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Crop Production and Yield Limiting Factors

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Abstract

Global warming has seriously affected human survival and sustainable development of agriculture. Due to the rapid global climate change, the situation has further deteriorated. In crop production, drought is undoubtedly the most important stress, which has a great impact on crop growth and productivity. Understanding the physiological, biochemical and ecological interventions associated with these stresses is important for better management. Abiotic stress is one of the main factors restricting crop production and food security in the world. This paper discusses the scientific basis of greenhouse gas emission and carbon absorption in farmland, describes the response of plants to drought stress and the negative effects of crop growth and yield formation, and evaluates the gap between actual yield and crop potential yield and the influence of limiting factors, which has not been reasonably eliminated. This phenomenon is common in the agricultural production of all countries in the world.

Keywords: Crop production, drouhgt stress, crop yield, limiting factors

INTRODUCTION

The world food consumption mainly depends on the seeds of wheat, rice, corn, barley and sorghum. These food crops are vulnerable to climate change, especially global warming and prolonged drought. The main impact of climate change will be rain fed agriculture, especially in Asia and Africa, where drought conditions are expected to significantly affect grain production and are likely to lose about 280 million tons of production (Singh et al., 2013). The warming of land ecosystem has a significant impact on agriculture in every region of the world. In many plant species, the increase of temperature results in the decrease of seed number, decrease of seed size and change of seed physiological conditions (Martínez et al., 2012; Singh et al., 2013). According to current forecasts for rising temperatures, rice and corn production in South Asia will drop by 10 per cent by 2030 and 30 per cent in southern Africa (Lobell et al., 2008). The results of the International Rice Institute (IRRI) show that during flowering, temperatures above 35 °C for more than an hour can cause sterility and thus no grain production. According to the prediction of the International Rice Institute, the increase of temperature leads to 20% reduction in rice production and 10% decrease in yield at night. This loss of production has had a significant impact on world food security, especially in Asia, where rice is the main food (Hybrid Rice (2014) www.irri. Organization / our work / research / rice and environment). In the recent global context, the food security situation has been hindered by the rapid increase of population and the rapid fluctuation of climate conditions (Hussain and sulaimon, 2018). Due to the change of climate conditions, high temperature and drought have become the most urgent problem restricting crop production, and eventually lead to food security. Changes in rainfall patterns and lack of precipitation lead to global drought like conditions (Rajsekhar and Gorelick, 2017). Extreme drought conditions have adverse effects on plant growth, physiology and reproduction, resulting in a significant decline in yield (Barnabas et al., 2008; Ansari and Lin, 2010; Ansari and Silva, 2012; Fathi and Tari, 2016). In the past few decades, due to global drought conditions, wheat and maize yields have decreased by 21% and 40%, respectively (Daryanto et al. 2016; Zhang et al., 2018). The severity of the damage caused by drought is usually unpredictable because it is controlled by a variety of factors, including rainfall patterns, soil water holding capacity and water deficit, which is due to high transpiration rate (Yan et al. 2016). The open image of the new window under drought conditions affects plant growth, affects the photosynthetic process by affecting the relationship with water-soluble nutrients, and eventually leads to a significant decline in crop productivity (Praba et al. 2009; Muhammad et al. 2012). The response of plants to drought stress usually varies among different species, depending on the growth stage and other ecological aspects (Cheruth et al., 2009). Under the condition of insufficient soil moisture, limited soaking of photosynthetic radiation, shortened Radiation Utilization adaptability and decreased harvest index were the main reasons for yield decline (Earl and Davis, 2003). When plants are severely stressed by drought, the patterns of growth, development and physiological processes are usually different (Duan et al., 2007). The morphological, physiological and biochemical changes induced by heat stress also interfere with plant growth and development (Akter and Islam, 2017; Jalil and Ansari, 2018). Drought caused by global warming is becoming the primary factor restricting crop yield and productivity. All these stresses greatly restrict the growth of plants, and also connive at the oxidative damage of plants. Reviewing the basic refutation of plant stress to drought conditions, this may contribute to the possibility of crop management and eliminate the destructive effects of drought stress, so it has economic value. Human diet is strongly dependent on wheat (*Triticum aestivum L.*), maize (*Zea mays L.*) and rice (*Oryza sativa L.*). Their production has increased dramatically over the past 50 years, partly due to the expansion of the area and new varieties, but mainly due to the strengthening of land management and the introduction of new technologies (Cassman, 1999; Wood et al., 2000; FAO, 2002a;). Demand for agricultural products is expected to continue to grow strongly in the future (Rosegrant and Cline, 2003). This growing demand is unlikely to be met through expansion of the area, as productive land is scarce and demand for non-agricultural purposes is growing (Rosegrant et al., 2001). Agricultural intensification, as a key role in improving actual crop production and food supply, has been discussed in a number of studies (Ruttan, 2002; Tilman et al., 2002; Barbier, 2003; Keys and McConnell, 2005). However, in many areas, the growth in food production has been declining (Cassman, 1999; Rosegrant and Cline, 2003; Trostle, 2008). The inefficient management of farmland may lead to the deviation between the actual and potential yield of crops: yield gap. Worldwide, there is little information on the spatial distribution of agricultural output gaps and the potential for agricultural intensification. There are three main reasons for this lack of information. First, there is little consistent information about the drivers of agricultural intensification worldwide. Keys and McConnell (2005) analyzed 91 published studies of tropical agricultural intensification to determine the important factors of agricultural intensification. They stressed that there are many factors that promote the reform of the agricultural system. Their relative contributions vary from region to region. Many studies have confirmed this issue, which investigate food production and try to identify factors that support or hinder food production on different scales (Kaufmann and Snell, 1997; Timsina and Connor, 2001; FAO, 2002a; Reidsma et al., 2007). These studies also show that most of these factors are local or regional, so it is difficult to propose a set of universal factors that apply to all countries. The second reason for the lack of reliable information on the global production gap is the limited availability of consistent data worldwide. Especially the lack of land management data. In quantifying the potential changes in crop yield, only biophysical factors such as climate are considered, while the limiting factors to improve actual crop yield are often ignored or captured by simple management factors, including all factors that lead to potential yield deviation (Alcamo et al., 1998; Harris and Kennedy, 1999; Ewert et al., 2005; Long et al., 2006). Finally, the lack of data leads to another difficulty. A common feature of many yield gap analyses is that they use crop models to simulate potential crop yields and compare them to actual yields (Casanova et al., 1999; Rockström and Falkenmark, 2000; Van ittersum et al., 2003). However, potential yield is a concept that describes crop yield without any restrictions. This concept requires assumptions about crop varieties and planting dates. Although this information is easily available locally, it is not available globally. In addition, the simplification degree of crop growth process is different from different models. This may lead to uncertainty in global simulations of potential production and make appropriate model calibration critical for global applications. Therefore, by comparing the simulated global crop yield with the actual crop yield, even beyond the yield gap itself, it is possible to deal with the error range and uncertainty of different data sources. Field trials and simulation models are useful tools for understanding crop yield gaps, but expanding these methods to understand the entire region remains a considerable challenge over time. Satellite data has been proved to provide information for many times. The information itself or combined with other data and models can accurately measure the crop yield in farmers' farmland. The resulting yield map provides a unique opportunity to overcome the challenges of spatial and temporal scales, thereby improving understanding of crop yield gaps (Lobell, 2013).

Crop production under drought condition

When root water supply is limited or transpiration loss is high, plants will be affected by drought conditions (Anjum et al., 2011). The severity of damage caused by drought is usually unpredictable, because drought is driven by a variety of factors, including rainfall patterns, soil water capacity and water loss caused by evapotranspiration. Drought interferes with growth, nutrient water relationship, photosynthesis and assimilate allocation, resulting in a significant decrease in crop yield (Farooq et al., 2009; Praba et al., 2009). The response of plants to drought stress usually varies with plant growth stage and other environmental factors (Demirevska et al., 2009). Under the condition of limited soil water supply, the reduction of photosynthetically active radiation absorption, the damage of radiation use efficiency and the decline of harvest index were the main factors for yield reduction (Earl and Davis, 2003). Plants show certain changes in growth patterns and physiological processes to cope with the severe effects of drought stress (Duan et al., 2007). The primary consequence of drought conditions on plants is the decrease of germination rate and shortening of seedling formation (Li Yunfang et al., 2013). Some studies have shown that drought stress can damage seed germination and seedling growth (Kaya et al., 2006; Hatzig et al., 2018). It is reported that under drought stress, the germination potential of rice, pea and alfalfa decreased, seedling growth and root crown dry weight decreased, hypocotyl length was too small and malnourished (Okcu et al.2005; Zeid and Sheeded 2006). Cell division and differentiation are the basic requirements of plant growth, followed by cell growth, but due to drought stress, cell elongation and mitosis are affected, which leads to plant growth reduction (Farooq et al.2009). Basu et al. (2016) described that cell growth was inhibited due to drought stress that hindered the expansion. Water restriction results in a decrease in cell elongation, mainly due to the decrease of water movement through xylem tissue and adjacent cells (Nonami,1998). Due to drought stress, the number and area of leaves are also reduced, because the expansion of leaf area is usually controlled by the expansion pressure. The decrease of photosynthetic rate and expansion pressure caused by drought stress mainly restricted the expansion of leaf area (Rucker et al., 1995). It is further reported that the fresh / dry weight ratio is decreasing due to the limited water resources (Zhao et al., 2006). The growth of plants is mainly accomplished by cell division, expansion and differentiation. Drought damages mitosis and cell elongation, leading to poor growth (Hussain et al., 2008). Fresh water and dry weight also decrease significantly under water limiting conditions (Zhao et al., 2006). Under the water restriction, the plant height, leaf size and stem circumference of maize decreased significantly (Khan et al., 2015). In another study, Kamara et al. (2003) reported that maize biomass accumulation decreased significantly under drought conditions applied at different growth stages. Considering crop yield, yield is mainly the fusion of multiple physiological processes (Ali, F. et al., 2017). Due to drought stress, various physiological processes in plants are adversely affected. The adverse effects of drought stress on crop production mainly depend on the severity of the stress and the growth stage of plants under this condition (Akram, 2011). Drought stress shortened the flowering time at the pre anthesis stage, which further affected grain filling (Farooq et al. 2009). The enzymes controlling grain filling are mainly controlled by ADP glucose pyrophosphorylase, starch branching enzyme and sucrose UDP glucosyltransferase (Ainsworth et al., 1995). Ahmadi and Baker (2001) reported that most cereal crops have an adverse effect on yield due to drought stress because of the decreased enzyme activity responsible for cereal fillings. Exposure of flowering plants to drought may lead to complete sterility of Pennisetum (Farooq et al. 2009). The decrease of plant yield under drought stress may be due to the following reasons: Photosynthesis rate decreased, assimilate allocation decreased and leaf development was insufficient (Rucker et al., 1995; Flexas et al., 2004; Farooq et al., 2009). Anjum et al. (2011) reported that maize crop yield decreased due to exposure to drought stress. Similarly, in cotton plants, boll yield decreased significantly under drought stress, resulting in limited lint yield (Loka et al., 2012). Yield is basically the synthesis of different physiological processes. Most of these physiological processes are negatively affected by drought stress. The negative effect of drought on yield mainly depends on the severity of stress and plant growth stage. It is reported that due to drought stress, the yield of main field crops has suffered a significant loss. Pre anthesis drought shortened flowering time and post anthesis drought shortened grain filling period (Estrada Campuzano et al., 2008). Plant exposure to drought stress during flowering may lead to complete sterility of Pennisetum glaucum L., which is usually due to the interference of assimilate movement to the developing ear (Yadav et al., 2004).

In terms of plant yield and growth, these stress conditions are more unfavorable to most plants than any other environmental factors. It is reported that the global wheat yield will decrease by about 6% with each temperature rise (Asseng et al. 2015). However, in some regions of the world with lower climate temperature, temperature rise is also conducive to the benign yield of crops, although the overall impact on food security on a global scale is inappropriate (Challinor et al., 2014). Due to the high transpiration rate, when the water supply to the root system is insufficient or short of water, plants will face a similar drought situation (Lisar et al. 2012). The detailed system representation is shown in Fig. 1.

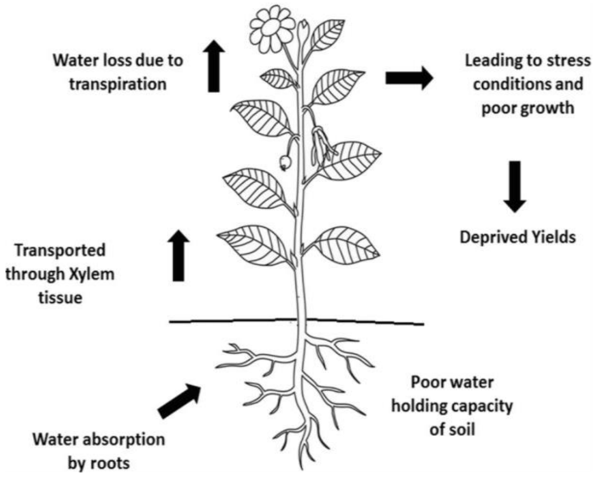

Fig. 1. A stress state in which plant yield decreases due to drought (Iqbal et al., 2020)

The primary response of almost all plants to water stress is to close stomata to avoid water loss during transpiration. The stomatal closure may be due to the decrease of leaf water potential (Ludlow and Mucchow, 1990) or the decrease of atmospheric humidity (Maroco et al., 1997). The stomatal closure inhibited the intake of carbon dioxide, which led to oxidative damage and non assimilation. The stomatal closure also increases the heat dissipation of the blades (Yokota et al., 2002). Interestingly, the soil water status has a greater impact on stomatal regulation than leaf moisture, which may be the reason why stoma reacts to ABA produced by roots under dry conditions (Turner et al., 2001). However, stomatal responses of different plant species vary greatly under dry conditions (Lawlor and Cornic, 2002). Photosynthesis is limited by the decrease of stomatal conductance under light and drought conditions, however, the damage of Rubisco function is the main factor affecting photosynthesis (Bota et al., 2004). Water shortage leads to cell contraction and reduced cell volume, so cell materials become more viscous, leading to protein denaturation. The increase of solute level in cytoplasm may also lead to ion toxicity, which has a serious impact on the activity of enzymes involved in photosynthesis and other plant processes. The concentration of Rubisco in leaves depends on the rate of its synthesis and degradation. Even in the case of severe water scarcity, it remains quite stable due to a few days of half-life (Hoekstra et al., 2001). However, the main damage was the reduction in Rubisco synthesis due to the reduction of small subunits of Rubisco (Vu J.C.V et al., 1999). Under drought stress, the binding of inhibitors such as 2-carboxyxylitol-1-phosphate with Rubisco catalytic sites is also common. Similarly, other important enzymes involved in photosynthesis are also negatively affected by drought and heat stress. It is reported that the reduction of phosphorylation and impaired ATP synthesis are the main factors limiting photosynthesis in light drought conditions. Under drought conditions, the yield of nicotinamide adenine dinucleotide phosphoric acid decreased, leading to the down regulation of acyclic electron transport chain, thus reducing the synthesis of ATP (Lawlor and Cornic, 2002). In plants, one of the key physiological processes affected by drought stress is photosynthesis (Jaleel et al., 2009). It is mainly affected by the reduction of leaf area, insufficient operation of photosynthetic mechanism and leaf senescence (Wahid et al. 2007). Drought stress leads to stomatal closure, reducing the availability of carbon dioxide and making plants more vulnerable to light damage (Lawlor and Cornic, 2002; Ansari and Lin, 2011). Shortened water accessibility can unnecessarily modify photosynthetic pigments, change photosynthetic mechanisms and weaken the production of important enzymes, resulting in a significant decline in plant growth and yield (Monakhova and Chernyadev, 2002; Fu J. and Huang B., 2001; Zang et al., 2019). Anjum et al. (2011) reported the damage of photosynthetic pigments and thylakoid membrane under drought stress, while Din et al. (2011) reported the decrease of chlorophyll content under drought stress. Under drought conditions, the content of chlorophyll will change because the content of chlorophyll b is lower than that of chlorophyll a (Keyvan, 2010). When Brassica plants were exposed to drought stress, a decrease in chlorophyll a and B ratios was observed (Rahbarian et al., 2011). The main response of almost all plants to humidity stress is to close stomata to avoid water loss caused by transpiration. Stomatal closure may be a response to decreased leaf water potential or water content (Ludlow and Muchow, 1990; Maroco et al., 1997). Stomatal closure inhibits the consumption of carbon dioxide, resulting in the destruction of free radicals and the loss of assimilation. In addition, stomatal closure reverses the thermal indulgence of leaves correspondingly (Schymanski et al. 2013). It is worth noting that soil moisture exaggerates stomatal regulation more than leaf water content, which may be due to stomatal response to abscisic acid (ABA) released by plant roots under drought stress (Munemasa et al. 2015). It has been reported that large fluctuations in stomatal closure were observed in different species of plants under drought stress (Lawlor and Cornic, 2002). However, due to drought stress, the photosynthetic process is mainly limited by stomatal conductance; the decrease of Rubisco function is the key factor to interfere with the photosynthetic mechanism (Lawlor and Tezara, 2009). The effect of drought stress on photosynthesis mechanism is shown in Fig. 2.

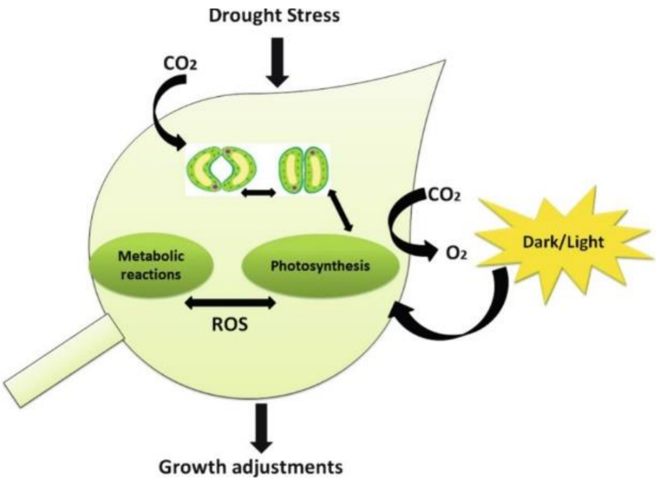

Fig. 2. Drought Stress Affects Photosynthesis and leads to growth and development (Iqbal et al., 2020)

Lack of water leads to cell shrinkage, resulting in cell volume reduction; as a result, the substances in cells become more viscous, leading to denaturation of various proteins (Ghosh and Dill, 2010). High levels of solute in the cytoplasm may lead to ionic toxicity, which has an extreme impact on the activities of several enzymes necessary for photosynthesis (Hussain et al. 2018). The extent to which Rubisco enzymes are present in plant leaves depends on the level of their production or degradation (Quick et al., 1991). Since the half-life is only a few days, it remains constant even in the case of severe water shortage (Hoekstra et al., 2001). Nevertheless, the main loss is due to the reduced production of Rubisco due to the contraction of its secondary subunit (Vu J.C.V. et al., 1999). Similarly, other essential enzymes involved in the photosynthesis process also become pretentious due to drought conditions (Farooq et al. 2012). Decreased phosphorylation and decreased ATP synthesis are considered to be key factors in regulating photosynthesis due to mild drought conditions (Lawlor and Cornic, 2002). Water correlations depend on some characteristics of plants, including leaf water potential, canopy and leaf temperature, transpiration rate, and stomatal conductance (Waring and Landsberg, 2011). According to the research of Elizamar et al. (2009), the effect of drought stress on stomatal conductance is greater than any other aspect of plant physiology. The transpiration rate and leaf water potential decreased significantly due to the final increase of canopy and leaf temperature under drought stress (Turner et al., 2001). Another important aspect of plant physiological regulation is water use efficiency, which is the ratio between accumulated dry matter and water absorption (Monclus et al., 2006). Abbate et al. (2004) reported that various wheat varieties had high water adaptability to drought conditions. The development of this water use capacity is mainly due to stomatal closure and transpiration rate reduction, and the use of limited water to increase dry matter. Obidiegwu et al. (2015) reported that in the early stage of water shortage, the decrease of water suitability was detected in Solanum plants, which eventually led to the decrease of biomass accumulation and yield. Drought conditions greatly affect the nutrient composition of plants. Several important nutrients, including magnesium, nitrogen, calcium and silicon, are accepted by roots with water absorption. Drought stress disturbs the relationship between nutrients through diffusion, resulting in plant growth retardation (Barber, 1995). As plants propagate, the surface area and length of roots further change their structure, thus retaining nutrients that are not easily transported (Lynch and Brown, 2001). Soil water deficit sometimes reduces root growth, thus reducing the absorption of phosphorus and other nutrients with poor mobility (Garg, 2003). The interaction between plant roots and microorganisms plays an important role in plant nutrition. Under drought conditions, the variability of oxygen and carbon fixation by nitrogen accumulation decreased, which inhibited the nitrogen fixation ability of some legumes (Ladrera et al. 2007). Schimel et al. (2007) further explained that the binding and activity of microbial colonies in soil is harmful and pretentious, because the lack of soil moisture will eventually interrupt the relationship between plant nutrients. On the other hand, the relationship between nutrients becomes more complex, because the sharing characteristics of various nutrients affect the almost complete physiology of plants. This part needs a comprehensive study at the fine molecular level. Water relationship is affected by some factors, including leaf water potential, leaf and canopy temperature, transpiration rate and stomatal conductance. Drought stress interfered with all these factors, but stomatal conductance was most affected (Farooq et al., 2009b). Under drought conditions, leaf water potential and transpiration rate decreased significantly, resulting in an increase in leaf and canopy temperature (Turner et al., 2001). Another important feature of plant physiological regulation is water use efficiency, which is the ratio of accumulated dry matter to consumed water (Monclus et al., 2006). High efficiency wheat varieties have higher water use efficiency under drought stress (Abbate et al., 2004). The increase of WUE was mainly due to stomatal closure, transpiration rate, water consumption and dry matter accumulation. When potato (*Solanum tuberosum L.*) was short of water in the early stage, water use efficiency decreased, resulting in biomass accumulation and yield reduction (Costa et al., 1997). Different crops have different responses to mineral elements absorption under water stress. Generally speaking, under drought conditions, nitrogen absorption increased, phosphorus absorption decreased, and potassium absorption was not affected. However, due to the interaction between different nutrients and the overall physiological characteristics of plants, the relationship between nutrients becomes more complex. This aspect needs to be studied in detail at the level of complex molecules. Abiotic stress is an important factor limiting crop yield. Plants have a wide range of responses to drought stress, mainly for plant growth and morphological changes. Although drought has adverse effects on the overall growth and development of plants, the main damage stage is reproductive growth. Light stress at flowering and filling stages significantly reduced crop yield. Other important effects of this stress include the destruction of photosynthetic mechanism, oxidative damage and membrane instability. The ability of plants to resist these stresses varies from species to species. In recent years, great achievements have been made in reducing the negative effects of abiotic stress by using genetic methods or induced stress resistance methods. Although QTL mapping, transgenic and other genetic methods have made great progress, there is still much room for improvement. Gene expression can be driven by conditional promoters at specific developmental stages, specific tissues / organs and / or specific environmental conditions, thus avoiding this problem and minimizing yield loss of transgenic crops under various abiotic stresses (Fahad, s et al., 2017). In the study of plant yield stability and other complex quantitative traits under drought stress, the integrated system method is essential (Fig. 3) research must use the latest genomics resources, combine the new technologies of quantitative genetics, genomics and Biomathematics with the ecophysiological understanding of the interaction between crop plant genotypes and growth environment, so as to provide better information for crop improvement (Hawkesford & Buchner, 2001; Araus et al., 2003; Alaus, 2004). Recently, most research projects lack this necessary interdisciplinary method. In addition, researchers need to engage more effectively with policy makers and social economists to explain the importance and urgency of research on this topic (Parry et al., 2005). Under drought stress, great efforts have been made to improve seed quality through plant breeding and biotechnology, and to develop new varieties and hybrid methods. In the past few years, seed companies have contributed to increasing crop yields. Under drought stress, seed genetic characteristics, such as insect resistance, water use efficiency and higher yield, have been used in genetic engineering and breeding programs (Rinukshi, 2015).

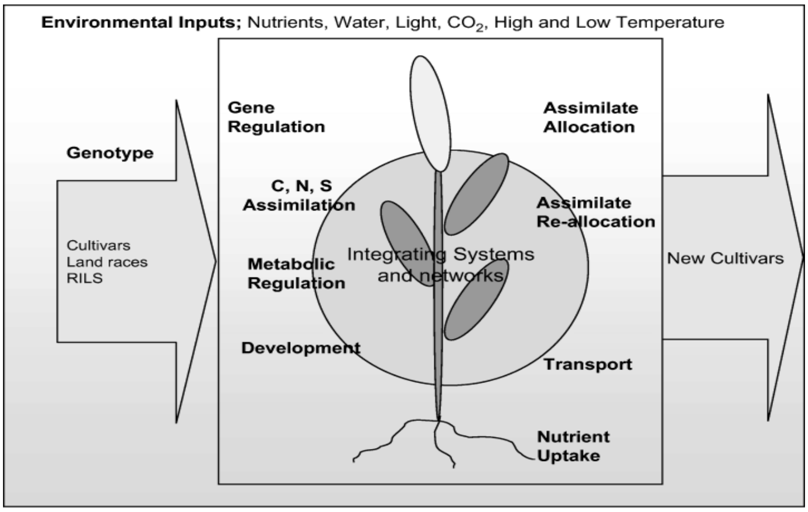

Fig. 3 The response of plants to drought stress is complex, which is determined by genetic and environmental factors. The optimization of field water use needs an integrated system approach that takes into account crop management, environmental and genetic factors. Recombined inbred lines (Parry et al., 2005).

Crop yield and limiting factors

There has been relatively little recent concern about meeting projected food demand through increased crop productivity, but it is increasingly recognized that "operating as usual" will not allow food production to keep up with demand, which could lead to a sharp rise in food prices, poverty and hunger (FAO, 2003; FAO, 2006, Royal Society of London, 2009; Koning and Van ittersum, 2009). In fact, until recently, the most widely used computational equilibrium model evaluates global food supply and demand and forecasts that food prices will remain unchanged or declining over the next few decades (Rosegrant et al., 1995; Colby et al., 1997; Cranfield et al., 1998; Rosegrant et al., 2002; Rosegrant and cline, 2003). There are three reasons for the significant change in the prediction of global food security: (1) the economic development rate of the countries with the largest population in the world has always exceeded the forecast (2) because of the rapid increase of purchasing power, the demand for energy, food and livestock products in these countries has increased significantly; And (3) global slowdown in grain crop yield rates (Cassman et al., 2003; Steinfeld et al., 2006; Royal Society of London, 2009; Cassman et al., 2010; Brisson et al., 2010; Fischer and Edmeades, 2010). It is clear that in the next few decades, with the population growing to a climax of more than nine billion, each hectare of existing crop land needs to produce far higher than the current level of production. However, due to the favorable climate and soil quality, some regions have greater potential than others, can support higher production in a sustainable way and, in some cases, irrigation can be obtained. In these favorable areas, the average farm production is currently very low. Therefore, there is a huge gap between the current rate of return and the theoretical realizable yield under ideal management. Given the need for sustainable strengthening, it is essential to identify areas with the greatest potential to increase food supply, for four reasons. Firstly, the yield gap analysis provides the basis for determining the most important crops. Soil and management factors limit the current agricultural yield and improvement practice to make up for the gap. Second, the priorities for research, development and interventions are effectively identified. Third, assess the impact of climate change and other future scenarios that affect land and natural resource utilization. Fourth, the results of these analyses are the key inputs to the economic models of food security and land use assessment on different spatial scales. The computable general equilibrium and partial equilibrium models usually depend on the trend of historical return and extrapolate the future. However, through strict yield gap analysis, the predicted agricultural technology base and related resource demand can be greatly improved. For all these reasons, a clear geographical assessment of the availability gap of the world's major food crops, which have local, agronomic relevance and public access, needs to be clearly assessed. While more detailed information on the income gap is needed, it is not enough to fully inform the research priorities and investment strategies. Market, policy, infrastructure and institutional factors need to be analyzed. Without an assessment of the yield gap, coupled with appropriate socio-economic analysis of constraints to productivity improvement, policymakers and researchers will find it difficult to accurately assess future food security and land use changes (Martin K et al., 2013). The effectiveness and strictness of the output gap analysis are proved by various examples. As early as the 1960s, the average yield of farmers was less than 5 mg ha^{-1}. In the Netherlands, it was calculated that wheat yield might exceed 10 mg ha^{-1} (De Wit, 1959, Alberda, 1962). Although few people believed it to be true at that time, since 1993, the average yield of farmers in important wheat growing areas in the Netherlands has often exceeded 9 mg or even 10 mg ha^{-1} (Central Bureau Voor of Statistics). In Australia, early work by French and Schultz (1984) estimated that water limited yield and showed that yield was limited by factors other than water, although farmers believed that water was the only limiting factor. Understanding of these other constraints has led to improvements in management practices, resulting in a smaller yield gap now (Hochman et al., 2012a, Hochman et al., 2012b). Yield gap analysis in Southeast Asia helps to explain yield trends in irrigated rice and suggests that nitrogen management must be improved to increase yield (Kropff et al., 1993). In Nebraska, a recent yield gap analysis of Irrigated Maize found that the recent yield stagnation in farmers' fields was related to the yield level of about 85% of the upper limit of yield potential (Grassini et al., 2011), which was similar to the yield level of other crops (Cassman et al., 2003, Cassman et al., 2010). Because there are many factors that affect crop growth and yield, predecessors have carried out a lot of research on the causes of yield gap from different perspectives at the field scale and regional scale, and developed a variety of research methods, including yield gap analysis, crop growth model, rapid rural appraisal (RRA), regression, path analysis, and so on Comparative advantage, principal component analysis and regression tree analysis methods. In recent years, the emergence of remote sensing and geographic information technology provides a new means to study the causes of regional crop yield difference. Many studies have shown that there are many reasons for the formation of yield difference, which are closely related to biological characteristics, environmental factors, technical level, economic status, policies and regulations; The main reasons for the yield difference at different levels may be different (Wang Chunzhi et al., 2009). For a long time, the theoretical research and practice of improving crop yield mainly focus on two aspects: one is to improve yield potential; the other is to narrow the yield gap. Under the current production management conditions, crop production potential is far from being fully exploited, and there is a large gap between the actual and potential yield of crops, including between different regions and different farmers in the same region, It is of great significance to meet the increasing demand for food, and it is an important subject for long-term research in Crop Science in the future (Wang Zhimin, 2004). Yield potential (Yp), also known as potential yield, refers to the yield of crop varieties grown under the conditions of effective control of water and nutrient non limiting and biological stress (Evans, 1993, Van itersum and Rabbinge, 1997). When growing at the condition of Yp, the growth rate of crops is determined only by the genetic characteristics of solar radiation, temperature, atmospheric CO_2 and the length of the controlled growth period (known as variety or hybrid maturity), and the light interception of crop canopy (such as canopy structure). Potential yields vary from climate to climate, but in theory do not depend on the nature of the soil, assuming that the water and nutrients required can be increased through management (of course, under the main soil constraints, such as physical barriers to salt or root proliferation, this is not practical or uneconomic and insurmountable). Therefore, in areas without major soil restrictions, Yp is the most relevant benchmark for systems with adequate water supply in irrigation systems or humid climates to avoid water shortage. For dry crops, water limited yield (Yw) is equivalent to potential water production, which is the most relevant benchmark. For some (supplementary) irrigation crops, Yp and Yw can be used as useful benchmarks. Yw is similar to Yp, but crop growth is also limited by water supply, and is therefore affected by soil types (water holding capacity and rooting depth) and field topography (runoff). Yp and Yw are calculated according to the best or recommended sowing date, planting density and variety (determining maturity). Average yield (Ya) refers to the actual yield obtained by farmers in the field. In order to represent the temporal and spatial changes in a specific geographical area, it is defined as the average yield (in space and time) obtained by farmers in the area under the most widely used management practices (sowing date, variety maturity and plant density, nutrient management and crop protection). The number of years used to estimate yield must be a trade-off between yield variability and the need to avoid confusing effects of temporary yield trends due to technology or climate change (Martin K et al., 2013). Crop yield level can be divided into different levels. The yield gap between different levels is called yield gap, and the factor causing the yield gap is called yield constraint. Generally, the level of crop yield is divided into four levels:

theoretical yield of light and temperature, high-yield record yield, regional test yield and average yield per unit area in field from high to low (Li Shaokun, 2011). Therefore, the difference of crop yield can be defined as shown in Fig. 3.

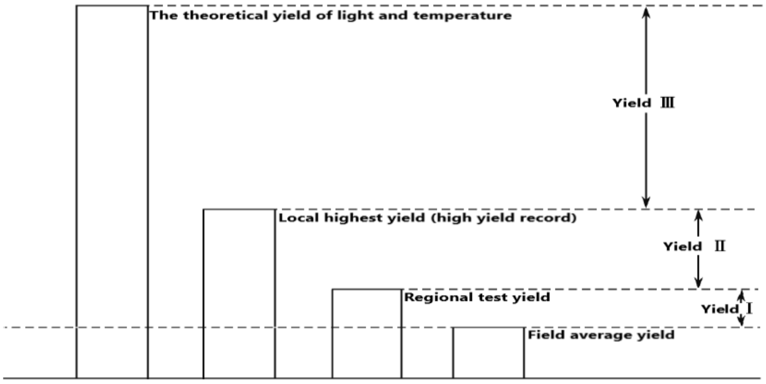

Fig. 4. Definition of crop yield potential and yield difference (Li Shaokun, 2011)

Among them, the theoretical yield of light and temperature is the highest theoretical yield determined by regional light and temperature resources; High yield record yield is the highest yield record in the region, which reflects the highest yield level in the region; The yield of regional test is the yield of regional test, which can be regarded as the yield level of test field; The average yield per unit area is the actual average yield level of local farmers. Yield difference I is the difference between the regional test yield and the field actual yield; Yield difference II is the difference between regional high yield record and regional test yield; Yield difference III is the difference between the theoretical yield of light and temperature and the local high yield record. Taking maize as an example, the theoretical yield distribution of light and temperature in China's main maize producing provinces (regions) is 27349.5 ~ 47490.0 kg / ha (in Guangxi) and the current record distribution of high yield is 13008.0 ~ 19896.0 kg / ha (in Shaanxi), The yield distribution of the regional test is 6807.9 (Guangxi) ～ 12325.1 kg (Gansu), while the field average yield is only 3836.3 (Yunnan) ～ 7271.0kg (Xinjiang). The average field yield of the main producing provinces is only 14.7% of the theoretical yield of light and temperature, and the regional test yield and high yield record yield are only 25.7% and 47.6% of the theoretical yield of light and temperature (Li Shaokun, 2011). In order to explore the causes of the yield gap, a variety of conceptual models of "yield gap" have emerged since the mid-1970s. These models generally find the factors that cause the yield gap by limiting factor components. For example, Gomez divided the limiting factors of the yield gap between the experimental station and the farmers into two groups: gap 1 is the gap between the available yield of the farmers and the yield of the experimental station, which is mainly attributed to the differences in environmental conditions; Gap II refers to the gap between the available yield and the actual yield, which is mainly due to the biological, technological and socio-economic constraints (Gomez KA, 1977). Lin Yifu pointed out that there are two kinds of yield gaps in China's rice production: one is the gap between the highest experimental yield and the yield a Gomez ailable to farmers under suitable conditions, which reflects the differences between experimental varieties and varieties used by farmers, and between the experimental plot environment and farmers' field environment; The second is the gap between farmers' available yield and farmers' actual yield under suitable conditions, which reflects the restriction of climate, environment, soil, diseases and pests on yield. Among them, the yield gap of more than 70% is the gap between the maximum yield of the experimental station and the available yield of farmers under suitable conditions. The causes include variety characteristics, environmental conditions (light, temperature, soil, etc.) and other uncontrollable factors. Drought, waterlogging, chilling injury, high temperature, lodging, weeds, diseases and insect pests and other factors in the key growth period are the main causes of the remaining 30% yield difference, that is, the gap between farmers' available yield and farmers' actual yield under suitable conditions. FAO used comparative performance analysis (CPA) to study the relative contribution rate of different limiting factors to the yield gap of rice. Water shortage accounted for 41%, diseases and pests accounted for 22%, sowing date accounted for 18%, lodging accounted for 10% and soil environment accounted for 8%. De Datta (1981) suggested that water control, seasonal factors (solar radiation) and economic factors were the main factors restricting the difference between potential rice yield and actual rice yield in the Philippines. De Bie (2000) further defined the yield as five levels, defined the yield difference at all levels, analyzed the main limiting factors of yield difference at all levels. Based on the definition of four yield levels: theoretical yield of light and temperature, record yield of high yield, regional test yield and field average yield, an operable yield difference model was constructed. It is considered that the difference of crop yield reflects the difference of technology demand structure at the internal level of crops.

In the production practice, the establishment of high-yield crops can be divided into two levels: one is to take the breakthrough of high-yield records in various places as the goal, through the activities of creating high-yield in small areas, clarify the realistic potential of crop yield, variety breeding and technological innovation ways, mobilize the enthusiasm of farmers to adopt new technologies and learn advanced experience, so as to accelerate the diffusion of high-yield new varieties and cultivation techniques, It plays a significant role in demonstration and promotion of regional crop sustainable high yield; The second is to narrow or eliminate the gap between the regional trial yield and the farmers' actual yield (yield difference I) and to carry out large-scale high-yield tackling, which is more important for ensuring food security at this stage (Li Shaokun, 2011). With the breakthrough of high yield, the gap between the actual yield and the potential yield will exist for a long time and increase. It is only the first step to study the factors limiting crop yield and narrowing the yield gap between different levels. Facing the increasingly tense situation of resource supply, we should carry out in-depth study on the causes of yield gap under resource constraints, explore economic and efficient technologies to narrow the yield gap, and realize "moderate low input, high efficiency and high output", It will be an important direction of agricultural development in the future (Evenson RE, 1997; Duvick DN and Cassman KG, 1999; James CR et al., 2000; Cassman KG et al., 2003). The scientific difficulties of deepening the understanding of crop yield difference and its causes mainly include the following aspects. (1) Due to the complexity of agroecosystem, it is difficult to quantitatively analyze all the factors in the system and set different input levels for each factor. The commonly used crop simulation model research method originated from the single point experiment, and many of the assumptions are based on the uniform production situation in the field. In fact, there are large spatial variability in crop, climate, soil and agricultural management, which also limits the diagnosis and application of regional yield difference of crop model. (2) Due to the lack of spatial data of crop yield and spatial distribution of yield limiting factors, it is difficult to quantitatively analyze the interaction among many factors in the past limited experiments, which limits the in-depth study on the causes of crop yield difference. Therefore, it is necessary to break through the research and analysis methods in the future. (3) For farmers, they are more concerned about the economic benefits. The contradiction among yield, resource efficiency and economic benefits in crop production will become increasingly prominent. The mechanism and balance point of the collaborative improvement of the three will be the key scientific issues to be discussed in the future (Li Shaokun, 2011). Yield gap (Yg) is the difference between Yp (irrigated crop) or Yw (dry crop) and actual yield (Ya). Water resources supporting dry farming and irrigated agriculture are also under pressure, making water productivity (the efficiency of water to food) another important benchmark for food production and resource use efficiency (Bessembinder et al., 2005; Passioura, 2006; Grassini et al., 2011b). Water productivity refers to the ratio of crop yield to seasonal water supply, including plant available soil water at planting, seasonal rainfall and applied irrigation minus residual plant available water in root zone at maturity (Martin K et al., 2013). Yp and Yw are defined according to crop species, varieties, climate, soil type (Yw) and water supply (Yw), so Yp and Yw are highly variable between regions and within regions. However, a large number of farmers are unlikely to achieve the crop and soil management required to achieve Yp or Yw perfectly, and it is usually not cost-effective, because the yield response to application input follows a decreasing return when farm yields approach the maximum yield (Koning et al., 2008, Lobell et al., 2009). In addition, from the perspective of resource use efficiency (De Wit, 1992), the goal is to narrow the yield gap at a lower yield level threshold (relative to Yp or Yw) when the factors controlling the highest yield have greater uncertainty (such as high temperature, variable rainfall, strong wind promoting lodging), and so on. Since the average farm yield tends to be stable when it reaches 75 – 85% of Yp or Yw, the developable yield gap is less than Yg (Van ittersum and Rabinge, 1997, Cassman, 1999, Cassman et al., 2003). In general, Yp, Yw, Yg and Wp determine the crop production potential of the existing cropping system under the conditions of land and water resources. The schematic diagram of these key parameters is shown in Fig. 4.

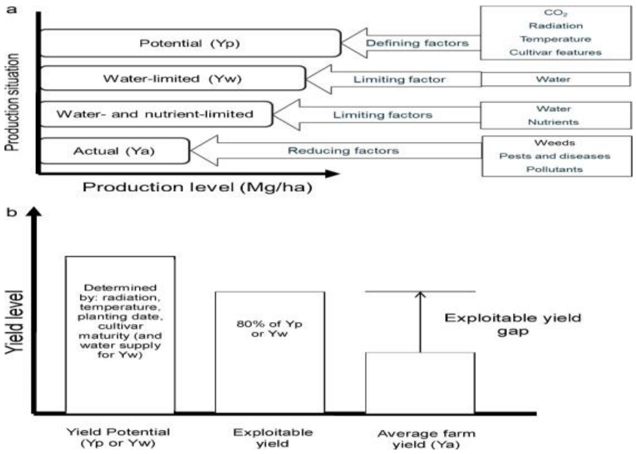

Fig. 5. Different levels of production determined by growth definition, limiting and reducing factors (a). The yield potential (Yp) of crops under non water limited irrigation depends on solar radiation (R), temperature condition (T) and growth period from planting to maturity. For crops grown under dry farming conditions, water limited yield (Yw) represents the highest yield (Van itersum and Rabbinge, 1997). The recoverable production gap (b) represents the difference between the average production and 80% of Yp or Yw, as described in the paper (modified from Lobell et al., 2009; Martin K et al., 2013).

It is estimated according to the geographical units and time frame defined by Yp, Yw, Ya and Yg. By using an appropriate amplification program to calculate its spatial and temporal changes, it is possible to quantify individual farmer farms in a given year or in a larger area and for a longer period of time (Ewert et al., 2011). Climate change may change Yp, Yw, Ya and Yg by directly changing the availability of temperature and water, or farmers' adaptation to planting date and variety maturity, or by indirectly affecting the prevalence and severity of diseases and pests. This manuscript focuses on quantifying the present value of various yield levels for two reasons. First, because the current value provides the basis for determining the cause of the yield limit and the extent of the potential yield increase. Second, accurate estimates of today's Yp and Yw are crucial to measuring the impact of climate change on future yields and food security (Martin K et al., 2013). Most discussions on crop yield gap have two objectives (Van itersum et al., 2013). The first is to measure the size of the yield gap, that is, the difference between the potential yield (Yp) and the average yield, so as to determine the potential range of increasing the average yield through management change. The second is to find out the main causes of the output gap, so as to give priority to efforts in promotion, research and policy to improve land and labor productivity (Martin K et al., 2013). A basic challenge to achieve these two goals is the spatial and temporal heterogeneity of agricultural landscape. For example, when measuring the output gap, the actual output of administrative units across hundreds or thousands of areas is often reported. At the same time, using agronomic experiments or fully tested crop simulation models, it is easiest to estimate the yield potential of a single farmland (Lobell et al., 2009). When calculating the yield gap, how to compare the two measurements on different spatial scales? Some studies ignore the scale mismatch and implicitly assume that the point level estimation of Yp is a good proxy for the reported average Yp in the spatial domain. Other studies try to estimate the Yp of multiple points in the domain, and then take the average value, which is a reasonable method, provided that there is enough quality data to estimate the Yp of multiple points (Martin K et al., 2013). Similarly, in order to understand the causes of the yield gap, we can evaluate the yield response of different management changes in the experimental station or farmers' field. However, the land analyzed may not represent the whole area, or the year studied may not represent the conditions faced by farmers. Agronomists have long recognized the challenge of extending results from several locations and years to a broader range related to regional performance measurement. Over the past two decades, remote sensing has become a useful tool for dealing with heterogeneity, complementing more traditional methods of real test or simulation models. In particular, remote sensing sensors installed on airplanes or satellites may provide observations for each growing season in an area. Although quantitative estimation based on remote sensing, such as crop yield, is often less accurate than field based measurement, in many applications, the unprecedented spatial and temporal coverage of remote sensing often outweighs its negative impact. It is necessary to further explore the potential value of satellite remote sensing in crop yield gap measurement and interpretation. With the increasing research on the yield gap, new methods that can supplement the traditional toolbox of agronomists have great potential value, and remote sensing may be such a tool (Lobell, 2013).

CONCLUSION

Abiotic stress is one of the main factors restricting world food production and food security. Due to the rapid global climate change, the situation has further deteriorated. Drought is undoubtedly the most important pressure affecting crop growth and productivity. Understanding the physiological, biochemical and ecological interventions associated with this stress is important for better management. Plant responses to these stresses can be summarized as morphological, physiological and biochemical responses. It is necessary to further understand the response mechanism of plants to drought stress and explore traditional and modern drought stress methods. Due to physical damage, physiological interference and biochemical changes, unsuitable water supply and abnormal temperature have adverse effects on crop growth and yield. The action of this kind of stress is multifaceted, so its mechanical action is complex. Understanding plant responses to these stresses is of great practical significance for plant repair and management. Significant responses to this important abiotic stress and side-by-side critical discussions of management strategies provide unique insights into this phenomenon. Under the current global climate change scenario, with the continuous increase of greenhouse gas emissions, it is expected that the severity and frequency of drought in the near future will further increase. Some plants escape drought by reducing growth and yield. In the aspect of dehydration tolerance, the metabolic activity of plants was enhanced under low tissue water potential. Osmotic adjustment, antioxidant activity and changes of growth regulators are the main physiological adaptations of plants under drought stress. Under certain conditions, conventional yield is higher (relative to potential yield or water limited yield). According to the definition of potential yield or water limited yield level, the nutrient stress must be low and the effect of pest control is better. Important directions for future work include further development and testing of yield estimation algorithms (especially for dry farming and non cereal crops), and comparison and integration of remote sensing and yield gap studies based on Simulation and experimental methods. Increasing awareness of the yield gap will play a key role in meeting future crop demand at affordable prices and with minimal environmental impact. The use of satellite data can speed up the pace of discovery, so it is an important area of future work. The estimation of exploitable gap between average yield and yield potential has serious limitations. It is necessary to clarify the basic hypotheses, models and parameters of yield gap research and verify them with the measured data. Only in this way can output gap assessment provide the necessary starting point for understanding the scope of increasing human food supply and (RE) designing systems and interventions to achieve sustainable intensification of the global agricultural system.

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