Research progress on the effect of drought on root system of summer maize

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Abstract. Under the background of global climate change, the occurrence of extreme climate events is becoming more and more frequent. Drought has become one of the most extensive and far-reaching disasters in the world. Drought is an objective natural phenomenon. In the past, researches on drought mainly focused on two aspects: one is the relationship between climate and drought; the other is the impact of drought on crops. The effects of drought on crops are shown in various aspects. In this paper, the effects of drought on summer maize roots and the main techniques and methods of root research were reviewed. In the results, previous studies mainly focused on the growth and development of summer maize, as well as the configuration, physiology and internal anatomical structure of root system, but the explanation of mechanism was relatively less. In addition, the effect of drought on the root system of summer maize was not completely damage, but also had compensation effect under certain water conditions. The future research is also prospected.

1. Introduction
With the deepening of the impact of climate change and human activities, most parts of the world are affected by drought, which has adverse effects on the improvement of people's quality of life and the development of social economy [1, 2]. The essence of drought is water shortage [3], which usually refers to the climate phenomenon that the total amount of fresh water is small and can not maintain human survival needs and economic development. Drought is one of the natural disasters that human beings have been facing since ancient times. China's arid and semi-arid areas account for most of the country's area and are vulnerable to drought; moreover, China is a large country mainly engaged in agricultural production, and agriculture is the foundation of national economy. Drought often affects crop growth, thus affecting food security and sustainable development [4, 5]. However, the growth and development of crops cannot be separated from roots [6]. In the whole life process of crops, roots are the key organs to absorb soil water and nutrients. If root development is hindered, the growth and development of the whole plant will be seriously affected. The growth and development of roots can be used as a means to judge the adaptability of plants to soil environment [7]. Therefore, the research on the effect of drought on crop root system is still a hot topic and foreword problem.
In order to understand the latest research progress at home and abroad, through the search of the key word "drought", this paper analyzes the researchers' research on drought in the past 20 years with knowledge map, as shown in Figure 1. The research on drought mainly focuses on two aspects: one is the relationship between climate and drought; the other is the impact of drought stress. Among them, the effects of drought stress on crops are mainly studied from the following three aspects: (1) to study the effects of drought stress on crops from the perspective of different growth periods; (2) to study the effects of drought stress on the aboveground and underground parts of crops from the perspective of crop organs; (3) to study the effects of drought stress on crop cells and individuals at the object level the influence of body.

In this paper, the effects of drought on the root system of summer maize were reviewed. At the same time, the research methods of root system were also discussed. Finally, the further research direction in the future was put forward.

Figure 1. Knowledge map of research direction

2. **Research Progress on effects of drought on root system of Summer Maize**
Maize is mainly planted in arid and semi-arid areas in China. Compared with wheat and sorghum, maize has a very important water requirement [8], and its whole growth period has a certain water demand rule. Drought in the maximum water demand period or critical water demand period will seriously affect the growth and yield of summer maize. Under the condition of water shortage, the root system of summer maize is affected firstly, and then the root system produces a series of morphological and physical and chemical reactions to adapt to drought, and transmits signals to the aboveground part. When the above ground part receives the signal of drought, it will make corresponding changes to adapt to drought, so that it shows certain drought resistance [9]. Due to the lack of water, photosynthesis will be inhibited at this time, resulting in the reduction of glucose, the product of photosynthesis, and the reduction of nutrients transported to various parts. This is an interactive and complex process. A large number of studies have shown that crops are beneficial to the growth and development under appropriate
drought stress conditions, and there is a certain "compensation effect"[10]; the types, varieties, growth period and drought season of crops are all the factors affecting crops.

2.1. Research progress on effects of drought on root architecture of Summer Maize

Root architecture includes root morphology, total root length, root distribution and root density. When the soil moisture conditions do not meet the growth and development of summer maize, summer maize will adjust the root configuration to adapt to the changes of the external environment, in order to better growth. The results of Qiao [11] showed that the root architecture of summer maize would change under drought stress. Under drought stress, the root number, root diameter, root width, total surface area and total root volume of maize roots decreased, while the total dry weight, root shoot ratio and root density increased significantly. Wang et al. [12] conducted different degrees of drought stress treatment on maize planted for 50 days, and found that the greater the degree of drought stress, the less the total root number of maize and the root number under 10 cm soil depth, only the number of maize roots growing in shallow soil layer increased, and the number of roots growing in deep soil decreased with the increase of drought degree and soil depth.

Drought stress promotes the growth of crop roots to the soil layer with high soil water content [13, 14], which is conducive to improving crop soil water use efficiency [15]. Due to different soil properties and soil moisture content in different places, the amount of water absorbed by the same crop is fixed [16]. Therefore, the root distribution of the same crops planted in the South and north is different. The roots of maize planted in the north are generally distributed in the deeper soil layer, about 60 ~ 80 cm, or even deeper soil layer; while the roots of maize planted in the south are distributed in the shallow soil layer, about 30 ~ 40cm or shallower soil layer [17]. In the summer crop growth period, the soil moisture content in subtropical red soil region is higher, and the soil water content below 30cm soil layer is generally greater than 28% [18, 19]. Therefore, appropriate loosening soil and deep ploughing are beneficial to root system rooting, and deep soil moisture should be fully utilized to alleviate drought [20].

2.2. Research progress on effects of drought on root physiology of summer maize

The physiological characteristics of summer maize roots mainly include: root activity, root osmotic adjustment, protective enzyme system, and root synthesis of bioactive substances. The predecessors mainly studied the physiological characteristics of summer maize roots from two aspects: one is to study the root physiological characteristics of different drought resistant varieties under drought stress; the other is to study the changes of root physiological characteristics from a single drought event. Many scholars [21, 22] have studied from the first aspect that: the functional period of root physiological characteristics of drought tolerant maize was longer than that non drought resistant maize. The root activity, superoxide dismutase activity and soluble protein content of drought tolerant maize were higher than those of non drought tolerant maize, on the contrary, the content of propylene glycol is lower [23]. Some scholars [24] have studied the changes of root activity and plasma membrane permeability in Maize under drought conditions, and found that the activity of deep roots decreased faster than that of shallow roots, and the plasma membrane permeability of deep roots increased faster than that of shallow roots. Under drought stress, the protective enzyme system in roots and leaves accelerated to reduce oxidative damage in order to adapt to drought, superoxide dismutase and malondialdehyde had complementary effects between roots and leaves [25].

The root diameter, vessel diameter and the thickness of root cortex affected the water absorption capacity of root system, the root vessel diameter was negatively correlated with the root hydraulic conductivity. There are two kinds of resistance to soil water absorption by root system, one is radial resistance, which refers to the resistance of water from outer skin to inner layer; the other is axial resistance, that is, resistance from underground root system to aboveground part [26]. The ability of root system to absorb soil water is related to radial resistance, root diameter and vessel diameter reflect the axial resistance. Wang et al. [27] studied the root water absorption capacity of different maize varieties,
and found that the maize progenies with strong drought resistance had stronger root water absorption capacity, higher root water conductivity and obvious advantages.

Root physiological characteristics are closely related to maize drought resistance. Through understanding the physiological effects of summer maize root under drought stress, we can use chemical control technology to change the activity of summer maize root enzymes, improve the root's ability to absorb soil water, so as to improve the drought resistance of summer maize.

2.3. Research Progress on the effect of drought on the internal anatomical structure of summer maize roots

The anatomical structure of root system determines the configuration of root system [28]. Under drought stress, root cells adapt to drought mainly through two ways: one is to protect the internal cells from drought by embolizing root epidermal cells to prevent water transpiration; the other is to protect root cells from drought by gene regulation under drought stress, which is also called programmed death of root cells [29]. Wang et al. [30] results showed that under normal water supply conditions, the roots of drought resistant varieties were developed, and the number of lateral roots, root hairs and long roots were more than that of non drought resistant varieties. The transverse anatomy of the roots of the two varieties showed that there was no significant difference between the two varieties from the outside to the inside, including epidermis, cortex, endodermis and vascular bundle. From the analysis of the generation of lateral roots, both varieties had lateral roots, but the drought resistant varieties had more lateral roots. On the cross section, it was observed that new roots were produced in the cortex and grew in the cortex.

3. Main research methods of root system

3.1. Root in situ observation and imaging system

In order to clearly observe the growth and distribution of roots in soil, many scholars have explored many effective methods, such as direct root digging observation method, indirect observation method based on other indicators and in-situ observation method. The direct root digging observation method was harmful to the root system of crops, and could not observe the root changes of the same plant in different periods; the indirect observation method was not accurate in observing the growth and distribution of root system; the situ observation technology is the most, which does not damage the root system, and can observe the root changes in different growth stages. The common observation techniques are penetrating ray imaging and micro root canal method.

3.1.1. Penetrating ray imaging. With the development of technology, X-ray tomography (XCT) and nuclear magnetic resonance imaging (MRI) are widely used in the study of root system, which is a new method and means [31]. In 1992, Wantanabe et al. [32] applied XCT technology to study the root system of Dioscorea opposita with 2-5mm resolution, but the technology did not show complete root morphology at this time; In 1997, Heerman et al. [33] used high-energy Industrial CT to study the root system of Dwarf Bean, at which time the root system with a diameter of about 0.35mm was successfully displayed. With the progress of technology, Tracy et al. [34] and Lucas et al. [35] used the improved XCT system to observe Arabidopsis fine roots with the diameter of micron.

3.1.2. Micro root canal method. The micro root canal method was put forward by Bates [36]. The glass tube was embedded in the soil before planting, and the probe was placed in different positions during the experimental period to obtain the root distribution images at different depths. This method has been applied to the study of root system of many crops. Chen et al. [37] carried out field experiment, used micro root canal method and traditional grid method to monitor cotton root growth, analyzed cotton root growth dynamics, and constructed regression model between morphological parameters measured by micro root canal method and morphological parameters measured by grid method. Deng et al. [38] used micro root canal method to analyze the variation of fine root morphological characteristics with fine
root diameter and its spatial variation, and estimated the number of samples needed for fine root variables. Ren et al. [39] taking cotton and alfalfa as the research objects, taking the standing crop, growth rate, death rate and the ratio of life and death as basic parameters, the micro root canal technology was used to study the growth, death and turnover of fine roots of cotton and alfalfa.

3.2. Root water absorption model
There are two kinds of root water absorption models [40, 41], micro water absorption model and macro water absorption model. Macroscopical water absorption model takes the whole root system as the object of study, and considers many influencing factors of root water absorption; while microscopic water absorption model usually takes single root as the research object, focusing on the research of root water absorption mechanism.

3.2.1. Macro model. The macro root water absorption model takes the whole root soil system as a whole and ignores the mechanism and hydraulic characteristics of root water absorption, so it is unnecessary to consider the parameters of soil and root that are difficult to define [42]. The macroscopical water absorption model usually adopts linear or nonlinear root distribution function [43]. Pang et al. [44] used the similar threshold to calculate the local water absorption compensation, and considered that as long as the water content of a place is higher than the given stress threshold, the transpiration of plants will remain at the potential level. In order to explore the relationship between maize root water absorption and soil salt movement in the root zone, Yuan [45] combined with the root water absorption model proposed by Feddes [46] and used water balance equation to calculate the root water absorption of different periods under different treatments, and established the water absorption model of maize root under salt stress.

3.2.2. Microscopic model. Micro root water absorption model is based on the single root scale, which focuses on the mechanism of water absorption by roots [47], and is often used to describe the process of water movement to roots. Many researchers have studied and improved the micro root water absorption model. According to the analysis of experimental data, Luo et al. [48] put forward the micro root water absorption model of winter wheat and maize. Novak [49] has studied the water absorption mechanism of crop roots under the condition that the soil profile is sufficiently wet and assuming that the root water uptake rate is exponential distribution on the soil profile, and the crop root water uptake model is obtained.

4. Conclusion and Prospect
In this paper, the research progress of the effect of drought on the root system of summer maize and the main technical methods of root research were summarized. At present, some achievements have been made in this field at home and abroad, but many problems still need to be solved.

1) The research on the impact of drought on crops is mainly from the impact of drought on the growth and development of crops, and there is lack of mechanism research on the impact.

2) The research on the effect of drought on crop roots is mainly from the plane geometric configuration of roots, but there is no comprehensive study on the three-dimensional configuration of roots. In the future research, we can construct the three-dimensional distribution characteristics of roots by exploring new models, so as to make up for the lack of research in this field.

3) Under drought stress, roots will produce or reduce certain substances to adapt to drought. The production or reduction of such substances will not only affect the crops themselves, but also affect the soil through a series of actions, thus changing the soil environment and root microorganisms. In other words, the interaction of crop soil combination scenarios in drought needs to be further studied.

4) In terms of root water uptake model, different factors should be considered in root water absorption and distribution. Therefore, the combination of macro and micro root water absorption models can more accurately describe the water absorption of plant roots.
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References
[1] Mishra A K and Singh V P 2010 Journal of Hydrology 391 1
[2] Wilhite D A 2000 A Global Assessment 1 3
[3] Woodhouse C A and Overpeck J T 1998 Bulletin of the American Meteorological Society 79 12
[4] Zou X K, Zhai P M and Zhang Q 2005 Geophysical Research Letters 32 4
[5] Lobell D B, Schenker W and Costa-Roberts J 1980 Science 333 6042
[6] Osmont K S, Sibout R and Hardtke C S 2007 Annual Review of Plant Biology 58 21
[7] Robinson D 1994 New Phytologist 127 4
[8] Li Y X, Shi C H, Qiao Y Z, Dong B D, Zhai H M and Liu M Y 2010 Agricultural Research in the Arid Areas 28 40
[9] Farooq M, Wahid A, Kobayashi D and Fujita S M A 2009 Agronomy for Sustainable Development 29 1
[10] Liu X Y and Luo Y P 2002 Agricultural Research in the Arid Areas 04 6
[11] Qiao S 2018 Diversity of Maize Root Traits and its response to drought stress
[12] Wang F, Li P, Xiong L, Chen J M and Lin L R 2017 Water Saving Irrigation 02 1
[13] Chen P S, Ji R P, Xie Y B, Shi K Q, Yang Y, Zhang H and Cai Fu 2018 Agricultural Research in the Arid Areas 36 156
[14] Jiang Y, Wang B Q, Xie B T, Zhang H Y, Duan W W, Wang Q M and Zhang L M 2016 Agricultural Science & Technology 17 245
[15] Lu H D, Xue J Q and Guo D W 2017 Agricultural Water Management 179 9
[16] Duan H P, Bian X M, Xie X L and Wang K R 2003 Chinese Journal of Agrometeorology 01 37
[17] Gao Y 2013 Study on water dynamics of red soil slope farmland based on Huydus model
[18] Lin L R, Chen J Z, Wang F, Zeng T, Wei Q and Song Z J 2015 Chinese Journal of Eco-Agriculture 23 159
[19] Zhang L L, Chen J Z, Lv G A, Luo Y and Wang S 2007 Journal of Soil and Water Conservation 03 162
[20] Liu W G, Shan L and Deng X P 2002 Acta Botanica Boreali-Occidentalia Sinica 04 107
[21] Song F B and Liu S Q 2008 Journal of Jilin Agricultural University 04 377
[22] Qi W, Zhang J W, Wang K J, Liu P and Dong S T 2010 Chinese Journal of Applied Ecology 21 48
[23] Han Y H, Wang X X, Song X L, Lu J, Zheng X, Wang J Q and Sun P Y 2016 Anhui Agricultural Science Bulletin 22 33
[24] Liu H L, Zheng G Z, Guan J F and Li G M 2002 Acta Agriculturae Boreali-Sinica 02 20
[25] Wang Z W, Mou S W, Yan L L, Han Q F and Yang B P 2013 Acta Botanica Boreali-Occidentalia Sinica 33 343
[26] Steudle E and Peterson C A. 1988 Steudle Ernst: Peterson Carol A 49 14
[27] Wang Z F, Zhang S Q and Liu X F 2005 Acta Botanica Boreali-Occidentalia Sinica 08 1607
[28] Macfall J S, Johnson G A and Kramer P 1991 New Phytologist 119 4
[29] Xu L X, Chen R J, Xu H J, Zhou Y C and Wu W R 2016 Chinese Science Bulletin 61 809
[30] Wang Z L, Zhang H Y, Yan X X, Ji X L and Li X Z 1998 Acta Botanica Boreali-Occidentalia Sinica 04 3
[31] Jahneke S, Menzel M I, Dusschoten D, Roeb G W, Bühler J, Minwuyelet S, Blümler P, Temperton V M, Hombach T, Streun M, Beer S, Khodaverdi M, Ziemons K, Coenen H and Schurr U 2009 The Plant journal : for cell and molecular biology 59 4
[32] Watanabe K, Mandang T and Tojo S 1992 C USA St Joseph: Paper-American Society of Agricultural Engineers 1992 15
[33] Heeraman D A, Hopmans J W and Clausnitze V 1997 Plant and Soil 189 2
[34] Tracy S R, Roberts J A, Black C R, McNeill A, Davidson R and Mooney S J The X-factor: visualizing undisturbed root architecture in soils using X-ray computed tomography 61 2
[35] Lucas M, Swarup R, Paponov I A, Swarup K, Casimiro I, Lake D, Peret B, Zappala S, Mairhofer S, Whitworth M, Wang J, Ljung K, Marchant A, Sandberg G, Holdsworth M J, Palme K, Pridmore T, Mooney S and Bennett, M J 2011 Plant Physiology 155 384
[36] Bates G H 1937 Nature 139 966
[37] Chen W L, Jin M G, Liu Y F, Xian Y and Huang J O 2017 Transactions of the Chinese Society of Agricultural Engineering 33 87
[38] Deng F, Chen G S, Huang C C, Xiong D C and Huang J X 2015 Journal of Subtropical Resources and Environment 10 24
[39] Ren A T, Lu W H, Yang J J and Ma C H 2015 Acta pratacultural Sinica 24 213
[40] Kang S Z 1993 Mechanics in Engineering 01 11
[41] Kuai B, Guo X H, Sun X H, Ma J J , Niu S J and Li B 2008 J Shanxi Water Resources 02 40
[42] Jan W H and Keith L B 2002 Advances in Agronomy 77
[43] Li K Y, Jong R D and Boisvert J B 2001 Journal of Hydrology 252 1
[44] Pang X P and Letey J 1998 Soil Science Society of America Journal 62 5
[45] Yuan C F 2018 Jiangxi Hydraulic Science & Technology 44 22
[46] Feddes R A and Zaradny H 1978 Model for simulating soil-water content considering evapotranspiration à Comments Feddes R.A Zaradny H 37 5
[47] Rami A, Jean-Claude M and Bruno C 2015 Agricultural Water Management 155 18
[48] Luo Y P and Li Y Z 1996 Root soil system and crop water and nitrogen utilization efficiency (Beijing: China Agricultural Science and Technology Press)
[49] Novák V 1987 Estimation of soil-water extraction patterns by roots Novák Viliam 12 4