www.czasopisma.pan.pl PAN www.journals.pan.pl

JOURNAL OF WATER AND LAND DEVELOPMENT

e-ISSN 2083-4535

Polish Academy of Sciences (PAN) Institute of Technology and Life Sciences – National Research Institute (ITP – PIB)

JOURNAL OF WATER AND LAND DEVELOPMENT
DOI: 10.24425/jwld.2023.146615
2023, No. 58 (VII–IX): 234–242

# The impact of maize irrigation intervals and potassium fertiliser rates on mealybug populations, vegetative growth, and resulting yield

Moustafa M.S. Bakry[1)] ✉, Dalal M. Aljedani[2)]

[1)] Agricultural Research Center, Plant Protection Research Institute, Department of Scale Insects and Mealybugs Research, 12619 Giza, Egypt

[2)] University of Jeddah, College of Science, Department of Biology, Jeddah, Saudi Arabia

RECEIVED 08.02.2023 ACCEPTED 17.05.2023 AVAILABLE ONLINE 29.09.2023

**Abstract:** The mealybug, *Phenacoccus solenopsis* (Hemiptera: Coccomorpha: Pseudococcidae), is one of the main pests attacking maize plants in Egypt. Field trials were carried out in the maize field to assess the influence of irrigation periods and potassium fertiliser rates on the mealybug (*P. solenopsis)* population estimates, vegetative growth, resulting yield, and its components for the maize cultivar ('Single-Hybrid 168 Yellow') in the Luxor Governorate, Egypt. Results revealed that unfertilised plants irrigated every seven days had higher pest population densities than other treatments over the two seasons. The fertilised treatments at 114 kg $K_2O\cdot ha^{-1}$ that received water every 10 days had the smallest population of *P. solenopsis* in every season. Data during the two seasons (2021 and 2022) revealed that the maize to which potassium fertiliser was added by 114 kg $K_2O\cdot ha^{-1}$ and irrigated every 10 days had vegetative growth (plant height, diameter, and number of green leaves per plant), yield and its components (average ear length, ear weight, number of grains per ear, weight of 1000 grains, and grain yield) significantly increased as compared to those of the plants that were irrigated every 7 days and without adding fertiliser. A higher dose of potassium fertiliser reduces the infestation of *P. solenopsis* but causes an increment of maize vegetative growth. This affects the final yield. This information aids farmers in comprehending the good agronomic techniques of maize plants to decrease the infestation of mealybugs and increase the yield.

**Keywords:** agronomic practices, crop productivity, maize, mealybug (*Phenacoccus solenopsis*), potassium fertilisation

## INTRODUCTION

Maize is considered of the most substantial cereal crops in the world. It is ranked the third main crop after wheat and rice in Egypt. It can be utilised as human food, animal feed, and raw material to manufacture numerous industrial products (Moghazy, 2021). In 2020, 871,076.12 ha of maize were grown in Egypt, with an average productivity of 8.154 $Mg\cdot ha^{-1}$ (Bakry and Abdel-Baky, 2023).

Maize plants are infested by different pests at all stages of growth. The mealybug, *Phenacoccus solenopsis* (Hemiptera: Coccomorpha: Pseudococcidae), is main of the pests that attack maize (Abd El-Mageed, Abdel-Razak and Haris, 2020). It is a polyphagous and dangerous pest (Babasaheb and Suroshe, 2015). This pest feeds on the sap of maize leaves, stems, ears, and cobs (Aheer, Shah and Saeed, 2009; Bakry *et al.*, 2023), deforming the plant as a result of the pest's toxic saliva and excretes copious quantities of honeydew that contribute to the growth of sooty mould. Delayed photosynthesis and lowered vegetative growth cause chlorosis, malformation, and death in infected plants (Sahayaraj, Kumar and Avery, 2014; Mohamed, 2021). An indication of an infestation is the appearance and accumulation of pest bodies in the affected maize parts. It is considered to be the primary virus vector (Saeed *et al.*, 2007; Shah, Agha and Memon, 2015). Controlling their population with foliar insecticides is extremely difficult because of their ability to cluster on plant buds and develop a waxy cover on their bodies (Joshi *et al.*, 2010). Pseudococcids, also known as mealybugs, are referred to as "tough to kill insects" (Saad, 2021).

Numerous factors influence maize productivity, but agricultural practices are the primary elements of good growth and resulting yield. These comprise the options of suitable irrigation intervals and potassium fertiliser rates to create the best conditions for growth and development, as well as to prevent diseases and insect infestations at essential growth stages (El-Rouby *et al.*, 2021).

The fertilisers are main sources of mineral elements that plants need for development and growth (Awadalla, Beleh and Mansour, 2017). Potassium is the main plant nutrient that is crucial for producing the highest possible economic yield. It controls stoma closure, prevents water waste, boosts water use efficiency, and is essential to many plant processes (El-Gedwy, 2020). The implementation of K fertiliser increases eventual yield of maize (He *et al.*, 2022). Water is crucial for the germination, growth, transportation of nutrients, photosynthesis, and biochemical processes of the plant. It is important to calculate the quantity of water required for the plant growth, in order to prevent either severe influences of drought or extravagant irrigation on plant growth and productivity (Dahmardeh, 2011).

Fertilisers are considered to increase crop productivity because they supply consistent volumes of nutrients. The shape of these inputs influences pest populations depending on the type of fertiliser utilised, plant grown, and the insect species (Ali *et al.*, 2013).

There is scarce knowledge in the literature on the impact of maize irrigation intervals and potassium fertiliser rates on mealybug populations. Thus, the aim of the current study was to estimate the prospective impacts of maize irrigation periods and potassium fertiliser levels, and their interactions on mealybug populations and the relationship between the mealybug infestation and maize vegetative growth, as well as the potential yield of the maize cultivar ('Single-Hybrid 168 Yellow') in the Luxor Governorate, Egypt. This could contribute to farmers' knowledge about suitable agronomic practices that reduce mealybug infestation in maize plants.

## MATERIALS AND METHODS

The work was executed in a private maize field (25°24'57" N, 32° 31'19" E) at the Esna district, Luxor Governorate, Egypt, during seasons of 2021 and 2022. The aim was to inspect the influence of irrigation dates and potassium fertiliser levels on maize plants in relation to mealybug populations, vegetative growth, and yield. The maize plants were cultivated over an area of 4200 $m^2$, including experimental units. The maize ('Single-Hybrid 168 Yellow') cultivar was sown on the designated date (first week of June every season). Except for pest management, regular agronomic procedures in line with recommendations of the Egyptian Agriculture Ministry and Land Reclamation were followed. Each experimental unit area was 42 $m^2$ (6 m × 7 m), which was distributed in a strip-plot design with two factors in randomised complete block arrangement with four replicates. The vertical strips represented two irrigation periods (every 7 and 10 days), whereas the horizontal strips received two potassium fertiliser levels ($K_2O$) at 0 and 114 kg·$ha^{-1}$. The experiment had four treatments and four replicates, the total of 16 units. As the maize crop differs in the nature of its irrigation on the soil and environmental conditions, especially the high summer temperature in the study area.

The treatment without the use of irrigation may cause the death of the plants and therefore no crop to study. Additionally, chemical control was not used because it reduces the insect population. The aim was to study the effect of different irrigation periods (two periods after 7 and 10 days) as well as levels of potassium fertilization (0 and 114 kg $K_2O$·$ha^{-1}$) on mealybug populations, vegetative growth, and resulting yield.

- **Population estimates of the mealybug, *P. solenopsis*, infesting maize plants**

Random samples of 40 maize plants per treatment, *i.e.* 10 plants from each replicate, roughly 10 cm long of leaf per plant, were picked out from various levels of the plant and examined weekly until crop harvesting. It was discovered that the pest infested maize plants when they were 15 days old. Samples were representative of all live individuals of insects and were clasped randomly from all different trends of the maize field to be recognised by professionals at the Department of Scale Insects and Mealybugs Research, Plant Protection Research Institute, Agricultural Research Center, Giza, Egypt.

The samples were gathered on a uniform foundation and transferred in plastic bags to the laboratory for checking with a stereoscopic microscope. The total number of alive insects per sample on the two faces of leaves was recorded and counted at every sample date to express the pest's population level.

- **Growth measurements and resultant yield and its components**

The following data for vegetative growth attributes and grain yield components of maize were estimated. At harvesting time, ten plants from each plot were picked randomly to evaluate the following characteristics:
1) plant height (cm);
2) stem diameter (cm);
3) number of green leaves/plant;
4) ear length (cm);
5) ear weight (g);
6) number of grains/ear:
7) weight of 1000 grains (g);
8) grain yield (Mg·$ha^{-1}$): determined in each experimental unit (6 m × 7 m = 42 $m^2$); grains from each plot were weighed after shelling to calculate the average grain yield (Mg·$ha^{-1}$) at 15.5% humidity.

The percentage of variation (±) in the tested parameters caused by increment treatments compared to that for the lower treatments was computed using the formula (1):

$$V = [(A - B)/A]100 \tag{1}$$

where: $V$ = percentage of variation, $A$ = average of a given estimation of the lower treatments, $B$ = average of the same variable across the higher treatments.

- **Data analysis**

The data was subjected to statistical evaluation utilising a strip-plot design with two factors in randomised complete block arrangement with four replicates. Means were analogised by applying the LSD test at $P < 0.05$, which was conducted applying the MSTAT–C Program software (MSTAT Development Team, 1991).

To estimate the relationship between the changes in *P. solenopsis* counts and the difference in measured parameters of the maize plants, simple correlation, regression coefficients, and explained variance estimates were used over the two seasons (2021 and 2022), according to Fisher (1950) and Hosny, Amin and El-Saadany (1972). This technique was helpful for displaying fundamental information around the quantity of variability in the measured attributes, as well determining the percentage of variance. The data (insect population, vegetative growth, and resulting yield) were estimated and calculated using the Microsoft Excel 2010 program.

## RESULTS AND DISCUSSION

### POPULATION ESTIMATES OF MEALYBUG (*Phenacoccus solenopsis*) INFESTING MAIZE PLANTS

Photographs of *P. solenopsis* infestation symptoms on the maize plant are shown in Photo 1. The weekly fluctuations of mean numbers of *P. solenopsis* on maize plants, as influenced by irrigation dates and potassium fertiliser levels for both research seasons (2021 and 2022), are shown in Table S1.

Data presented in Table S1 revealed that total live *P. solenopsis* populations were observed on maize plants over the interval from the third week of June to the period of crop harvest through each season, which appeared in the 3$^{rd}$ week of July, the 2$^{nd}$ week of August, and the 1$^{st}$ week of September in all the plots studied. Moreover, the total counts of *P. solenopsis* over 2021 season were greater (105.70 ±6.31 individuals) than in the 2022 season (94.44 ±5.63 individuals per sample). Existing literature offers similar results, Bakry (2022) in Luxor, Egypt, reported three seasonal peaks of *P. solenopsis* every season on okra plants, whereas Bakry *et al.* (2023) in Luxor, Egypt, mentioned three peaks of *P. solenopsis* per season on maize plants.

The analysis of variance revealed significant variations in the numbers of *P. solenopsis* on the several inspected dates in each season in all tested treatments, when the comparisons were done for each treatment independently. Furthermore, interactions between irrigation periods, potassium levels, and inspection dates in the two seasons had a highly significant influence on the average population numbers; the *LSD* values were 14.72 and 14.63, respectively (Tab. S1).

Data in Table S2 demonstrated that the irrigation every 10 days reduced the population density of *P. solenopsis* with an average of 95.89 ±10.20 and 85.22 ±9.06 per sample as compared to the population in the plot with the irrigation every 7 days an average of 115.51 ±6.31 and 103.65 ±11.16 in 2021 and 2022 seasons, respectively. Additionally, the numbers of *P. solenopsis* increased by 16.99 and 17.78% on the maize plants in the plots that were irrigated every 7 days, as compared to that for the irrigated plots every 10 days throughout 2021 and 2022 seasons, respectively. The pests population size may increase as a result of moisture available through shorter irrigation periods.

A statistical examination of the data mentioned the presence of substantial variances in the counts of *P. solenopsis* between the two irrigation treatments (*LSD* values were 13.29 and 11.33) during 2021 and 2022, respectively.

Regarding potassium fertiliser treatments, the addition of potassium ($K_2O$) at a rate of 114 kg·ha$^{-1}$ reduced the counts of *P. solenopsis* by an average of 79.85 ±8.49 and 71.83 ±7.63 per sample, as compared without fertiliser with average of 131.56 ±14.10 and 117.04 ±12.56, during 2021 and 2022, respectively. Moreover, the numbers of *P. solenopsis* were increased signifi-


**Photo 1.** The damage symptoms of *Phenacoccus solenopsis* on maize plants: A) initiating the infestation on maize roots, B) *P. solenopsis* infesting leaves, C) and D) maize leaves and stem entirely colonised with *P. solenopsis* (phot.: *M.M.S. Bakry*)

cantly by 39.31 and 38.63% on the maize plants in the plots that were unfertilised plots, when compared to fertilised plots in 2021 and 2022, respectively. The potassium fertiliser rates realised a very important impact on the mean population of *P. solenopsis* (*LSD* values were 6.95 and 6.46) in both growing seasons, respectively.

In terms of the combined effects of different factors (irrigation frequency and potassium fertiliser rates) on the population estimates of *P. solenopsis*, the findings demonstrated that the highest population size of pest was attained by the unfertilised plots that were irrigated every 7 days with an average of 148.39 ±16.04 and 132.97 ±14.40 individuals per sample than the other treatments, respectively (Tab. S2). In contrast, the lowest pest population densities were obtained in fertilised treatments that were watered every 10 days, with averages of 77.06 ±8.21 and 69.33 ±7.39 individuals per sample than the tested other treatments, in 2021 and 2022, respectively. The interaction impacts of irrigation frequency and potassium fertiliser rates had a highly significant influence on *P. solenopsis* population size across both growth seasons, with *LSD* values of 9.83 and 9.13, respectively (Tab. S2).

As a general average, the numbers of *P. solenopsis* relatively increased by 22.69 and 23.96% for the maize plants in the unfertilised plots that were irrigated every 7 days as compared to unfertilised plots that were watered every 10 days during 2021 and 2022, respectively. Furthermore, there was a significant increase in the counts of pests by 6.76 and 6.73% in the fertilised treatments that were irrigated every 7 days than in the fertilised plots that were irrigated every 10 days during 2021 and 2022, respectively (Tab. S2).

## THE BINARY INFLUENCES OF IRRIGATION PERIODS AND POTASSIUM FERTILISER LEVELS ON VEGETATIVE GROWTH AND MAIZE YIELD AND ITS COMPONENTS

### Vegetative growth measurements

Three plant growth variables for maize plants were examined in this experiment: plant height, stem diameter, and the number of green leaves per plant (Moghazy, 2021).

- **Plant height (cm)**

According to Table S2, the height of maize plants was influenced by irrigation treatments and potassium fertiliser rates in 2021 and 2022 seasons. The irrigation every 10 days resulted in the plant height by an average of 243.25 ±1.88 and 248.50 ±2.00 cm as compared with the irrigation every 7 days (231.00 ±0.58 and 235.83 ±0.44), during 2021 and 2022, respectively. During the two seasons, the plant height was higher by 5.30 and 5.37% in plots irrigated every 10 days, compared to plots irrigated every 7 days. The statistical analysis detected the presence of important variations in the plant height between the two irrigation treatments (*LSD* values were 10.26 and 10.12), over 2021 and 2022, respectively.

The impact of different levels of potassium on maize indicated that potassium application enhanced the plant height; the use of 114 kg $K_2O{\cdot}ha^{-1}$ led to an increase in this parameter by 10.62 and 10.81% in (2021 and 2022, respectively) as compared to unfertilised plots. The potassium fertiliser rates registered highly significant variations in the plant height (*LSD* values were 4.23 and 3.64 for 2021 and 2022 seasons, respectively).

It was noticed that the maximum plant height values (258.83 ±2.17 and 264.17 ±2.20 cm) were observed in the plots that received 114 kg $K_2O{\cdot}ha^{-1}$ and were irrigated every 10 days, compared to the tested other treatments, during 2021 and 2022, respectively. While the minimum plant height value (222.67 ±0.67 and 226.67 ±0.67 cm) was recorded in the unfertilised plots that were irrigated every 7 days compared to the evaluated other treatments, during the two seasons, respectively (Tab. S2). The interaction effects of irrigation times and potassium fertiliser rates had highly significant variations on plant height over two seasons (the *LSD* values were 5.99 and 5.15, respectively, Tab. S2).

It is obvious that the plant height was relatively higher by 2.25 and 2.72% for the maize plants in the unfertilised plots that were irrigated every 10 days as compared to unfertilised plots that were watered every 7 days during the two seasons. Moreover, there was an obvious increment in height of plant of 8.15 and 7.82% in the fertilised treatments that were irrigated every 10 days compared to the fertilised plots that were irrigated every 7 days during 2021 and 2022, respectively (Tab. S2). These findings are in harmony with those of El-Mahdy (2015) who mentioned that the influence of different rates of potassium fertilisation on maize and clearly indicated that potassium application enhanced the plant height. Also, found that the use of 114 kg $K_2O{\cdot}ha^{-1}$ led to an increase in this characteristic by 2.0 and 3.5% during the two seasons, as compared to unfertilised treatments.

- **Stem diameter**

As shown in Table S2, the data revealed that the maize plants irrigated every 7 days had smaller stem diameters (3.45 ±0.03 and 3.30 ±0.01 cm) than the plants irrigated every 10 days (3.62 ±0.04 and 3.47 ±0.02) in 2021 and 2022, respectively, as well, the stem diameter of the plant irrigated every 10 days was bigger than that of the plant irrigated every 7 days by 4.95 and 5.24% during 2021 and 2022, respectively. Furthermore, statistical examination of the data revealed substantial variances in stem diameter between the two irrigation periods (the *LSD* values were 0.16 and 0.14) in 2021 and 2022, respectively. Lima de *et al.* (2010) indicated that insect activity reduced plant biomass by reducing leaf area, stem diameter, and root development. According to our findings, the plant height and stem diameter dropped.

Additionally, the application of 114 kg $K_2O{\cdot}ha^{-1}$ of plant during the two seasons realised the stem diameter with an average of 3.70 ±0.03 and 3.56 ±0.02 cm, while this parameter of unfertilised plants was 3.37 ±0.02 and 3.22 ±0.02 cm. It increased by 9.77 and 10.49% in 2021 and 2022, respectively. Moreover, the potassium fertiliser rates had highly significant variations in the stem diameter (*LSD* value was 0.07 in each season).

It was observed that the bigger stem diameter values (3.83 ±0.04 and 3.69 ±0.04 cm) were noticed in the plants that utilised 114 kg $K_2O{\cdot}ha^{-1}$ and were irrigated every 10 days, compared to the different treatments, over the two seasons. However, the minimum value of this parameter (3.33 ±0.02 and 3.18 ±0.01cm) was registered in the unfertilised treatments that were irrigated every 7 days compared to the assessed other treatments, throughout 2021 and 2022, respectively (Tab. S2). As well, the interaction impact of these factors on stem diameter had significant variations (*LSD* value was 0.10) over each season (Tab. S2).

It is evident that the stem diameter relatively increased by 2.25 and 2.16% for the maize plants in the unfertilised plants that were watered every 10 days as compared to unfertilised plants that were irrigated every 7 days. However, the minimum value of this parameter (3.33 ±0.02 and 3.18 ±0.01cm) was registered in the unfertilised treatments that were irrigated every 7 days compared to the other treatments, during 2021 and 2022, respectively (Tab. S2). Furthermore, there was an important increase in the stem diameter by 7.48 and 8.12% in the fertilised plants that were irrigated every 10 days than in the fertilised plants that were irrigated every 7 days during the two seasons (Tab. S2). The findings are consistent with **Sabiel and Abdelmula (2007)** who mentioned that there was a positive and significant important relation between stem diameter and plant height.

- **Number of green leaves per plant**

Results revealed that the maize plants irrigated every 7 days produced fewer leaves per plant, as an average was (13.83 ±0.17 and 15.17 ±0.17 leaves/plant) compared to the plants irrigated every 10 days (14.42 ±0.08 and 15.75 ±0.25 leaves/plant) during 2021 and 2022, respectively (Tab. S2). The increment in the number of leaves per plant was greater in the plots irrigated every 10 days (4.22 and 3.85%) than in the plots irrigated every 7 days, for the two seasons. In addition, the variances in the number of leaves per plant between watered maize plants every 7 and 10 days had extremely important (*LSD* values were 0.36 and 0.37) during 2021 sand 2022, respectively.

Data showed that adding of 114 kg $K_2O\cdot ha^{-1}$ to plants led to a pronounced increase in the number of leaves per plant with an average of 15.17 ±0.30 and 16.50 ±0.25 compared to unfertilised plants (13.08 ±0.22 and 14.42 ±0.36), during the two seasons. It increased by 15.92 and 14.45% through 2021 and 2022, respectively. Moreover, the potassium fertiliser levels produced highly significant variations in the number of leaves per plant (*LSD* values were 1.16 and 1.17) in 2021 and 2022, respectively.

Over the two seasons, it was discovered that the plants that used 114 kg $K_2O\cdot ha^{-1}$and were irrigated every 10 days had produced larger leaves (15.50 ±0.29 and 16.83 ±0.44) than the other treatments. However, the unfertilised plants that were irrigated every 7 days had the lowest value of this parameter (12.83 ±0.17 and 14.17 ±0.44) compared to the other treatments evaluated 2021 and 2022, respectively (Tab. S2). At the same time, all the possible interactions of the binary factors had an insignificant effect on this parameter.

Moreover, the number of leaves per plant was incremented by 3.90 and 3.53% for the maize plants in the unfertilised plots that were watered every 10 days compared to unfertilised plants that were watered every 7 days across the two seasons. Moreover, there was a significant increase in this parameter by 4.49 and 4.12% in the fertilised plants that were irrigated every 10 days than in the fertilised plots that were irrigated every 7 days in 2021 and 2022, respectively (Tab. S2).

The findings coincide with those by Ebrahimi *et al.* (2011) who concluded that a growing water shortage caused a decrease in the number and size of leaves. Kadasiddappa (2015) discovered that incrementing the quantity and frequency of irrigation in maize plants increased the number of leaves per plant and their height. El-Mahdy (2015) who reported that the greatest number of green leaves per plant in the two studied seasons occurred at 114 kg $K_2O\cdot ha^{-1}$. This is likely due to the critical role of K in the translocation of nutrients and enzymes in phloem and xylem tissues, according to Cao and Tibbitts (1991).

## Yield and its components

- **Ear length (cm)**

As it can be seen in Table S3, the maize plants watered every 10 days had higher mean length of ear with an average of 21.25 ±0.04 and 22.05 ±0.05 cm as compared to 20.54 ±0.08 and 20.80 ±0.01 cm for the plants that were irrigated every 7 days, through the two growing seasons. Furthermore, the ear length in the maize plants irrigated every 10 days increased by 3.45 and 5.97% as compared with those of the plants irrigated every 7 days, during 2021 and 2022 seasons, respectively. Data analysis showed important variances in the length of the ear among irrigation periods (*LSD* values were 0.49 and 0.14) during 2021 and 2022 seasons, respectively.

Data revealed that the use of 114 kg $K_2O\cdot ha^{-1}$ resulted in an increase in the mean length of ear by an average of 21.96 ±0.01 and 2.49 ±0.10 cm as compared to the unfertilised treatments, which resulted in 19.83 ±0.09 and 20.36 ±0.13 cm. The length of the cob in fertilised plants increased by 10.71 and 10.48% at an application of 114 kg $K_2O\cdot ha^{-1}$ throughout the two seasons, respectively. Moreover, statistical analysis of the data appeared highly important variances in ear length between potassium fertiliser treatments (*LSD* values of 0.36 and 0.48) over the two successive seasons. These outcomes could be attributed to potassium fertiliser's role in raising photosynthetic assimilation and enzymatic activity, which sped up plant growth and produced large ears. The results are in harmony with El-Mahdy (2015). These results showed that the maximum ear length (cm) values occurred with the use of 114 kg $K_2O\cdot ha^{-1}$ and irrigation every 10 days, i.e. 22.38 ±0.07 and 23.22 ±0.07 cm, over the two seasons. The minimum ear length was observed in the unfertilised plants that were watered every 7 days, namely 19.55 ±0.10 and 19.84 ±0.17 cm, comparing to the other treatments tested in the two seasons (Tab. S3). The ear length was insignificantly influenced by the interaction between the tested binary factors every season.

Furthermore, the ear length of plant in unfertilised plots that were irrigated every 10 days enhanced by 2.90 and 5.21% compared to unfertilised plots that were watered every 7 days across the two seasons. Additionally, throughout the two seasons, there was a substantial increase in this parameter by 3.95 and 6.67% in the fertilised plants that were watered every 10 days compared to the fertilised plots that were watered every 7 days (Tab. S3).

- **Ear weight (g)**

Results in Table S3 show that the ear weight in the maize plants irrigated every 10 days was significantly higher, with an average of 268.75 ±1.88 and 277.08 ±2.32 g compared to the plants that were irrigated every 7 days (254.53 ±0.39 and 261.67 ±0.87 g), over the two seasons. Moreover, the cob weight of the plants irrigated every 10 days increased by about 5.59 and 5.89% of their weight as compared with the plants watered every 7 days, during the two growing seasons. There were significant differences in the weight of the ear among the irrigation treatments (*LSD* values were 8.95 and 13.63) in 2021 and 2022, respectively.

Moreover, the unfertilised plants resulted in the lower ear weight (average weight 248.28 ±1.70 and 256.50 ±1.88 g) during the two seasons, compared to the use of 114 kg $K_2O\cdot ha^{-1}$, which resulted in 275.00 ±1.18 and 282.25 ±0.95 g during the two seasons. At an addition of 114 kg $K_2O\cdot ha^{-1}$, the ear weight in fertilised plants increased by 10.76 and 10.04% during the two seasons. Over the two seasons, there were very important variances in the ear weight among the potassium fertiliser levels (*LSD* values were 5.46 and 6.03).

The aforementioned findings are in line with those by **El-Mahdy (2015),** who reported that potassium played a crucial role in the photosynthesis-related enzyme activities, which increased photosynthetic assimilates and dry matter accumulation in the growing ear.

These findings revealed that the addition of 114 kg $K_2O\cdot ha^{-1}$ and irrigation every 10 days resulted in the largest ear weight gain (286.00 ±2.18 and 294.50 ±2.29 g), across the two seasons. The lowest ear weight was noticed in the unfertilised plots that were watered every 7 days, being 245.07 ±1.32 and 53.33 ±1.17 g comparing to the other treatments examined in the two seasons (Tab. S3). The interaction between the examined binary parameters had a substantial impact on the ear weight for both seasons (*LSD* values were 7.72 and 8.53).

Additionally, the ear weight was larger by 2.63 and 2.50% in unfertilised plots that were irrigated every 10 days than unfertilised plots that were watered every 7 days during the two seasons. Likewise, there was a significant rise in this parameter (8.33 and 9.07%) in the fertilised plants that were watered every 10 days compared to the fertilised plots that were watered every 7 days across the two seasons (Tab. S3).

- **Number of grains per ear**

Data presented in Table S3 revealed that the number of grains per ear in the maize plants irrigated every 7 days was lower with an average of 452.92 ±7.91 and 495.67 ±5.47 grains/ear than 480.08 ±2.96 and 520.17 ±1.86 grains/ear for the plants that were irrigated every 10 days, over the two growing seasons (Tab. S3). Additionally, the number of grains per ear in plants that were irrigated every 10 days increased by 6.00 and 4.94% when compared to plants watered every 7 days, for the two seasons. Moreover, the differences in the number of grains per ear between irrigation treatments were significant (*LSD* values were 22.69 and 23.97) in 2021 and 2022, respectively.

Results indicated that the use of 114 kg $K_2O\cdot ha^{-1}$ exhibited an increase in this characteristic (average value 492.58 ±10.68 and 531.92 ±8.47) as compared to the unfertilised plots (440.42 ±2.98 and 483.92 ±6.42) during the two seasons. The length of the cob in fertilised plants was 114 kg $K_2O\cdot ha^{-1}$ (11.84 and 9.92% longer than in unfertilised plots) during the two seasons, respectively. Additionally, the interaction influence of these factors on this attribute had significant variations (*LSD* values were 22.81 and 32.09), over the two seasons. These outcomes could be attributed to the potassium's role in boosting photosynthetic assimilation and enzymatic activity, which sped up plant growth and produced larger ears (El-Mahdy, 2015).

Concerning the interaction between irrigation periods and potassium fertilisation levels, these findings showed that the lowest number of grains per ear was noticed in the unfertilised plants that were watered every 7 days, being 419.50 ±3.04 and 464.17 ±8.81 grains/ear across the two seasons. Conversely, the highest number of grains per ear appeared when the dose of 114 kg $K_2O\cdot ha^{-1}$ was applied and plants were irrigated every 10 days, on average 498.83 ±7.07 and 536.67 ±1.76 grains/ear, through the two seasons, respectively. Furthermore, the possible interaction between the irrigation periods and potassium fertiliser doses had a negligible impact on this character.

Furthermore, the number of grains/ear enhanced by 2.57 and 1.80% in fertilised plots that were irrigated every 10 days compared to fertilised plants that were watered every 7 days for the two seasons, respectively. Similarly, there was a large increase in the parameter (9.97 and 8.51%) in the unfertilised plants that were watered every 10 days than the unfertilised plots that were watered every 7 days, during the two seasons (Tab. S3).

- **1000 grain weight (g)**

As shown in Table S3, the average weight of 1000 grains in the maize plants irrigated every 7 days was lower (298.67 ±0.73 and 307.17 ±1.97 g) than in the plants irrigated every 10 days (315.58 ±2.80 and 319.42 ±2.84 g), over the two growing seasons, respectively. Additionally, the weight of 1000 grains of the plants that received irrigation every 10 days increased by approximately 5.66 and 3.99% of their weight in comparison to the plants irrigated every 7 days, during 2021 and 2022, respectively. Additionally, there were significant differences in 1000 grain weight between irrigation periods (*LSD* values of 15.04 and 3.78), in 2021 and 2022, respectively.

Furthermore, the application of 114 kg $K_2O\cdot ha^{-1}$ to plants resulted in an increase in the weight of 1000 grains (average value 323.08 ±1.26 and 332.75 ±2.36 g), as opposed to the unfertilised plants, which exhibited an average of 291.17 ±2.17 and 293.83 ±2.76 g during 2021 and 2022, respectively. The weight of 1000 grains in fertilised plants increased with the application of 114 kg $K_2O\cdot ha^{-1}$ by 10.96 and 13.42% over the two seasons, respectively. The weight of 1000 grains varied extremely significantly among the potassium fertiliser levels (*LSD* values were 6.96 and 3.70), during the two seasons. This could be attributed to potassium's influence on carbohydrate synthesis as well as promotion of $CO_2$ assimilation and the movement of assimilates from different plant parts to the ears during grain filling. The findings are in agreement with El-Mahdy (2015).

The maximum weight of 1000 grains with an average of 336.17 ±3.24 and 340.83 ±3.00 g was observed with the application of 114 kg $K_2O\cdot ha^{-1}$ and irrigation every 10 days, over the two growing seasons. The minimum weight of 1000 grains 287.33 ±1.45 and 289.67 ±2.60 g was recorded in the unfertilised plots that were watered every 7 days (Tab. S3). Likewise, the potential interaction had a significant impact on this parameter (*LSD* values were 9.84 and 5.23) over 2021 and 2022, respectively.

Moreover, the weight of 1000 grains was larger by 2.67 and 2.88% in unfertilised plots that were watered every 10 days compared to unfertilised plots watered every 7 days during the two seasons. Additionally, there was a significant increase in this parameter by 8.44 and 4.98% in the fertilised plants that were irrigated every 10 days compared to the fertilised plots that were watered every 7 days across the two seasons (Tab. S3).

- **Grain yield ($Mg\cdot ha^{-1}$)**

Data in Table S3 proved that the maize plants irrigated every 10 days had a higher grain yield with an average weight of 6.16 ±0.04 and 6.50 ±0.04 $Mg\cdot ha^{-1}$ compared to the plants irrigated every 7 days (5.84 ±0.03 and 6.15 ±0.02 $Mg\cdot ha^{-1}$) for the two seasons of 2021 and 2022, respectively. Moreover, the weight of grain yield from the plants irrigated every 10 days increased by about 5.45 and 5.60% of their weight as compared with the plants irrigated every 7 days through the two growing seasons. The weight of grain yield per hectare varied significantly depending on the irrigation periods (*LSD* values of 0.18 and 0.16), over 2021 and 2022, respectively.

It was clear that the unfertilised plants had lower grain yields (average weight was 5.69 ±0.04 and 6.01 ±0.07 $Mg \cdot ha^{-1}$) than the fertilised plants that received 114 kg $K_2O \cdot ha^{-1}$ with an average of 6.31 ±0.03 and 6.65 ±0.04 $Mg \cdot ha^{-1}$, during 2021 and 2022, respectively. The increase in the average weight of grain yield in fertilised plants with the application of 114 kg $K_2O \cdot ha^{-1}$ was 10.77 and 10.72% compared to the unfertilised plants during the two seasons. Likewise, all conceivable interactions had a very significant impact on grain yield (*LSD* values were 0.13 and 0.18), across the two seasons. The aforementioned findings are in line with El-Mahdy (2015), who mentioned that the use of 114 kg $K_2O \cdot ha^{-1}$ and 57 kg $K_2O \cdot ha^{-1}$ on maize led to a higher increase in the grain yield by 17.2 and 5.8% in the 2011 season, and by 26.8 and 16.8% in the 2012 season, as compared to unfertilised treatments, respectively.

It was noticed that the application of 114 kg $K_2O \cdot ha^{-1}$ and irrigation every 10 days resulted in the highest weight of grain yield (6.56 ±0.04 and 6.93 ±0.05 $Mg \cdot ha^{-1}$), across the two seasons (2021 and 2022, respectively). However, the lowest weight of grain yield was produced in the unfertilised plots that were irrigated every 7 days, with an average of 5.63 ±0.04 and 5.94 ±0.07 $Mg \cdot ha^{-1}$ during the two seasons. Moreover, the grain yield for both seasons was significantly influenced by the interaction between the investigated binary parameters (*LSD* values were 1.87 and 0.26), respectively. Furthermore, grain yield was higher in unfertilised plants that were irrigated every 10 days (2.32%) compared to unfertilised plants that were watered every 7 days in every season. Likewise, there was a large increase in the grain yield (8.35 and 8.66%) in the fertilised plants that received water every 10 days as opposed to the fertilised plots that were watered every 7 days, through 2021 and 2022, respectively (Tab. S3).

The above mentioned results emphasise that the maximum population densities of *P. solenopsis* were recorded in the unfertilised plants that were irrigated every seven days. However, its lowest population was registered in fertilised plants at 114 kg $K_2O \cdot ha^{-1}$ that received water every 10 days during both growing seasons (2021 and 2022). Furthermore, the vegetative growth measurements (plant height, diameter, and number of green leaves per plant), yield, and its component attributes (average ear length, ear weight, number of grains per ear, weight of 1000 grains, and grain yield) in maize plants irrigated every 10 days and when fertilised with a 114 kg $K_2O \cdot ha^{-1}$ potassium fertiliser were significantly higher than in plants irrigated every 7 days without fertiliser, as shown in Tables S2 and S3. These findings are in line with Abdelgalil *et al.* (2022). They mentioned that irrigation at every 10 days produced the highest plant height, cob length, weight of 100 grains and grain yield as compared to the irrigation every 15 and 20 days.

## ESTIMATED RELATIONSHIP BETWEEN CHANGES IN THE COUNTS OF *Phenacoccus solenopsis* AND THE DIFFERENCE IN MEASURED PARAMETERS OF THE MAIZE PLANTS

Results exhibited an extremely significant negative correlation between the mean numbers of *P. solenopsis* individual and the vegetative growth attributes, *i.e.* plant height, stem diameter, and number of green leaves per plant (*r* values: –0.84, –0.82 and –0.87 through 2021 and –0.85, –0.83 and –0.78 over 2022, respectively). The calculated regression coefficient (*b*) showed that an increment of one insect per 10 maize plants would decrease the vegetative growth properties, *i.e.* plant height (0.40 and 0.47 cm), stem diameter (0.01 and 0.01 cm), and the number of green leaves per plant (0.03 and 0.04 leaves), during 2021 and 2022, respectively (Tab. S4).

Furthermore, the calculated simple correlation between the mean population estimates of *P. solenopsis* and the yield and its components, namely ear length, its weight, number of grains/ear, 1000-grains weight and grain yield, were very negative; being –0.94, –0.85, –0.91, –0.84 and –0.85 during 2021 and –0.91, –0.81, –0.85, –0.92 and –0.84 during 2022. Likewise, the estimated regression coefficient showed that an increase of one individual pest per 10 plants would decrease the ear length (0.04 and 0.04 cm), weight (0.46 and 0.50 g), number of grains per ear (1.01 and 1.01 grains), weight of 1000 grains (0.55 and 0.74 g) and grain yield (0.01 and 0.01 $Mg \cdot ha^{-1}$) during the two seasons of 2021 and 2022, respectively (Tab. S4).

Consequently, the number of *P. solenopsis* individuals per 10 plants was clearly negatively correlated with all tested measurements of vegetative growth, grain yield, and its components.

## CONCLUSIONS

The mealybug, *Phenacoccus solenopsis* (Hemiptera: Coccomorpha: Pseudococcidae) is one of the main pests attacking maize plants in Egypt. This pest feeds on the sap of corn leaves and stems, reduces vegetative growth, and causes chlorosis, deformation, and death in infected plants. Data collected for both growing seasons of 2021 and 2022 revealed that the unfertilised plants that were irrigated every seven days had higher pest population densities than the other treatments over the two seasons. However, the fertilised treatments at 114 kg $K_2O \cdot ha^{-1}$ that received water every 10 days had the smallest population of *P. solenopsis* in every season. Results showed that the vegetative growth measurements (plant height, diameter, and number of green leaves per plant), yield, and its component attributes (average ear length, ear weight, number of grains per ear, weight of 1000 grains, and grain yield) in the maize plants to which 114 kg $K_2O \cdot ha^{-1}$ potassium fertiliser was added and irrigated every 10 days were significantly increased as compared to those of the plants that were irrigated every 7 days and without adding fertiliser.

These results show that the general average of *P. solenopsis* individuals decreased with increasing potassium fertilisation levels. An increase in mealybug populations in decreased potassium treatments tended to reduce maize grain yield. With this knowledge, farmers may better understand good agronomic techniques for maize plants in order to reduce mealybug infestation and increase yield.

## SUPPLEMENTARY MATERIAL

Supplementary material to this article can be found online at https://www.jwld.pl/files/Supplementary_material_Bakry.pdf

## REFRENCES

Abdelgalil, A. *et al.* (2022) "Effect of irrigation intervals and foliar spray of zinc and silicon treatments on maize growth and yield components of maize," *Current Chemistry Letters*, 11, pp. 219–226. Available at: https://doi.org/10.5267/j.ccl.2021.12.002.

Abd El-Mageed, S.A.M., Abdel-Razak, S.I. and Haris, H.M. (2020) "Ecological studies on the cotton mealybug *Phenacoccus solenopsis* (Hemiptera: Pseudocccidae) on maize in Upper Egypt," *Egyptian Journal of Plant Protection Research Institute*, 3(4), pp. 1098–1110. Available at: http://www.ejppri.eg.net/pdf/v3n4/19.pdf (Accessed: December 28, 2020).

Aheer, G.M., Shah, Z. and Saeed, M. (2009) "Seasonal history and biology of cotton mealybug, *Phenacoccus solenopsis* Tinsley," *Journal of Agricultural Research*, 47(4), pp. 423–431.

Ali, L. *et al.* (2013) "Inorganic fertilization of wheat in relation to aphid infestation, natural enemies population, growth and grain yield," *International Journal of Agriculture & Bio*logy, 15, pp. 719–724. Available at: http://www.fspublishers.org/published_papers/58388_..pdf (Accessed: December 15, 2022).

Awadalla, S.S., Beleh, S.B. and Mansour, M.R.K. (2017) "Influence of nitrogen and potassium fertilization levels on the population density of the bird cherry – oat aphid, *Rhopalosiphum padi* Linnaeus (Homoptera: Aphididae)," *Journal of Plant Protection and Pathology*," 8(2), pp. 87–89. Available at: https://jppp.journals.ekb.eg/article_46153_c612e279cc368562b4e39acd196d1f0b.pdf (Accessed: February 27, 2017).

Bakry, M.M.S. (2022) "Distribution of *Phenacoccus solenopsis* infesting okra plants: Evidence for improving a pest scouting method," *Journal of Advanced Zoology*, 43(1) pp. 56–72. Available at: http://jazindia.com/index.php/jaz/article/view/114 (Accessed: August 20, 2022).

Bakry, M.M.S. and Abdel-Baky, N.F. (2023) "Population density of the fall armyworm, *Spodoptera frugiperda* (Smith) (Lepidoptera: Noctuidae) and its response to some ecological phenomena in maize crop, Egypt," *Brazilian Journal of Biology*, 83, e271354. Available at: https://doi.org/10.1590/1519-6984.271354.

Bakry, M.M.S. *et al.* (2023) "Influence of maize planting methods and nitrogen fertilization rates on mealybug infestations, growth characteristics, and eventual yield of maize," *International Journal of Agriculture and Biology*, 29, pp. 401–409. Available at: https://doi.org/10.17957/IJAB/15.2046.

Cao, W. and Tibbitts, T.W. (1991) "Potassium concentration effect on growth, gas exchange and mineral accumulation in potatoes," *Journal of Plant Nutrition*, 14(6), pp. 525–537. Available at: https://doi.org/10.1080/01904169109364222.

Dahmardeh, M. (2011) "Economical and biological yield of corn (*Zea mays* L.) as affected by nitrogen fertilization under different irrigation interstices," *Journal of Food, Agriculture and Environment*, 9(3&4), pp. 472–474. Available at: https://www.wflpublisher.com/Abstract/2306 (Accessed: January 12, 2023).

Ebrahimi, S.T. *et al.* (2011) "Effect of potassium fertilizer on corn yield (Jeta cv.) under drought stress condition," *American-Eurasian Journal of Agricultural and Environmental Sciences*, 10(2), pp. 257–263. Available at: https://idosi.org/aejaes/jaes10(2)/19.pdf (Accessed: December 15, 2022).

El-Gedwy, E. (2020) "Effect of water stress, nitrogen and potassium fertilizers on maize yield productivity," *Annals of Agricultural Science Moshtohor*, 58(3), pp. 515–534. Available at: https://doi.org/10.21608/assjm.2020.122030.

El-Mahdy A.M. (2015) *Effect of irrigation scheduling, planting ridge width and potassium fertilization on maize crop under upper Egypt conditions*. MSc thesis. Department of soils and water Faculty of Agriculture Sohag University.

El-Rouby, M.G. *et al.* (2021) "Determination of grain yield inputs of the maize hybrid Giza 168 using a six-factor central composite design in Mediterranean regions under irrigation," *Journal of Desert and Environmental Agriculture*, 1(1), pp. 1–15. Available at: https://doi.org/10.21608/jdea.2021.51532.1002.

Fand, B.B. and Suroshe, S.S. (2015) "The invasive mealybug, *Phenacoccus solenopsis* Tinsely, a threat to tropical and subtropical agricultural and horticultural production systems – A review," *Crop Protection*, 69, pp. 34–43. Available at: https://doi.org/10.1016/j.cropro.2014.12.001.

Fisher, R.A. (1950) *Statistical methods for research workers*. 12$^{th}$ edn. Edinburgh, London: Oliver and Boyd Ltd.

He, B. *et al.* (2022) "Effect of different long-term potassium dosages on crop yield and potassium use efficiency in the maize–wheat rotation system," *Agronomy*, 12(10), 2565. Available at: https://doi.org/10.3390/agronomy12102565.

Hosny, M.M., Amin, A.H. and El-Saadany, G.B. (1972) "The damage threshold of the red scale, *Aonidiella aurantii* (Maskell) infesting mandarin trees in Egypt," *Zeitschrift für Angewandte Entomologie*, 77, pp. 286–296. Available at: https://doi.org/10.1111/j.1439-0418.1972.tb01750.x.

Joshi, M.D. *et al.* (2010) "Cotton mealy bug, *Phenacoccus solenopsis*," *Agricultural Reviews*, 31, pp. 113–119. Available at: https://arccarticles.s3.amazonaws.com/webArticle/articles/ar312004.pdf (Accessed: December 15, 2022).

Kadasiddappa, M. (2015) *Drip irrigated maize and sunflower: Growth, yield, evapotranspiration and water production functions*. PhD Thesis. Hyderabad: PJTSAU.

Lima de, M. *et al.* (2010) "Corn yield response to weed and fall armyworm controls," *Planta Daninha*, 28(1), pp. 103–111. Available at: https://doi.org/10.1590/s0100-83582010000100013.

Moghazy, A.A.A. (2021) *Integrated irrigation regime, nitrogen fertilization and intercropping practices for maximizing water productivity under Upper Egypt conditions*. MSc. Thesis. Assiut: Al-Azhar University.

Mohamed, G.S. (2021) "Studies on population dynamic, biology of the cotton mealybug, *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae) and its natural enemies as a new insect on okra plant, (*Abelmoschus esculentus* (L.) Moench) at Qena Governorate, Egypt," *Egyptian Academic Journal of Biological Sciences. A, Entomology*, 14(3), pp. 1–16. Available at: https://doi.org/10.21608/eajbsa.2021.182944.

MSTAT Development Team (1991) *MSTAT C: A microcomputer program of the design management and analysis of agronomic research experiments*. East Lansing, USA: Michigan State University.

Saad, L.H.A. (2021) *Efficacy of some insecticides against cotton mealybug Phenacoccus solenopsis Tinsley (Hemiptera: Pseudococcidae)*. PhD Thesis. Mansoura, Egypt: Mansoura University.

Sabiel, S.A.I. and Abdelmula, A.A. (2007) "Genotypic and differential responses of growth and yield of some maize (*Zea mays* L.) genotypes to drought stress," in *Utilisation of diversity in land use systems: Sustainable and organic approaches to meet human needs. Conference on International Agricultural Research for Development*. Tropentag October 11, 2007. University of Kassel-Witzenhausen and University of Göttingen, pp. 1–6.

Saeed, S. *et al.* (2007) "Insecticidal control of the mealybug *Phenacoccus gossypiphilous* (Hemiptera: Pseudococcidae), a new pest of cotton in Pakistan," *Entomological Research*, 37(2), pp. 76–80. Available at: https://doi.org/10.1111/j.1748-5967.2007.00047.x.

Sahayaraj, K., Kumar, V. and Avery, P.B. (2014) "Functional response of *Rhynocoris kumarii* (Hemiptera: Reduviidae) to different population densities of *Phenacoccus solenopsis* (Hemiptera: Pseudococcidae) recorded in the laboratory," *European Journal of Entomology*, 112(1), pp. 69–74. Available at: https://doi.org/10.14411/eje.2015.020.

Shah, T.N., Agha, M.A. and Memon, N. 2015. Population dynamics of cotton mealybug, *Phenacoccus solepnosis* Tinsely in three talukas of district Sanghar (Sindh). Journal of Entomology and Zoology Studies, 3(5), pp. 162–167. Available at: https://www.entomoljournal.com/vol3Issue5/pdf/3-5-35.1.pdf (Accessed: September 9, 2015).