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Enhancing Crop Resilience to Drought Stress: Antitranspirants, Zeolite and Water Conservation Strategies for Strategic Crop Productivity

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ABSTRACT

This review endeavors to present a comprehensive overview of the current state of understanding regarding the ramifications of drought stress on the productivity of strategically important crops. It also delves into the positive effects of applying antitranspirants to plants subjected to drought stress. Moreover, this review seeks to explore the advantageous role of zeolite amendment in conserving irrigation water. By thoroughly analyzing the existing literature, this review aims to amalgamate and scrutinize the principal discoveries, emerging patterns, and research gaps up to the present time.The review will emphasize the imminent threats posed by water scarcity to the agricultural sector in Egypt and underscore the strategies for ameliorating the detrimental impact of water deficits through the reduction of irrigation water requirements. It will further examine the influence of water deficits on plant performance and highlight the efficacy of zeolite, employed as a soil conditioner alongside antitranspirants like kaolin and magnesium carbonate, in both conserving irrigation water and enhancing plant growth. Additionally, this review will pinpoint substantial challenges and prospects in the field, with the ultimate objective of guiding future avenues of research and pragmatic applications.

Keywords: Drought, zeolite, kaolin, magnesium carbonate

INTRODUCTION

Mismanagement of water resources, unequal distribution of water, and ineffective irrigation methods are among the primary contributors causing significant challenges to water security in Egypt. The nation has been grappling with acute water scarcity in recent times (El-Hadidi *et al.*, 2020). When higher plants experience a water deficit, it can negatively influence their growth and development. Water deficit can be harmful to plant performance, as water is essential for plant growth (El-Sherpiny *et al.* 2023). Plants require it to carry out many essential physiological processes *e.g.*, transpiration, photosynthesis and nutrient uptake as well as it is important for cell expansion. Thus, the water deficit leads to reduce photosynthetic rates, which can limit their ability to grow and produce (Parkash and Singh, 2020). Zeolite is a naturally occurring mineral that has a unique molecular structure. It is often used as a water-absorbent substance due to its high porosity and ability to trap water molecules within its pores. When zeolite comes into contact with water, it will absorb the water and hold it within its structure. This makes it useful for a variety of applications, including saving irrigation water, and soil remediation. One of the advantages of using zeolite as a water-absorbent substance is that it is a natural material, meaning that it is environmentally friendly and non-toxic. However, it is important to note that the effectiveness of zeolite as a water-absorbent substance can vary depending on the specific application and the quality of the zeolite used (Moshoeshoe *et al.*, 2017). Zeolite is one of the soil amendments which improves soil properties and saves soil water for agronomic crops. Numerous studies have indicated its capacity to retain significant quantities of irrigation water and nutrients, subsequently releasing them in accordance with plants' needs (Khalifa, *et al.*, 2019 and El-Sherpiny *et al.*, 2020). Anti-transpirants are substances that are used to reduce water loss from plants by limiting transpiration. Transpiration is the process by which water is lost from the leaves of plants through evaporation. Anti-transpirants work by forming a thin film on the surface of the leaves, which reduces the rate of water loss through transpiration (Abdallah *et al.*, 2020). Anti-transpirants *e.g.,* kaolin and magnesium carbonate, calcium carbonate, green miracle ….. *etc*. are chemical materials that are sprayed on surfaces of plants to reduce water loss through the transpiration process, where these substances not only alleviate the water loss but also increase disease resistance and yield and quality in the Poaceae plant family *e.g.,* rice, as mentioned by El-Hadidi *et al.*, (2020) as well as anti-transpirants can enhance physiological processes (Guo-Li *et al.*, 2020). Kaolin has demonstrated beneficial effects on plant growth and performance, particularly in drought conditions. Applying kaolin to the leaves results in lowered leaf temperatures, thereby reducing transpiration rates and enhancing the metabolic processes in plants subjected to water deficit stress (Ibrahim and Selim, 2010). Magnesium carbonate ($MgCO_3$) as anti-transpirants leads to closes stomata and subsequently positively affects metabolic processes in leaves tissues (Ahmed *et al.*, 2019).

In pursuit of the objectives of this study, a comprehensive exploration of relevant literature has been conducted, focusing on the subsequent critical areas;

1. Threats of water scarcity for agriculture sector in Egypt

Water scarcity is a significant challenge for the agriculture sector in Egypt, which relies heavily on irrigation for crop production. The country's agriculture sector accounts

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for about 14% of its GDP and employs about 28% of its workforce (Gad, 2017).

Here are some of the threats of water scarcity for the agriculture sector in Egypt:

Limited water resources: Egypt is one of the most water-scarce countries in the world, with an annual water supply of only 570 cubic meters per capita. The country relies mainly on the Nile River for its water supply, which is already over-utilized and faces increasing demands from other sectors (Ouda, 2018). Climate change: Climate change is expected to exacerbate water scarcity in Egypt, leading to more frequent droughts and lower river flows. This will impact agriculture production and could cause a decline in crop yields, especially for water-intensive crops like rice (Gayar and Hamed, 2018). Groundwater depletion: Egypt heavily relies on groundwater for irrigation, with estimates suggesting that up to 70% of the water used for irrigation comes from underground sources. However, the over-extraction of groundwater has led to the depletion of aquifers, and in some areas, the water table has dropped to unsustainable levels (Ahmed and Abdelmohsen, 2018). Inefficient water use: The agriculture sector in Egypt has traditionally relied on flood irrigation, which is highly inefficient and can waste up to 50% of the water applied. This has led to a significant loss of water resources and is not sustainable in the long term (Christoforidou *et al.,* 2022). Competition for water resources: The agriculture sector in Egypt faces increasing competition for water resources from other sectors, including domestic, industrial, and tourism. This could lead to conflicts over water allocation, with potential impacts on agricultural production (Ouda *et al.,* 2022).

Overall, water scarcity is a significant threat to the agriculture sector in Egypt, and addressing this challenge will require a combination of policies and investments in water management, irrigation efficiency, and sustainable agriculture practices.

Shortage of freshwater resources and inability to meet the demanding standard of irrigation

Shortage of freshwater resources to meet the demand for irrigation water is a major challenge for agriculture in many parts of the world, including Egypt. The demand for irrigation water is increasing due to the growing population, expanding urbanization, and changing dietary patterns. However, the availability of freshwater resources is limited and is affected by climate change, pollution, and over-extraction (Abd Ellah *et al.,* 2020). In Egypt, the agriculture sector consumes about 85% of the country's freshwater resources, with most of it used for irrigation. However, the Nile River, which is the main source of freshwater in Egypt, is already over-utilized, and its flow is affected by upstream developments and climate change (Ouda *et al.,* 2020). To address the shortage of freshwater resources for irrigation, Egypt has implemented several strategies, including:

Expansion of irrigation efficiency: The government has been promoting the use of efficient irrigation methods, such as drip irrigation and sprinkler systems, to reduce water losses and increase crop yields. This has led to significant water savings and improved water use efficiency (Mostafa *et al.,* 2021). Recycling of agricultural drainage water: The drainage water from irrigated agriculture can be recycled and reused for irrigation, reducing the demand for freshwater resources (Ashour *et al.,* 2021; Ayad *et al.,* 2021). Use of non-conventional water resources: Egypt has been exploring the use of non-conventional water resources, such as desalination of seawater and wastewater treatment, to supplement the freshwater supply for irrigation (Elkholy, 2021).Water demand management: The government has been implementing water demand management policies, such as water pricing and water allocation systems, to encourage efficient water use and reduce water wastage (El-Fakharany and Salem, 2021; Saad *et al.,* 2023).

Overall, the shortage of freshwater resources to meet the demand for irrigation water is a significant challenge for agriculture in Egypt, but the government has been implementing strategies to address this challenge and ensure the sustainability of the agriculture sector.

Effect of water deficit on maize performance

Water deficit, which is a shortage of water supply to crops, can have a significant impact on the performance of maize crops. Maize is a water-intensive crop that requires sufficient water supply for optimal growth, development, and yield. When maize plants experience water deficit, their physiological and biochemical processes are affected, leading to reduced growth, development, and yield (Cai *et al.,* 2020). Water deficit limits the availability of water for maize plants, leading to reduced photosynthesis. Water deficit causes a reduction in cell expansion, leading to stunted growth of the maize plant. Maize yield is highly dependent on water supply, and water deficit during critical stages of crop growth, such as flowering and grain filling, can significantly reduce yield. Water deficit can also affect the quality of maize grain, resulting in smaller and less nutritious grains. Water-stressed maize plants are more susceptible to pest and disease attacks, which can further reduce yield (Elbeltagi *et al.,* 2020). Sah *et al.,* (2020) studied the influence of water deficit stress (WDS) on maize. The findings revealed that WDS led to a delay in maturity days, extended flowering duration, increased interval between anthesis and silk emergence, altered expression of secondary stress-responsive characteristics, reduced leaf count and disrupted normal root structure. These combined effects ultimately resulted in a decrease in grain yield. In the study by Fouda (2021), the impact of three different water regimes was examined on the growth and overall yield of maize plants. These water regimes consisted of irrigation with 7920 m^3 water ha^{-1} (representing standard irrigation), and reduced irrigation levels of 6720 and 5856 m^3 water ha^{-1} (representing water deficit conditions). The findings revealed that maize plants subjected to the reduced irrigation levels of 6720 and 5856 m^3 water ha^{-1} exhibited diminished performance and lower yield compared to those irrigated with the standard 7920 m^3 water ha^{-1}. Ghazi and El-Sherpiny (2021) conducted an examination of various irrigation intervals (8, 10, and 12 days between irrigation events) and their impact on the performance and yield of maize plants. The results highlighted that implementing deficit irrigation strategies, specifically with intervals of 10 and 12 days, resulted in a significant reduction in grain and biological yield (metric ton h^{-1}), harvest index (%), number of grains per cob, 1000-grain weight (g), number of rows per cob, total carbohydrate content(%), and crude oil content(%) in the grain, in comparison to the 8-day irrigation interval. However, it was observed that the drought treatments using the 10 and 12-day irrigation intervals stimulated the production of antioxidants in plants, serving as a protective mechanism against the harmful effects of reactive oxygen species (ROS). Weisany *et al.,* (2021) investigated the attributes and nutrient levels of maize plants under conditions of drought stress. The drought stress conditions were applied through irrigation intervals of every 8 days (non-stress), 12 days (moderate drought stress), and 16 days (severe drought stress). The findings indicated that drought stress led to reductions in the phosphorus, zinc, potassium and nitrogen contents of both seeds and shoots. Moreover, the drought stress conditions resulted in diminished vegetative and reproductive growth, as evidenced by decreased plant height, dry and fresh weights, ears per plant, ear weight, and grain yield. Abdelgalil *et al.*, (2022) conducted a study to explore the impact of varying irrigation intervals on the growth and yield of maize. The outcomes revealed that the most favorable outcomes in terms of plant height, cob length, biological yield, and grain yield were observed with irrigation occurring every 10 days. Subsequently, irrigation at intervals of 15 and 20 days followed suit with decreasing values of these traits. Conversely, the least favorable results across all the mentioned characteristics were observed when irrigation was administered every 25 days. Wang *et al.*, (2022) examined the impacts of varying irrigation treatments on two distinct corn hybrids with different maturity characteristics. These treatments encompassed severe water stress, mild water stress, and non-stress conditions, all applied using two irrigation techniques: flood irrigation and surface drip irrigation. The findings revealed that under severe water stress, there was a notable reduction in the net photosynthetic rate, which consequently led to a decrease in grain yield. El-Sherpiny *et al.*, (2023) assessed three irrigation regimes *i.e.*, 8000 m^3 ha^{-1} as traditional full irrigation, 6000 m^3 ha^{-1} (water deficit treatment) and 4000 m^3 ha^{-1} (water deficit treatment) on maize plant. The water deficit treatments led to a raise in the enzymatic antioxidants production as well as caused a significant decline in the performance and productivity in comparison with the traditional irrigation.

Overall, the water deficit is a significant challenge for maize production, and addressing this challenge is essential for ensuring food security and sustainable agriculture.

1.Mitigating the harmful effect of water deficit via reducing the irrigation water requirements

To ensure crop sustainability under water scarcity conditions, scientists in Egypt are working on raising the efficiency of irrigation water thorough designing another technique of furrow irrigation or adding substances holding water for a long time.

***Via* soil additions (zeolite substance)**

In contemporary times, the combination of climatic irregularities, rapid urbanization, water scarcity, and declining water quality, coupled with the rising need to sustainably feed the expanding global population, underscores the urgency for a more effective agricultural production approach. Within this framework, the utilization of zeolite materials within the agricultural sector has garnered substantial interest in recent years, owing to its diverse range of benefits across multiple disciplines.

Zeolite natural as a water absorbent substance

Zeolite is a type of naturally occurring aluminosilicate that is hydrated and commonly found in sedimentary rocks. These rocks are widespread and known for their environmentally friendly characteristics (Azarpour *et al.* 2011). Margeta *et al.*, (2013) highlighted that natural zeolites can be categorized into seven primary groups based on factors such as their crystal structure, morphology, physical properties, as well as the various methods of connecting secondary units within the three-dimensional framework. These classifications also encompass aspects like free pore volume and the types of exchangeable cations present within the zeolite's structure. Hardi *et al.*, (2020) pointed out that the agricultural utility of natural zeolite is contingent upon its physical and chemical attributes, which are closely linked to the geological formations in which it is found. Mosa *et al.*, (2020) discovered that natural zeolite exhibits a uniformly distributed porous structure. This substance is categorized as "tectosilicates" and is naturally present as hydrated aluminosilicate minerals, characterized by three-dimensional tetrahedral frameworks consisting of AlO_3 and SiO_4 units. Mondal *et al.* (2021) described the structure of zeolite as shown in shown in Fig 1. Also, illustrated the multidimensional usages of zeolites in sector of agriculture (Fig 2).

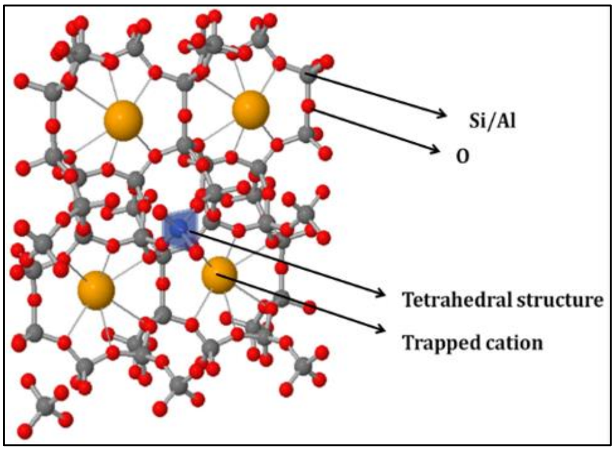

Fig 1. Zeolite structure (C.F. Mondal *et al.* 2021)

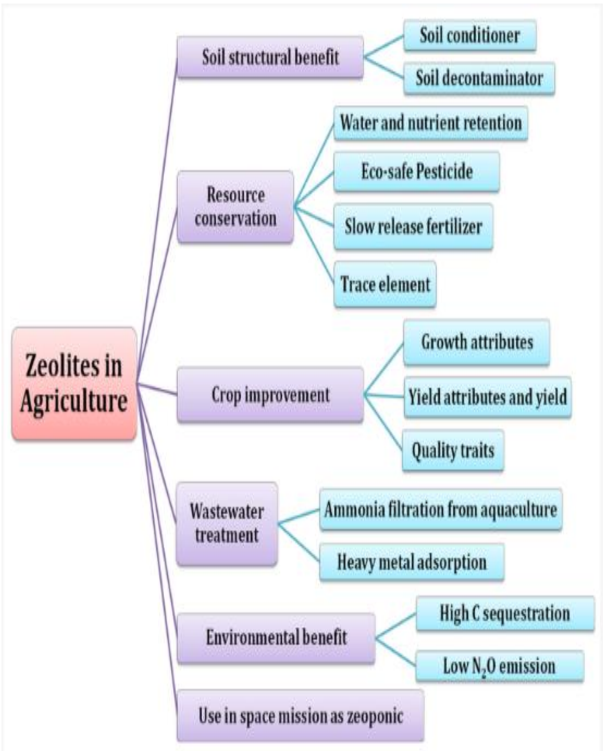

Fig 2. Multidimensional usages of zeolites in sector of agriculture (C.F. Mondal *et al.* 2021)

Its positive effect on plant growth performance and productivity under water deficit

Malekian *et al.,* (2011) reported that the utilization of zeolite as a carrier for fertilizers led to a more favorable response in maize plants. Nur-Aainaa *et al.,* (2018) highlighted that incorporating zeolite along with 75% of the recommended dose of synthetic fertilizers led to a comparable maize cob yield when compared to using the complete recommended dose of fertilizer. Shahsavari, (2019) investigated the effect of zeolite (0.0 and 15 ton ha^{-1}) on the qualitative characteristics of canola at different moisture regimes (normal irrigation, restricted irrigation). The values of yield and its components as well as oil yield confirmed the positive role of zeolite in raising plant tolerance to restricted irrigation. Wu *et al.,* (2019) concluded that the application of zeolite improved the drought resistance of rice plants. Their study examined the impact of zeolite on rice under an alternate wet-dry irrigation scheme. The findings revealed that the alternate wet-dry irrigation practice caused a reduction in rice grain yield. However, the introduction of zeolite substance led to substantial improvements in water and nutrient retention, consequently boosting water productivity by 8.9%. Furthermore, the zeolite substance notably increased the accumulation of nitrogen in rice root systems. Ippolito *et al.,* (2019) documented that applying zeolite at a rate of 22 Mg ha^{-1} resulted in an increase in corn weight in comparison to the control group. Nevertheless, when the zeolite application rate was raised to 90 Mg ha^{-1}, there was a reduction in corn weight. This decrease was attributed to the higher sodium content (3%) present in the zeolite at this elevated application level. El-Sherpiny *et al.,* (2020) conducted an assessment of the impact of zeolite application at two rates (0.0 and 10 Mg h^{-1}) alongside three irrigation intervals: irrigation every 12 days (representing traditional irrigation) as well as 14 days and 16 days (representing deficit irrigation conditions). The results indicated that incorporating zeolite along with irrigation every 14 days led to enhancements in both quantitative and qualitative yield attributes, in contrast to the combination of not using zeolite under the traditional irrigation interval of every 12 days. El-Mahdy *et al.,* (2022) evaluated three irrigation intervals (every 7, 9 and 11 days], soil addition of zeolite on the performance and productivity of soybean plants. The findings indicated that the addition of zeolite improved all studied growth and production criteria, under water deficit treatments, compared to the corresponding soybean plants grown on un-amended soil.

Its positive effect on soil properties

Presently, numerous studies have highlighted that the incorporation of zeolite contributes to the enhancement of soil properties, encompassing both physical and chemical aspects. This inclusion is known to positively impact nutrient dynamics, in addition to augmenting the soil's ability to retain both water and nutrients. Xiubin and Zhanbin (2001) observed that soil treated with zeolite exhibited higher water content compared to untreated soil after a 25-hour period of water application. Additionally, they found that the water holding capacity of the treated soil increased by 0.4–1.8% during drought conditions and by 5–15% under normal circumstances, compared to non-treated soil. Bernardi *et al.,* (2010) stated that the addition of zeolite to the soil resulted in an enhancement of irrigation water usage efficiency. This improvement was attributed to the increase in the soil's water holding capacity (WHC) and its improved availability to plants. Ozbahce *et al.,* (2015) discussed how zeolite functions as a soil conditioner, leading to an increase in the cation exchange capacity (CEC) of the soil. Furthermore, they emphasized that zeolite plays a vital role in enhancing nutrient retention within soils and consequently improving the overall efficiency of nutrient utilization. Nakhli *et al.,* (2017) affirmed that the application of zeolite led to enhancements in various soil properties, including increased water holding capacity, improved saturated hydraulic conductivity, and elevated cation exchange capacity. Abdel-Hassan and Radi (2018) investigated the impact of different levels of natural zeolite (ranging from 0.2% to 1%) on specific soil properties. Their findings demonstrated that as the concentration of zeolite increased, the soil's capacity for water absorption and total porosity also increased. Khalifa, (2019) depicted that the inclusion of zeolite substance led to a reduction in soil bulk density. Additionally, this treatment resulted in an increase in total porosity, water holding capacity, permanent wilting point, cation exchange capacity, and available water content when compared to untreated soil. Ippolito *et al.,* (2019) examined the influence of different methods of adding zeolite to soil on soil moisture. They discovered that fully integrating zeolite into the soil through mixing led to an improvement in the soil's water status. Rosalina *et al.,* (2019) demonstrated that the introduction of zeolite resulted in an increase in total nitrogen (N) content, cation exchange capacity, and available P_2O_5. Seddik *et al.,* (2019) assessed the impact of zeolite application at a rate of 2.0 ton fed^{-1} on various soil properties. The results revealed that the application of natural zeolite resulted in heightened values of soil moisture-related characteristics, including field capacity, available water, and wilting point. Additionally, the introduction of zeolite led to an increase in total porosity and enhanced the availability of soil nutrients such as nitrogen (N), phosphorus (P), and potassium (K). In a study by Wu *et al.,* (2019), the impacts of employing zeolite substance within an alternate wet-dry irrigation regimen were investigated. The study delved into its effects on soil-water retention, water consumption, and diverse soil nutrients. The outcomes indicated that the utilization of zeolite substance notably enhanced field capacity and led to a decrease in the count of ineffective tillers. This subsequently resulted in water savings of 5.8% during the tillering stage and 12% during the milky ripening stage of the crop. El-Sherpiny *et al.,* (2020) conducted an assessment of the impact of zeolite application, with rates of 0.0 and 10 Mg h^{-1}, in the context of three different irrigation intervals: traditional irrigation every 12 days, and deficit irrigation at intervals of 14 and 16 days. The results indicated that incorporating zeolite led to enhancements in several soil properties, including increased water holding capacity, total porosity, and cation exchange capacity (CEC). El-Mahdy *et al.,* (2022) examined the impact of adding zeolite to soil on soil fertility after the harvest. The outcomes revealed that zeolite exhibited a beneficial effect in augmenting soil fertility attributes, with a notable improvement in water holding capacity. This enhancement in soil properties contributed to water savings in terms of irrigation requirements.

***Via* foliar applications (anti-transpirants)**

Its action mechanism

The mechanism of action of anti-transpirants involves the following steps:

Formation of a thin film: Anti-transpirants are sprayed onto the leaves of plants, where they form a thin film on the surface of the leaves. This film acts as a barrier, reducing the rate of water loss through transpiration (Zhang and Zhang, 2014). Stomatal closure: The film formed by the anti-transpirant can also cause the stomata, small openings on the surface of the leaves, to close partially or completely. This limits the amount of water that is lost through transpiration (AbdAllah *et al.,* 2018).

Reduced transpiration: By forming a film and causing stomatal closure, anti-transpirants can significantly reduce the rate of water loss from plants through transpiration. This can help plants to conserve water, especially during periods of drought or water stress (Mphande *et al.,* 2020). Overall, anti-transpirants can help to reduce water loss from plants and improve their ability to survive under water-stressed conditions. However, it is important to note that anti-transpirants should be used judiciously, as excessive use can have negative effects on plant growth and development (Kumari *et al.,* 2022).

Its positive effect on plant growth performance and productivity under water deficit

Kaolin

Kaolin is commonly used as an anti-transpirants in the agricultural sector, where it can help to reflect sunlight and reduce heat stress on the plants. It acts as a physical barrier on the plant surface, which can also help to deter insect pests and reduce the incidence of certain plant diseases. This is because the fine particles of kaolin can interfere with the ability of insects to locate and feed on the plant, and can also make it more difficult for fungal spores to adhere to the plant's surface. In addition, kaolin can help to reduce water loss from the plant, which can be beneficial in arid or drought-prone areas.

Gaballah and Moursy (2004) performed a pot trial on wheat for reducing moisture loss through transpiration by spraying plants with kaolin.The results illustrated that the reflectant treatment enhanced growth and yield characteristics as well as reduced water loss and limited the potential for evaporative leaf cooling compared to control treatment. Muti, (2016) studied the effect of foliar-applied kaolin on evapotranspiration and the yield of maize. Application of kaolin during wetter conditions in irrigated maize crops caused significant increases in biomass and grain yield. Kaolin had short and long term‖ influences on levels of soil moisture, seasonal evapotranspiration and biomass. The response of maize yield to kaolin was highest at floral stages and under stress conditions. Abdulameer *et al.,* (2017) studied the effect of different levels of kaolin (0.0, 40, 60 mg L^{-1}) on some characteristics of maize under different irrigation intervals (5, 10 and 15 days). Results showed the use of kaolin increased growth performance and maize yield under irrigation every 10 and 15 days compared to the corresponding plants grown without kaolin. Adelian *et al.,* (2019) evaluated the effects of anti-transpiration materials and irrigation regimes on maize. The irrigation treatments were irrigation after 25% water depletion of F.C (no water deficit stress), irrigation after 40% water depletion of F.C (mild water deficit stress) and Irrigation after 60% water depletion of F.C (severe water deficit stress). Also, kaolin and control treatments (without anti-transpiration materials) were studied. The results showed that the application of kaolin as anti-transpiration was beneficial to improve the quantitative and qualitative yield of maize compared to the control treatment. Amid water stress circumstances, Patel *et al.* (2019) investigated the impact of applying kaolin at different rates (0%, 4%, 6%, and 8%) to rice plants as a foliar treatment. The findings demonstrated that with increasing levels of kaolin application, both the growth performance and yield of the rice plants exhibited enhancement. Morsy and Mehanna, (2022) evaluated maize crop response to three irrigation levels (60, 70 and 80% of the crop evapotranspiration "ETc") and some antitranspirants treatments *e.g.,* control and kaolin at 6%. Results revealed that foliar spraying with kaolin at 6% led to a tremendous impact on growth traits, yield and its components by alleviating the water deficit stress and reducing the rate of transpiration.

Magnesium carbonate

Magnesium carbonate is used in agriculture. It is commonly used as a soil amendment to help adjust soil pH and provide essential nutrients to plants. Instead, it is sometimes used as an anti-transpirants. Gaballah and Moursy, (2004) performed a pot trial on wheat for reducing moisture loss through transpiration by spraying plants with magnesium carbonate as reflectant. The results illustrated that the reflectants treatments enhanced growth and yield characteristics as well as reduced water loss and limited the potential for evaporative leaf cooling. El-Hadidi *et al.,* (2020) studied the effect of $MgCO_3$ as an antitranspirants (at a rate of 7%) on rice grown under different irrigation regimes (irrigation every 4, 8 and 12 days). The findings indicated that the best values of all studied parameters *e.g.,* panicle length, 1000 grains weight, grain yield (kg fed^{-1}) were recorded when rice plants were irrigated every 4 days and foliar application of $MgCO_3$ 7 %. Also, spraying plants with $MgCO_3$ under irrigation every 8 days or 12 days achieved better results than untreated plants under irrigation every 4 days. Hellal *et al.,* (2020) studied the role of $MgCO_3$ as an antitranspirants application in alleviating drought-induced changes in barley. Foliar application of the antitranspirant registered a positive impact on plant pigment, nutrient contents, proline accumulation and relative water content under drought stress conditions.

CONCLUSION

The study concludes that water deficit stress significantly hindered plant growth. However, the application of zeolite to the soil and the use of antitranspirants like kaolin and magnesium carbonate as foliar sprays have the potential to alleviate the negative effects of drought stress on plants. These findings suggest that these strategies could be valuable tools in improving the water-deficit stress tolerance of strategic crops in the agricultural sector. Further research and practical application are likely needed to fully understand the effectiveness and practicality of these approaches on a larger scale.

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تعزيز قدرة المحاصيل على مقاومة إجهاد الجفاف: مضادات النتح والزيوليت واستراتيجيات الحفاظ على المياه من أجل إنتاجية المحاصيل الاستراتيجية

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الملخص

تسعى هذه المراجعة إلى تقديم نظرة شاملة لفهم آثار إجهاد الجفاف على إنتاج المحاصيل الاستراتيجية. كما تتناول الآثار الإيجابية لتطبيق مضادات النتح على النباتات المعرضة لإجهاد الجفاف. وعلاوة على ذلك، تسعى هذه المراجعة إلى استكشاف الدور المفيد للزيولايت في توفير مياه الري. تهدف هذه المراجعة إلى تجميع وفحص الاكتشافات الرئيسية والاتجاهات الناشئة والثغرات في البحث حتى الوقت الحالي. ستؤكد المراجعة على التهديدات الوشيكة التي تشكلها ندرة المياه على قطاع الزراعة في مصر وستسلط الضوء على استراتيجيات مجابهة التأثير الضار للعجز المائي من خلال تقليل متطلبات الري. ستبحث المراجعة أيضًا تأثير نقص المياه على أداء النباتات وستسلط الضوء على فعالية الزيولايت كتعديل للتربة جنبًا إلى جنب مع مضادات النتح مثل الكاؤلين وكربونات المغنيسيوم، في توفير مياه الري وتعزيز نمو النباتات. وبالإضافة إلى ذلك، ستحدد هذه المراجعة التحديات والفرص الكبيرة في هذا المجال، بهدف توجيه مسارات البحث المستقبلية وتطبيقاتها العملية.