20th ed., American Public Health Association. Washington, DC, USA.

Ashwani, K., Joanna F.D., Aditi, G., Satyawati, S., Jack, A.G., Parvaiz, A. 2015. Current developments in arbuscular mycorrhizal fungi research and its role in salinity stress alleviation: A biotechnological perspective. Crit. Rev. Biotechnol. 35: 461– 474

Auge´, R.M., Schekel, K.A., Wample, R.L. 1987. Rose leaf elasticity changes in response to mycorrhizal colonization and drought acclimation. Physiol. Plant. 70: 175–82.

Baskerville, G.L., Emin, P. 1969. Rapid estimation of heat accumulation from maximum and minimum temperatures. Ecology. 50: 514–517.

Bates, L.S., Waklren, R.P., Teare, L.D. 1973. Rapid determination of free proline for water stress studies. Plant Soil. 39: 205–207.

Bezemer, T.M., De Deyn, G.B., Bossinga, T.M., Van Dam, N.M., Harvey, J.A., Van der Putten, W.H. 2005. Soil community composition drives aboveground plant-herbivore-parasitoid interactions. Ecol. Lett. 8: 652–661.

Borde, M., Dudhane, M., Jite, P., 2011. Growth photosynthetic activity and antioxidant responses of mycorrhizal and non-mycorrhizal bajra (*Pennisetum glaucum*) crop under salinity stress condition. Crop Prot. 30: 265–271.

Bos, M.G. 1979. Standards for irrigation efficiencies of ICID. J. Irrig. Drain. Div. 105: 37–43.

Brundrett, M., Bougher, N., Dell, B., Grove, T., Malajczuk, N. 1996. Working with Mycorrhizas in Forestry and Agriculture. ACIAR Monograph 32. Australian Centre for International Agricultural Research. Canberra. ACT, Australia.

Brundrett, M.C., Piche´, Y., Peterson, R.L. 1984. A new method for observing the morphology of vesicular-arbuscular mycorrhizae. Can. J. Bot. 62: 2128–2134.

Campanelli, A., Ruta, C., De Mastro, G., Morone-Fortunato, I. 2012. The role of arbuscular mycorrhizal fungi in alleviating salt stress in *Medicago sativa* L. var. icon. Symbiosis. 59: 1–12.

Colla, G., Rouphael, Y., Cardarelli, M. 2008. Alleviation of salt stress by arbuscular mycorrhizal in zucchini plants grown at low and high phosphorus concentration. Biol. Fertil. Soil. 44: 501–509.

Yu, M.H., Ding, G.D., Gao, G.L., Zhao, Y.Y., Yan, L., Sai, K. 2015. Using plant temperature to evaluate the response of stomatal conductance to soil moisture deficit. Forests. 6: 3748–3762.

Drost, D., Johnson, M. 2010. Kohlrabi in the garden. Utah State cooperative extension. https://digitalcommons.usu.edu/cgi/viewcontent.cgi?referer=https://www.google.com.eg/&httpsredir=1&article=1673&context=extension_curall, 1 October 2018.

Duncan, D.B. 1955. Multiple range and multiple F tests. Biometrics. 11: 1–42.

Evelin, H., Kapoor, R., Giri, B. 2009. Arbuscular mycorrhizal fungi in alleviation of salt stress: a review. Ann. Bot. 104: 1263–1280.

Fagbola, O., Osonubi, O., Mulongoy, K., Odunfa, S.A. 2001. Effects of drought stress and arbuscular mycorrhiza on the growth of *Gliricidia sepium* (Jacq). Walp, and *Leucaena leucocephala* (Lam.) de Wit. In simulated eroded soil conditions. Mycorrhiza. 11: 215–223.

Ferree, D.C., Hall, F.R. 1980. Effects of soil water stress and two spotted spider mites on net photosynthesis and transpiration of apple leaves. Photosynth. Res. 1: 189–197.

Fontana, A., Reichelt, M., Hempel, S., Gershenzon, J., Unsicker, S.B. 2009. The effects of arbuscular mycorrhizal fungi on direct and indirect defense metabolites of *Plantago lanceolata* L. J. Chem. Ecol. 35: 833–843.

Gange, A.C. 2001. Species-specific responses of a root- and shoot-feeding insect to arbuscular mycorrhizal colonization of its host plant. New Phytol. 150: 611–618.

Guerrieri, E., Lingua, G., Digilio, M.C., Massa, N., Berta G. 2004. Do interactions between plant roots and the rhizosphere affect parasitoid behavior? Ecol. Entomol. 29: 753–756.

Hoffmann, D., Vierheilig, H., Schausberger, P. 2011. Mycorrhiza-induced trophic cascade enhances fitness and population growth of an acarine predator. Oecologia. 166: 141–149.

Hoffmann, D., Vierheilig, H., Riegler, P., Schausberger, P. 2009. Arbuscular mycorrhizal symbiosis increases host plant acceptance and population growth rates of the two-spotted spider mite *Tetranychus urticae*. Oecologia. 158: 663–671.

Howell, T.A. 1996. Irrigation scheduling research and its impact on water use. In: Camp, C.R., Sadler, E.J. Yoder, R.E. (Eds.). Evapotranspiration and Irrigation Scheduling, Proceedings of the International Conference, ASAE. St. Joseph, MI, USA, pp. 21–33.

Huang, Z., Zou, Z., He, C., He, Z., Zhang, Z., Li, J. 2011. Physiological and photosynthetic responses of melon (*Cucumis melo* L.) seedlings to three glomus species under water deficit. Plant Soil. 339: 391–399.

Jin, M.G., Zhang, R.Q., Gao, Y.F. 1999. Temporal and spatial soil water management: A case study in the Heiloonggang region, PR China. Agric. Water Manage. 42: 173–187.

Kapoor, R., Sharma, D., Bhatnagar, A.K. 2008. Arbuscular mycorrhizae in micropropagation systems and their potential applications. Sci. Hortic. 116: 227–239.

Kingra, P.K., Prabhjyot-Kaur. 2012. Effect of dates of sowing on thermal utilization and heat use efficiency of groundnut cultivars in central Punjab. J. Agr. Phys. 12: 54–62.

Konica Minolta Optics. 2012. Chlorophyll Meter SPAD-502Plus-A lightweight handheld meter for measuring the chlorophyll content of leaves without causing damage to plants. http://www.konicaminolta.com/instruments/download/catalog/color/pdf/spad502plus_e1.pdf, 6 February 2019.

Koricheva, J., Gange, A.C., Jones, T. 2009. Effects of mycorrhizal fungi on insect herbivores: A meta-analysis. Ecology. 90: 2088–2097.

Koske, R.E., Gemma, J.N. 1989. A modified procedure for staining roots to detect VA mycorrhizas. Mycol. Res. 92: 486–488.

Kruger, E., Schmidt, G., Bruckner, U. 1999. Scheduling strawberry irrigation based upon tensiometer measurement and a climatic water balance model. Sci. Hort. 81: 409–424.

Landeros, J., Guevara, L.P., Badii, M.H., Flores, A.E., Pámane, A. 2004. Effect of different densities of the twospotted spider mite *Tetranychus urticae* on $CO_2$ assimilation, transpiration, and stomatal behaviour in rose leaves. Exp. Appl. Acarol. 32: 187–198.

Li, G.Y., Wang, X.W., Huang, X.F., Zhang, X.M. 2001. Study on water use of drip irrigated peach tree under the conditions of fully irrigated and regulated deficit irrigation. J. Hydraul. Eng. 9: 55–58.

Luis, S.P., Oweis, T., Zairi, A. 2002. Irrigation management under water scarcity. Agr. Water Manage. 57:175–206.

Maria, V.C., Stutzel, H., Kage, H. 2004. Irrigation scheduling of kohlrabi (*Brassica oleracea* var. *gongylodes*) using crop water index. Hort. Science. 39: 276–279.

Murthy, V.R.K. 2003. Crop growth modelling and its applications in agricultural meteorology. In: Satellite Remote Sensing and GIS Applications in Agricultural Meteorology, Proceedings of a Training Workshop, 7th–11th July 2003. Dehra Dun, India, pp. 235–261.

Nair, S., Johnson, J., Wang, C. 2013. Efficiency of irrigation water use: A review from the perspectives of multiple disciplines. Agron. J. 105: 351–363

Oloumi-Sadeghi, H., Helm, C.G., Kogan, M. Schoeneweiss, D.F. 1988. Effect of water stress on abundance of twospotted spider mite on soybeans under greenhouse conditions. Entomol. Exp. Appl. 48: 85–90.

Passioura, J.B. 1988. Response to Dr P.J. Kramer's article, "Changing concepts regarding plant water relations". Plant Cell Environ. 11: 569–571

Phocaides, A. 2007. Handbook on Pressurized Irrigation Techniques, 2nd ed. Food and Agriculture Organization of the United Nations. Rome, Italy

Rao, V.U.M., Singh, D., Singh, R. 1999. Heat use efficiency of winter crops in Haryana. J. Agrometeorol. 1: 143–148.

Rong-hua, L., Guo, P., Baum, M., Grando, S. 2006. Evaluation of chlorophyll content and fluorescence parameters as indicators of drought tolerance in barley. Agr. Sci. China. 5: 751–757.

Ruiz-Lozano, J., Azco´n, R., Gomez, M. 1995. Effects of arbuscular-mycorrhizal glomus species on drought tolerance: physiological and nutritional plant responses. Appl. Environ. Microb. 61: 456–460.

Schausberger, P., Peneder, S., Jürschik, S., Hoffmann, D. 2012. Mycorrhiza changes plant volatiles to attract spider mite enemies. Funct. Ecol. 26: 441–449.

Sheng, M, Tang, M, Chen, H, et al. 2008. Influence of arbuscular mycorrhizae on photosynthesis and water status of maize plants under salt stress. Mycorrhiza 18: 287–96.

Smith, S.E., Read, D.J. 2008. Mycorrhizal Symbiosis, 3rd ed. Elsevier. Amsterdam, the Netherlands.

Snyder, R.L., Spano, D., Cesaraccio, C., Duce, P. 1999. Determining degree-day thresholds from field observations. Int. J. Biometeorol. 42: 177–182.

Verbruggen, N., Hermans, C. 2008. Proline accumulation in plants: A review. Amino Acids. 35: 753–759.

Vermeiren, L. Jobling, G.A. 1984. Localized irrigation. FAO irrigation and drainage Paper No.36. FAO. Rome, Italy.

Wilcox, J., Makowski, D. 2014. A meta-analysis of the predicted effects of climate change on wheat yields using simulation studies. Field Crops Res. 156: 180–190.

Wilson, G.W., Rice, C.W., Rillig, M.C., Springer, A., Hartnett, D.C., 2009. Soil aggregation and carbon sequestration are tightly correlated with the abundance of arbuscular mycorrhizal fungi: results from long-term field experiments. Ecol. Lett. 12: 452–461.

Wolfe, B.E., Husband, B.C., Klironomos, J.N. 2005. Effects of a belowground mutualism on an aboveground mutualism. Ecol. Lett. 8: 218–223.

Zhang, H., Oweis, T. 1999. Water-yield relations and optimal irrigation scheduling of wheat in the Mediterranean region. Agr. Water Manage. 38: 195–211.

Zuccarini, P. 2007. Mycorrhizal infection ameliorates chlorophyll content and nutrient uptake of lettuce exposed to saline irrigation. Plant Soil Environ. 53: 283–289.