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Effects of Irrigation Regulation on Maize Growth and Development

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Abstract Maize (*Zea mays* L.) is an important food crop in the world, widely used for food, feed and industrial processing. Its growth, development and yield are highly dependent on water supply, especially in areas with insufficient precipitation or unstable climate. This study systematically explored the role of irrigation regulation in different growth stages of maize, focusing on its effects on maize physiological characteristics, yield formation and quality stability. Studies have shown that timely and appropriate irrigation can help improve photosynthetic capacity, promote root development and nutrient absorption, thereby increasing grain yield and water use efficiency. This study compared various irrigation methods such as drip irrigation, sprinkler irrigation and furrow irrigation, and explored the effects of irrigation timing and frequency on yield and resource efficiency. Through case analysis of semi-arid areas in North China and oasis agriculture in Northwest China, the application effect of regionalized and precision irrigation strategies was demonstrated, hoping to provide technical guidance for maize production in different climate zones, improve irrigation efficiency and resource utilization, and achieve the win-win goal of increasing grain production and protecting the environment.

Keywords Maize; Irrigation regulation; Water use efficiency; Growth stage; Yield

1 Introduction

Maize (*Zea mays* L.) is a globally important crop. It can be used as a staple food, animal feed, and industrial raw material. Because of its high yield and strong adaptability, maize plays an important role in agriculture in many countries. Maize has played a major role in food security and economic development in both developed and developing countries (Żarski and Kuśmierek-Tomaszewska, 2023; Huang et al., 2024).

Water is particularly critical for maize, especially in areas with drought or unstable rainfall. Good irrigation can not only increase yield and water use efficiency, but also improve maize photosynthesis, nutrient absorption capacity, and drought resistance (Comas et al., 2019; Li et al., 2020; Qu et al., 2024). Now some new irrigation methods, such as water-deficit irrigation and drip irrigation, have been shown to use water more rationally, which can stabilize yields and reduce environmental impacts (Zheng et al., 2019; Li et al., 2022).

This study will review the current research results on the effects of irrigation regulation on corn growth and development, evaluate the effects of different irrigation strategies on corn yield, physiological characteristics and water use efficiency, explore the interaction between irrigation, nutrient management and environmental factors, and provide guidance for optimizing irrigation practices under different agricultural ecological environments. It is expected to provide a theoretical basis and technical reference for the scientific formulation of corn irrigation strategies.

2 Water Sensitivity Across Maize Developmental Stages

2.1 Water requirements from germination to jointing stage

Corn is particularly sensitive to water from seed germination to seedling stage. As long as there is enough water, the seeds can germinate quickly and the germination rate is high. Studies have found that when the water supply is 150% to 325% of the seed thousand-grain weight (TKW), it is most conducive to seedling growth. But in fact, as long as the water reaches 25% of TKW, the seeds can begin to germinate (Khaeim et al., 2022). If there is a lack of water at this stage, not only will the germination rate decrease, but the seedlings will also tend to grow weak or

even die (Queiroz et al., 2019; Xue et al., 2021). Corn is more afraid of early water shortage than many crops, so from sowing to jointing, the soil must be kept moist to allow the root system to grow well and the seedlings to be stronger.

2.2 Irrigation timing during tasseling and pollination

During the tasseling and pollination stages, corn is more sensitive to water. If there is a lack of water at this time, it will directly affect the flowering and pollination processes, the fruiting rate will drop significantly, and ultimately lead to lower yields (Sah et al., 2020; Fawen et al., 2022). Many studies have pointed out that corn is most sensitive to water during the heading and flowering period, especially during the heading period, which requires more irrigation to prevent biomass reduction or bald ears. Watering should be done in time during heading and pollination to ensure that the filaments grow smoothly and the pollen is sufficiently active, thereby increasing the pollination success rate and fruiting rate.

2.3 Water control strategies during grain filling and maturity

After entering the filling period, although the sensitivity of corn to water shortage is reduced, water should not be cut off at this time. Maintaining a certain soil moisture helps the grains continue to fill, grow fuller, and eventually have better yields. If there is too little water at this stage, the grain weight will decrease, and the total yield will also decrease, but the impact is not as great as when it was flowering. Many places use controlled irrigation or slightly water-deficient irrigation during this period, which can save water without seriously reducing production, provided that the key water supply has been guaranteed in the early stage (Meng et al., 2016). In addition, when it comes to maturity, attention should also be paid to seed moisture content. Studies have suggested that the seed moisture content should be kept at around 30% to 35% at harvest, so that the quality and vitality of the seeds are better, especially when encountering adversity, and the yield and quality can be maintained (Rahbari and Madandoust, 2024).

3. Effects of Irrigation Regulation on Growth Parameters

3.1 Changes in plant height and leaf area index (LAI)

The amount of irrigation and the time of irrigation will directly affect the height and leaf area index (LAI) of corn. If enough water is applied at the right time, combined with appropriate fertilization, the plant height and leaf area of corn will grow better, the aboveground biomass will be more, and the final yield will be high (Qi et al., 2020; Chen et al., 2024). Methods such as alternating furrow irrigation or watering only part of the root zone, combined with appropriate nitrogen application, can significantly increase the leaf area index when corn is critical to growth, and can also allow more aboveground organisms to grow when mature. However, if there is not enough water during the vegetative growth period, or the drought period is too long, the corn will grow short, have fewer leaves, absorb less sunlight, and photosynthesis will also decrease (Comas et al., 2019).

3.2 Root development and soil moisture utilization

The irrigation method will affect the growth and distribution of roots, and also affect the ability of corn to absorb water. Appropriately reducing irrigation, especially when partial root zone irrigation is used, can allow roots to grow deeper and wider. In this way, the roots can better absorb water and nutrients (Gheysari et al., 2017; Qi and Hu, 2022; Gao et al., 2024). For example, drip irrigation can not only make the roots longer, but also increase the proportion of coarse roots in the upper soil layer, which is closely related to high yields. If aerated irrigation is added, the root weight can be increased, and the beneficial bacteria in the soil will increase, which is more beneficial to both corn and soil (Yu et al., 2022). However, if the irrigation is too little, the roots will not grow well, especially they cannot grow deep, and the corn will not be able to absorb enough water from the deep soil (Jaswal and Sandal, 2024).

3.3 Biomass accumulation and dry matter distribution

The biomass and dry matter distribution of corn are affected by the irrigation method. If irrigation is well managed and fertilized properly, not only will aboveground biomass increase, but dry matter and harvest index will also increase (Gheysari et al., 2017; Chen et al., 2024). In some growth periods that are not very sensitive, reducing

irrigation appropriately will not have much impact, and can save water while maintaining yield (Comas et al., 2019). In addition, if irrigation and nitrogen fertilization are done well, more dry matter will flow to the grains, so that corn will not only produce more, but also use more water. On the contrary, if there is too little water, plant growth will slow down, and aboveground dry matter and total biomass will decrease. The extent of the impact depends on when the drought occurs and how long it lasts.

4 Optimization of Irrigation Modes and Timing

4.1 Comparison of drip, sprinkler, and furrow irrigation

In corn cultivation, drip irrigation or underground drip irrigation is usually more effective than traditional furrow irrigation. These methods can not only increase yields, but also increase leaf area index (LAI) and water and nitrogen use efficiency (Sandhu et al., 2019; Wu et al., 2019; Li et al., 2021). For example, center pivot irrigation and underground drip irrigation systems generally have yields that are 8% to 25% higher than furrow irrigation. After drip irrigation, the leaf area index of corn can be increased by an average of 24% (Irmak et al., 2022). Compared with furrow irrigation and sprinkler irrigation, drip irrigation, especially when used in conjunction with mulching, has higher water use efficiency and economic benefits (Wang et al., 2020). In addition, drip irrigation can reduce the time and cost of field management and is more environmentally friendly, so it is quite attractive to farmers who engage in sustainable cultivation (Patra et al., 2023).

4.2 Effects of irrigation frequency on physiological traits

When using drip irrigation, increasing the number of irrigations and fertilizations can make maize produce more and use water and fertilizer more reasonably. If irrigation is done with a small amount of water and more times, such as once every 7 days, the yield and water use efficiency of maize will be better than low-frequency or high-volume irrigation (Ma et al., 2022). This method can also allow maize to better absorb nitrogen fertilizer, improve photosynthesis efficiency, and have a more developed root system. Especially when used together with conservation tillage, the effect is more obvious (Li et al., 2023). To make these effects most obvious, the key is to match the supply of water and fertilizer with the needs of maize at different growth stages (Sandhu et al., 2019).

4.3 Precision irrigation and fertigation practices

Precision irrigation technology and drip irrigation and fertilization technology can achieve "water and fertilizer follow the seedlings". This means that according to the different stages of maize growth, water and fertilizer are supplied on demand, not more or less, so that both yield and resource utilization can be increased. Compared with the old method, such as traditional furrow irrigation + fertilization, drip irrigation can increase corn yield by 12%, increase water use efficiency by 26%, and use nitrogen fertilizer more efficiently by 34% (Li et al., 2021). A better irrigation plan is to maintain a medium-high irrigation level, that is, 90% to 100% of the crop water requirement, and then combine it with staged fertilization. This will not only increase the yield, improve fertilizer absorption, and increase income, but also reduce nitrate loss, which is not good for the environment (Fan et al., 2020; Yan et al., 2021). Moreover, if managed properly, even if less fertilizer is used, it will not affect the yield, but will be more environmentally friendly and save more money.

5 Impact of Irrigation Regulation on Yield and Quality

5.1 Regulation of kernel number and thousand-kernel weight

The time and amount of irrigation will directly affect the number of grains and thousand-grain weight of corn. Especially during the period from flowering to grain filling, if there is a lack of water, the number of grains per ear will decrease and the total yield will decrease significantly. This decrease is closely related to the duration and severity of water shortage (Mansouri-Far et al., 2010). If water can be supplemented during the grain filling period, it can not only reduce the pressure caused by high temperature and drought, but also allow corn to produce more grains, extend the grain filling time, make the grains fuller, and increase the thousand-grain weight. In drought weather, this can increase the yield by about 15% to 22% (Figure 1) (Wang et al., 2020; 2021; Jian et al., 2024). If a reasonable irrigation plan is arranged throughout the growing season and water is used in the critical period, not only can the number of grains increase, but the grain weight can also remain stable, and the final yield will be higher and more stable (Cao et al., 2022).

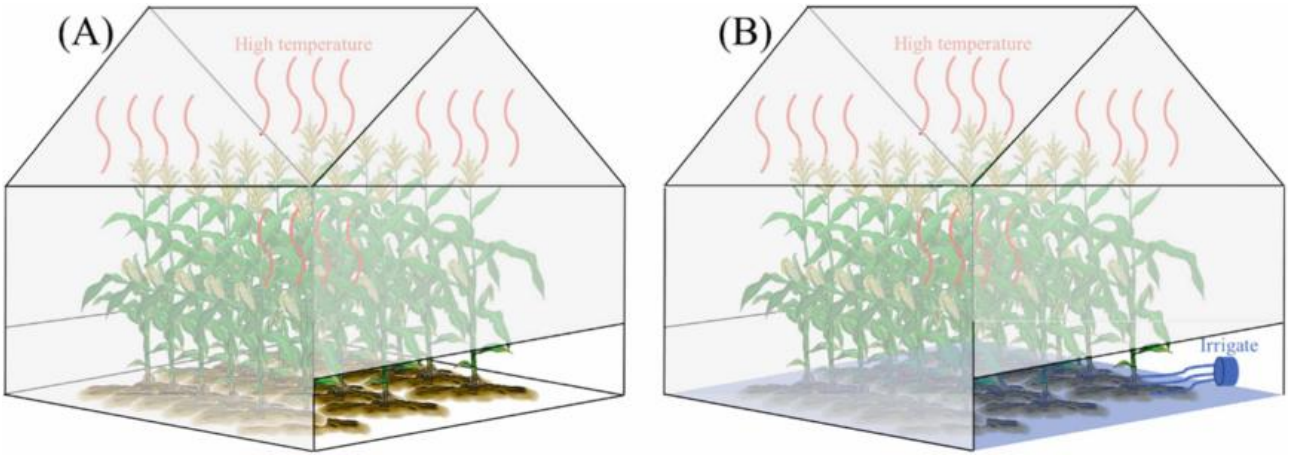

Figure 1 Schematic diagram of artificial warming shed; high temperature (A); high temperature+supplemental irrigation (B) (Adopted from Jian et al., 2024)

5.2 Changes in soluble sugar and protein content

Irrigation can also affect the nutritional quality of corn, such as sugar and protein in the kernels. Studies have found that when the water volume is controlled at around 70%, the sugar and protein content of sweet corn is the highest. If there is less water, not only will the yield decrease, but the quality will also deteriorate (Ertek and Kara, 2013). Proper watering during the filling period can increase the starch and soluble sugar in the stems and leaves. These substances will flow to the kernels, help filling, and make the corn taste better and more nutritious, especially when encountering high temperatures (Jian et al., 2024). Therefore, a reasonable arrangement of water volume can not only increase yield, but also improve the nutritional value and processing quality of corn.

5.3 Influence of irrigation rhythm on quality stability

The rhythm and frequency of irrigation will also affect whether the quality of the kernels is stable. If irrigation can be done on time and as needed, such as using interval drip irrigation or adjusting the irrigation system, the corn filling process can be more uniform, the grain weight can be more consistent, and it will not be easily affected by weather changes (Wang et al., 2020; 2021; Cao et al., 2022; Ocwa et al., 2024). In addition, optimizing irrigation methods and planting methods together can further maintain seed quality, such as reducing unfilled grains and reducing germination failure rates, so that the yield and water use efficiency of the entire field can be improved. These studies show that irrigation must be coordinated with the growth rhythm of corn, especially during the critical growth stage, so as to ensure high yields and stable grain quality.

6 Case Studies: Regional Irrigation Management Practices

6.1 Water-saving irrigation in the semi-arid North China Plain

Water resources in the North China Plain are tight, and the groundwater level has been declining. In order to ensure that corn can continue to have high yields, water-saving irrigation has been promoted locally. Long-term studies have found that in the rotation of winter wheat and summer corn, if the amount of wheat irrigation is appropriately reduced, although the wheat yield will decrease slightly, the corn yield can be maintained or even increased, and the overall water use is more efficient. For example, there is a practice called "minimum irrigation (MI)", which controls the soil moisture within a suitable range during sowing and no longer irrigates in the later stage. In this way, corn can save half of the water used in a year, the water use efficiency can be increased by 10%, and the yield is only about 13% less than that of full irrigation. In addition, there is another way to irrigate wheat twice and corn only once (W2M1), which is more effective than the traditional method of irrigation with more water and large investment. Not only does it stabilize grain production, but it can also slow down the decline of groundwater (Wang et al., 2018; Yang et al., 2022; 2024). On this basis, if mulching, deep plowing, and returning straw to the field are used in combination, the water utilization rate can be further improved (Zheng et al., 2020).

6.2 Precision supplemental irrigation in Northwest oasis farming

In Northwest oasis agricultural areas such as the Hexi Corridor, water resources are very limited, so water replenishment is more precise. Local farmers use drip irrigation and scientific nitrogen application to make corn grow better and save water and fertilizer. Studies have found that corn yields are highest when there is enough water and moderate nitrogen fertilizer. If too much nitrogen fertilizer is added, the water utilization rate will decrease, and resources may be wasted. Using sub-film drip irrigation, coupled with a reasonable amount of irrigation (about 337.5 mm) and a suitable density (for example, 90 000 plants per hectare), not only is the yield higher, but the water utilization rate is also better, and the economic benefits are increased by more than 20% compared to when more water is irrigated (Figure 2) (Pan et al., 2024). This shows that in arid areas, it is particularly important to use water and fertilizer well (Zou et al., 2020; Guo et al., 2021).

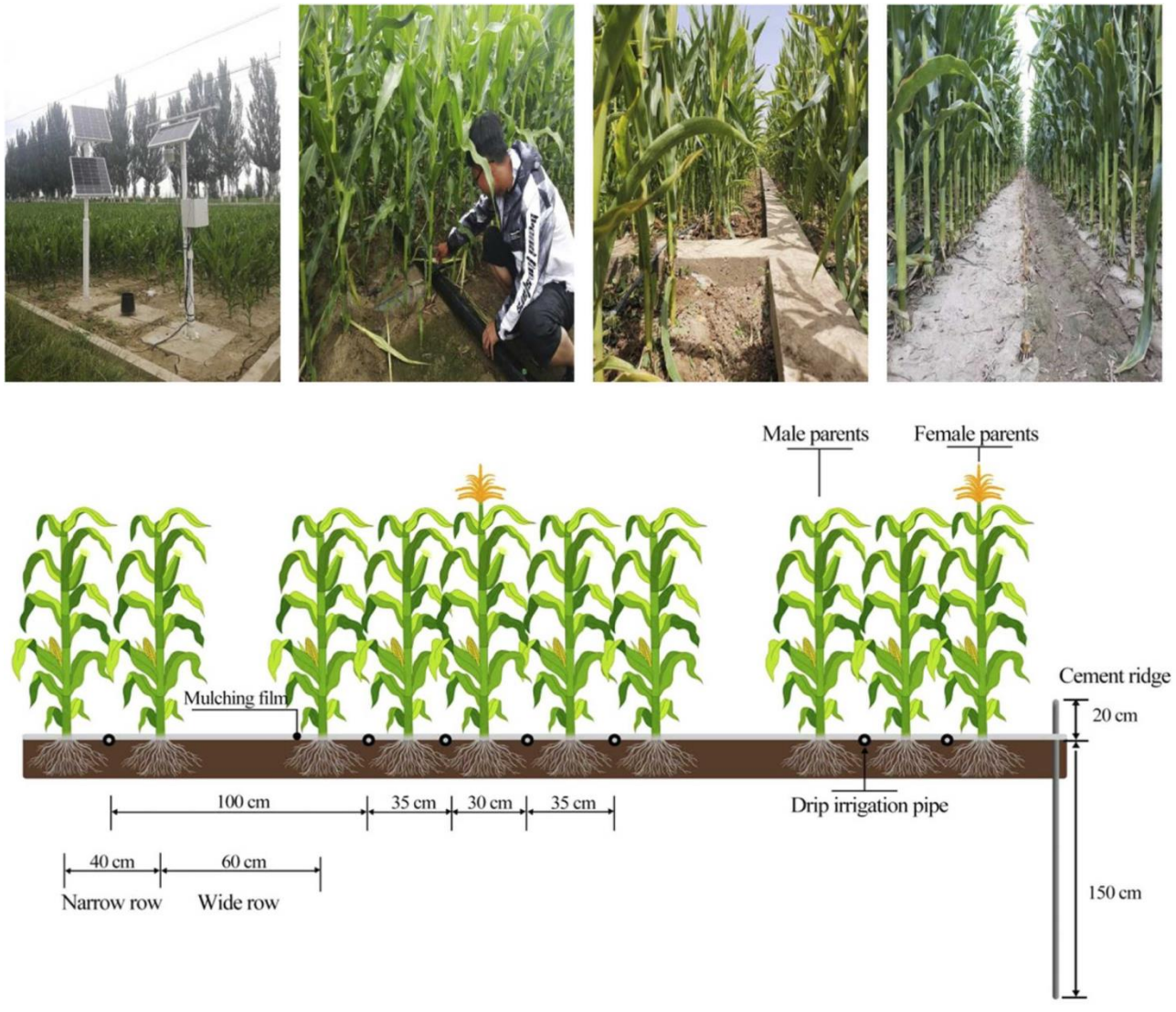

Figure 2 Schematic diagram of the layout of the integrated experiment of corn irrigation and fertilization based on drip irrigation and mulching (Adapted from Pan et al., 2024)

6.3 Irrigation schemes in high-yielding maize fields of Northeast China

Northeast China has relatively more rain and is one of the areas with the most corn in my country. The water productivity here is also the highest, with an average of 25.8 kg of corn produced per millimeter of rain (Zheng et al., 2020). Because of the heavy rain, rain-fed methods are mostly used here, but if the yield and farming methods can be optimized, not only can more be produced, but also carbon emissions can be reduced. In some high-yield fields, farmers do not rely on frequent irrigation, but use conservation tillage and scientific management of soil

moisture to increase yields. Simulation studies have also found that this approach can reduce greenhouse gas emissions while maintaining production, which is beneficial to both the environment and the economy (Huo et al., 2024).

7 Concluding Remarks

Irrigation regulation affects key stages of corn growth, especially water supply. This regulation helps corn absorb nutrients better and improves water use efficiency, which affects crop growth, yield and environmental impact. If irrigation is timed appropriately and managed properly, corn yields can be increased by more than 30% compared to non-irrigation, water use efficiency will be higher, and greenhouse gas emissions and nitrogen loss can be reduced. The coordination between irrigation and nitrogen application is also critical. If water and nitrogen management are synchronized, not only can yields be higher, but resource utilization efficiency can also be improved, while reducing pressure on the environment.

The climate is becoming more and more unstable, so in order to ensure stable and high yields of corn, some intelligent and local irrigation methods must be adopted. Some irrigation systems are now controlled by IoT technology and real-time monitoring of soil moisture, which can save water by up to 35% and can also harvest earlier. But when using these systems, you should also be careful not to affect yields because of water saving. Different irrigation methods are suitable for different regions. For example, drought-scarce areas can adopt water-deficient irrigation; oasis areas can implement precision scheduling; and rain-fed areas that rely on the weather can cooperate with conservation tillage. These practices can make water and nutrient inputs more in line with local climate and soil conditions, and can also increase yields and resource utilization.

In the face of future climate change and resource pressure, the following measures are very important. For example, promote precision irrigation technology in water-scarce areas to reduce waste; arrange irrigation plans reasonably during different growth stages of corn, such as seedling, jointing and flowering; in addition, combine moderate water-deficient irrigation with reasonable fertilization, which can also take into account high yield and environmental protection. It is also necessary to continue to study which irrigation thresholds are most suitable under different climatic conditions and how to manage them according to local conditions. Only in this way can the yield gap between different regions be narrowed, and the function of agricultural ecosystems can be enhanced. Promoting irrigation and soil management methods that are more in line with climate characteristics and regional conditions will help ensure the long-term sustainability and risk resistance of corn production.

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Conflict of Interest Disclosure

The author affirms that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

References

Cao Y., Cai H., Sun S., Gu X., Mu Q., Duan W., and Zhao Z., 2022, Effects of drip irrigation methods on yield and water productivity of maize in Northwest China, Agricultural Water Management, 259: 107227.
https://doi.org/10.1016/j.agwat.2021.107227

Chen L., Yue S., Sun L., Gao M., and Wang R., 2024, Study on the effects of irrigation quotas and amendments on salinized soil and maize growth, Water, 16(15): 2194.
https://doi.org/10.3390/w16152194

Comas L., Trout T., DeJonge K., Zhang H., and Gleason S., 2019, Water productivity under strategic growth stage-based deficit irrigation in maize, Agricultural Water Management, 212: 433-440.
https://doi.org/10.1016/J.AGWAT.2018.07.015

Ertek A., and Kara B., 2013, Yield and quality of sweet corn under deficit irrigation, Agricultural Water Management, 129: 138-144.
https://doi.org/10.1016/J.AGWAT.2013.07.012

Fan J., Lu X., Gu S., and Guo X., 2020, Improving nutrient and water use efficiencies using water-drip irrigation and fertilization technology in Northeast China, Agricultural Water Management, 241: 106352.
https://doi.org/10.1016/j.agwat.2020.106352

Fawen L., Manjing Z., and Yaoze L., 2022, Quantitative research on drought loss sensitivity of summer maize based on AquaCrop model, Natural Hazards, 112: 1065-1084.
https://doi.org/10.1007/s11069-022-05218-w

Gao J., Liu Z., Wang P., and Huang S., 2024, Drip irrigation coupled with appropriate N input increased maize (*Zea mays* L.) yield and lodging resistance via optimizing root and stem trait, European Journal of Agronomy, 160: 127298.
https://doi.org/10.1016/j.eja.2024.127298

Gheysari M., Sadeghi S., Loescher H., Amiri S., Zareian M., Majidi M., Asgarinia P., and Payero J., 2017, Comparison of deficit irrigation management strategies on root, plant growth and biomass productivity of silage maize, Agricultural Water Management, 182: 126-138.
https://doi.org/10.1016/J.AGWAT.2016.12.014

Guo Q., Huang G., Guo Y., Zhang M., Zhou Y., and Duan L., 2021, Optimizing irrigation and planting density of spring maize under mulch drip irrigation system in the arid region of Northwest China, Field Crops Research, 266: 108141.
https://doi.org/10.1016/J.FCR.2021.108141

Huang Y., Gao F., Khan R., Ali S., and Zhou X., 2024, Synergistic effects of irrigation and nitrogen fertilisation on maize photosynthetic performance and yield of rainfed systems in drought-prone environments, Journal of Agronomy and Crop Science, 210(6): e12782.
https://doi.org/10.1111/jac.12782

Huo Y., Mi G., Zhu M., Chen S., Li J., Hao Z., Cai D., and Zhang F., 2024, Carbon footprint of farming practices in farmland ecosystems on the North and Northeast China plains, Journal of Environmental Management, 354: 120378.
https://doi.org/10.1016/j.jenvman.2024.120378

Irmak S., Mohammed A., and Kukal M., 2022, Maize response to coupled irrigation and nitrogen fertilization under center pivot, subsurface drip and surface (furrow) irrigation: growth, development and productivity, Agricultural Water Management, 263: 107457.
https://doi.org/10.1016/j.agwat.2022.107457

Jaswal R., and Sandal S., 2024, Effect of conservation tillage and irrigation on soil water content, shoot-root growth parameters and yield in maize (*Zea mays*)-wheat (*Triticum aestivum*) cropping sequence, Journal of Soil Science and Plant Nutrition, 24: 7965-7979.
https://doi.org/10.1007/s42729-024-02091-3

Jian H., Gao Z., Guo Y., Xu X., Li X., Yu M., Liu G., Bian D., Cui Y., and Du X., 2024, Supplemental irrigation mitigates yield loss of maize through reducing canopy temperature under heat stress, Agricultural Water Management, 299: 108888.
https://doi.org/10.1016/j.agwat.2024.108888

Khaeim H., Kende Z., Jolánkai M., Kovács G., Gyuricza C., and Tarnawa Á., 2022, Impact of temperature and water on seed germination and seedling growth of maize (*Zea mays* L.), Agronomy, 12(2): 397.
https://doi.org/10.3390/agronomy12020397

Li G., Zhao B., Dong S., Zhang J., Liu P., and Lu W., 2020, Controlled-release urea combining with optimal irrigation improved grain yield, nitrogen uptake, and growth of maize, Agricultural Water Management, 227: 105834.
https://doi.org/10.1016/j.agwat.2019.105834

Li H., Mei X., Wang J., Huang F., Hao W., and Li B., 2021, Drip fertigation significantly increased crop yield, water productivity and nitrogen use efficiency with respect to traditional irrigation and fertilization practices: a meta-analysis in China, Agricultural Water Management, 244: 106534.
https://doi.org/10.1016/J.AGWAT.2020.106534

Li Q., Chen Y., Sun S., Zhu M., Xue J., Gao Z., Zhao J., and Tang Y., 2022, Research on crop irrigation schedules under deficit irrigation—a meta-analysis, Water Resources Management, 36: 4799-4817.
https://doi.org/10.1007/s11269-022-03278-y

Li Z., Zou H., Lai Z., Zhang F., and Fan J., 2023, Optimal drip fertigation regimes improved soil micro-environment, root growth and grain yield of spring maize in arid Northwest China, Agronomy, 13(1): 227.
https://doi.org/10.3390/agronomy13010227

Ma C., Liu S., Wang X., Wang L., Muhammad T., Xiao Y., Wang Y., Sun Z., and Li Y., 2022, Coupling regulation of root-zone soil water and fertilizer for summer maize with drip irrigation, Water, 14(22): 3680.
https://doi.org/10.3390/w14223680

Mansouri-Far C., Sanavy S., and Saberali S., 2010, Maize yield response to deficit irrigation during low-sensitive growth stages and nitrogen rate under semi-arid climatic conditions, Agricultural Water Management, 97: 12-22.
https://doi.org/10.1016/J.AGWAT.2009.08.003

Meng Q., Chen X., Lobell D., Cui Z., Zhang Y., Yang H., and Zhang F., 2016, Growing sensitivity of maize to water scarcity under climate change, Scientific Reports, 6: 19605.
https://doi.org/10.1038/srep19605

Ocwa A., Bojtor C., Illés Á., Ssemugenze B., Balaout I., Rátonyi T., Széles A., and Harsányi E., 2024, Precision drip irrigation system and foliar application of biostimulant and fertilizers containing micronutrients optimize photochemical efficiency and grain yield of maize (*Zea mays* L), Journal of Soil Science and Plant Nutrition, 24: 7786-7800.
https://doi.org/10.1007/s42729-024-02074-4

Pan X., Zhang H., Yu S., Deng H., Chen X., Zhou C., and Li F., 2024, Strategies for the management of water and nitrogen interaction in seed maize production; a case study from China Hexi Corridor Oasis Agricultural Area, Agricultural Water Management, 292: 108685.
https://doi.org/10.1016/j.agwat.2024.108685

Patra K., Parihar C., Nayak H., Rana B., Sena D., Anand A., Reddy K., Chowdhury M., Pandey R., Kumar A., Singh L., Ghatala M., Sidhu H., and Jat M., 2023, Appraisal of complementarity of subsurface drip fertigation and conservation agriculture for physiological performance and water economy of maize, Agricultural Water Management, 283: 108308.
https://doi.org/10.1016/j.agwat.2023.108308

Qi D., and Hu T., 2022, Effects of nitrogen application rates and irrigation regimes on root growth and nitrogen-use efficiency of maize under alternate partial root-zone irrigation, Journal of Soil Science and Plant Nutrition, 22: 2793-2804.
https://doi.org/10.1007/s42729-022-00846-4

Qi D., Hu T., and Liu T., 2020, Biomass accumulation and distribution, yield formation and water use efficiency responses of maize (*Zea mays* L.) to nitrogen supply methods under partial root-zone irrigation, Agricultural Water Management, 230: 105981.
https://doi.org/10.1016/j.agwat.2019.105981

Qu Z., Chen Q., Yin S., Feng H., Liu Y., and Li C., 2024, Effects of drip irrigation coupled with controlled release potassium fertilizer on maize growth and soil properties, Agricultural Water Management, 301: 108948.
https://doi.org/10.1016/j.agwat.2024.108948

Queiroz M., Oliveira C., Steiner F., Zuffo A., Zoz T., Vendruscolo E., Silva M., De Mello B., Cabral R., and Menis F., 2019, Drought stresses on seed germination and early growth of maize and sorghum, Journal of Agricultural Science, 11(2): 310.
https://doi.org/10.5539/JAS.V11N2P310

Rahbari K., and Madandoust M., 2024, The effect of seed moisture content of hybrid maize at harvest time on seed germination traits and antioxidant enzymes activity under simulated environmental stresses with silicon foliar application, Silicon, 16: 3629-3639.
https://doi.org/10.1007/s12633-024-02953-6

Sah R., Chakraborty M., Prasad K., Pandit M., Tudu V., Chakravarty M., Narayan S., Rana M., and Moharana D., 2020, Impact of water deficit stress in maize: phenology and yield components, Scientific Reports, 10: 2944.
https://doi.org/10.1038/s41598-020-59689-7

Sandhu O., Gupta R., Thind H., Jat M., Sidhu H., and Yadvinder-Singh, 2019, Drip irrigation and nitrogen management for improving crop yields, nitrogen use efficiency and water productivity of maize-wheat system on permanent beds in north-west India, Agricultural Water Management, 219: 19-26.
https://doi.org/10.1016/J.AGWAT.2019.03.040

Wang D., Li G., Mo Y., Zhang D., Xu X., Wilkerson C., and Hoogenboom G., 2020, Evaluation of subsurface, mulched and non-mulched surface drip irrigation for maize production and economic benefits in northeast China, Irrigation Science, 39: 159-171.
https://doi.org/10.1007/s00271-020-00692-1

Wang F., Xie R., Ming B., Wang K., Hou P., Chen J., Liu G., Zhang G., Xue J., and Li S., 2021, Dry matter accumulation after silking and kernel weight are the key factors for increasing maize yield and water use efficiency, Agricultural Water Management, 254: 106938.
https://doi.org/10.1016/J.AGWAT.2021.106938

Wang Y., Zhang Y., Zhang R., Li J., Zhang M., Zhou S., and Wang Z., 2018, Reduced irrigation increases the water use efficiency and productivity of winter wheat-summer maize rotation on the North China Plain, The Science of the Total Environment, 618: 112-120.
https://doi.org/10.1016/j.scitotenv.2017.10.284

Wu D., Xu X., Chen Y., Shao H., Sokolowski E., and Mi G., 2019, Effect of different drip fertigation methods on maize yield, nutrient and water productivity in two-soils in Northeast China, Agricultural Water Management, 213: 200-211.
https://doi.org/10.1016/J.AGWAT.2018.10.018

Xue X., Du S., Jiao F., Xi M., Wang A., Xu H., Jiao Q., Zhang X., Jiang H., Chen J., and Wang M., 2021, The regulatory network behind maize seed germination: effects of temperature, water, phytohormones, and nutrients, The Crop Journal, 9(4): 718-724.
https://doi.org/10.1016/J.CJ.2020.11.005

Yan F., Zhang F., Fan X., Fan J., Wang Y., Zou H., Wang H., and Li G., 2021, Determining irrigation amount and fertilization rate to simultaneously optimize grain yield, grain nitrogen accumulation and economic benefit of drip-fertigated spring maize in northwest China, Agricultural Water Management, 243: 106440.
https://doi.org/10.1016/j.agwat.2020.106440

Yang L., Fang X., Zhou J., Zhao J., Hou X., Yang Y., Zang H., and Zeng Z., 2024, Optimal irrigation for wheat-maize rotation depending on precipitation in the North China Plain: evidence from a four-year experiment, Agricultural Water Management, 294: 108726.
https://doi.org/10.1016/j.agwat.2024.108726

Yang X., Wang G., Chen Y., Sui P., Pacenka S., Steenhuis T., and Siddique K., 2022, Reduced groundwater use and increased grain production by optimized irrigation scheduling in winter wheat–summer maize double cropping system—a 16-year field study in North China Plain, Field Crops Research, 275: 108364.
https://doi.org/10.1016/j.fcr.2021.108364

Yu Z., Wang C., Zou H., Wang H., Li H., Sun H., and Yu D., 2022, The effects of aerated irrigation on soil respiration and the yield of the maize root zone, Sustainability, 14(8): 4378.
https://doi.org/10.3390/su14084378

Żarski J., and Kuśmierek-Tomaszewska R., 2023, Effects of drip irrigation and top dressing nitrogen fertigation on maize grain yield in Central Poland, Agronomy, 13(2): 360.
https://doi.org/10.3390/agronomy13020360

Zheng H., Shao R., Xue Y., Ying H., Yin Y., Cui Z., and Yang Q., 2020, Water productivity of irrigated maize production systems in Northern China: a meta-analysis, Agricultural Water Management, 234: 106119.
https://doi.org/10.1016/j.agwat.2020.106119

Zheng H., Ying H., Yin Y., Wang Y., He G., Bian Q., Cui Z., and Yang Q., 2019, Irrigation leads to greater maize yield at higher water productivity and lower environmental costs: a global meta-analysis, Agriculture, Ecosystems & Environment, 273: 62-69.
https://doi.org/10.1016/J.AGEE.2018.12.009

Zou H., Fan J., Zhang F., Xiang Y., Wu L., and Yan S., 2020, Optimization of drip irrigation and fertilization regimes for high grain yield, crop water productivity and economic benefits of spring maize in Northwest China, Agricultural Water Management, 230: 105986.
https://doi.org/10.1016/j.agwat.2019.105986