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RESEARCH ARTICLE

Top-grain filling characteristics at an early stage of maize (*Zea mays* L.) with different nitrogen use efficiencies

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Abstract

Maize genotypes vary significantly in their nitrogen use efficiencies (NUEs). Better understanding of early grain filling characteristics of maize is important, especially for maize with different NUEs. The objectives of this research were (i) to investigate the difference in apical kernel development of maize with different NUEs, (ii) to determine the reaction of apical kernel development to N application levels, and (iii) to evaluate the relationship between apical kernel development and grain yield (GY) for different genotypes of maize. Three maize hybrid varieties with different NUEs were cultivated in a field with different levels of N fertilizer arranged during two growing seasons. Kernel fresh weight (KFW), volume (KV) and dry weight (KDW) of apical kernel were evaluated at an early grain filling stage. Ear characteristics, GY and its components were determined at maturity stage. Apical kernel of the high N and high efficiency (HN-HE) type (under low N, the yield is lower, and under higher N, the yield is higher) developed better under high N (N210 and N240, pure N of 210 and 240 kg ha^{-1}) than at low N (N120 and N140, pure N of 120 and 140 kg ha^{-1}). The low N and high efficiency (LN-HE) type (under low N, the yield is higher, while under higher N, the yield is not significantly higher) developed better under low N than at high N. The double high efficiency (D-HE) type (for both low and high N, the yield is higher) performed well under both high and low N. Apical kernel reacted differently to the N supply. Apical kernel developed well at an early grain filling stage and resulted in a higher kernel number (KN), kernel weight (KW) and GY with better ear characteristics at maturity.

Keywords: *Zea mays* L., grain filling, nitrogen use efficiency, kernel development

1. Introduction

Maize (*Zea mays* L.) is one of the most important food, forage and industrial raw materials. It holds a key position for economic development. Nitrogen (N) fertilizer is essential in agronomic practices to obtain high production yields of maize under low N conditions or for efficiently converting N fertilizer into yield under high N conditions. The global demand for N fertilizer is continuously increasing, driven mainly by cereal production. Meanwhile, global maize production consumes almost one-fifth of the total N fertilizer. Problems with nitrogen use efficiency (NUE) have been widely recognized because N overuse is costly to farmers and is also harmful to the environment (Bowman *et al*. 2008; Wang *et al*. 2014). Currently, the average NUE at agricultural fields is approximately 30% because most N fertilizer is lost from plant-soil systems (Jayasundara *et al*. 2007). Low NUE directly translates into environmental hazards.

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Nitrate pollution in both surface and sub-surface water, with the main sources leached of unused N in the form of nitrate from agricultural field, is a major environmental problem due to its harmful biological effects on health (Santamaria 2006; Anjana *et al*. 2007; Zhang *et al*. 2014). It is becoming important and urgent to develop farming systems that eliminate the leaching of nitrate from fields and decrease the concentration and load of nitrate in water. Significant efforts have been made to increase NUE but their adoption was limited for various reasons (Raghuram *et al*. 2006; Li *et al*. 2016). Therefore, breeding hybrids with high NUE is the most economical and effective approach to increase NUE because hybrids have the most significant potential for genetic improvement. In addition, in regions where N fertilizer is overused, maize cultivars with high N uptake efficiency can help accumulate excess N and subsequently reduce N leaching into the environment.

NUE in maize is often defined as grain production per unit of available N in the soil. This concept commonly provides a quantitative measure of the plant effectiveness to take up and convert available N into grain yield (GY) within a cropping system. NUE consists of two main components: N uptake efficiency (the ability of plants to remove N from the soil) and N utilization efficiency (the ability of plants to use N to produce GY). Individual evaluation of these NUE components is useful for advancing the understanding of physiological mechanisms and processes (such as N uptake, assimilation, translocation, and remobilization) of the N cycle within the plant, which consequently affects the final grain NUE. Some authors observed that with a sufficient N supply in the field, variation in NUE was primarily due to differences in N uptake ability (Liu *et al*. 2002; Luan and Yun 2005; Mi *et al*. 2010). Whereas, with deficient N supply, variation in NUE was mainly due to differences in utilization of the accumulated N in plants (Ma and Dwyer 1998).

Maize is generally considered to have a high soil fertility requirement to attain maximal yields, and different genotypes of maize varied widely in their NUEs (Paponov *et al*. 2005a, b; Uribelarrea *et al*. 2009; Li *et al*. 2010; Gondwe *et al*. 2014; Ahmed *et al*. 2015). Most studies that aimed to understand the genetic and physiological basis of NUE in maize primarily focused on vegetative source organs such as leaves and roots (Hirel *et al*. 2005a, b). The increase in root size (root dry weight, root length, and root density) improves the N uptake ability and yield formation in maize (Chen X C *et al*. 2013; Mu *et al*. 2015). Effective root system architecture is important in breeding maize genotypes for high N uptake efficiency, and it can be strongly influenced by N availability in the soil. In low-N soil, maize plants reduce the number of crown roots but increase the total root length. However, in high-N soil, the lateral roots are stimulated to branch and elongate (Chun *et al*. 2005; Liu *et al*. 2010).

The current research on maize NUE mainly concentrated on roots (N absorption), leaves (N reduction and assimilation) and stalks (N accumulation and distribution) (Hammer *et al*. 2009; Liu *et al*. 2009; Uribelarrea *et al*. 2009; Ma *et al*. 2014). Few studies concentrated on reproductive sink organs such as the ear. However, there is a strong evidence that these organs are important for controlling NUE during kernel filling stage (Seebauer *et al*. 2004). It has been clearly demonstrated that N assimilation and N remobilization occur simultaneously in source leaves and contribute almost equally to the supply of organic N to the developing ear (Gallais *et al*. 2006; Hirel *et al*. 2007). Though the relationship between NUE and shoot growth potential in aboveground parts of maize attracted the attention of scholars, little work was done on kernel development, especially the early development of apical kernel, which determines kernel number (KN) in maize with different NUEs (Xu *et al*. 2009; Peng *et al*. 2010).

Maize GY is mainly related to KN at maturity stage and, to a lesser extent, to kernel weight (KW), which is commonly recognized as a component that is not strongly influenced by agronomic and environmental variables (Andrade *et al*. 1999). However, large deviations in crop yield estimation can occur because of the weight variation of individual kernels (Borrás and Gambín 2010). KN is affected by apical kernel abortion, which mainly occurs during early grain filling stage. Improvement of apical kernel development and simultaneous reduction of apical kernel abortion contribute to the number of kernels per ear (Otegui *et al*. 1995; Otegui 1997; Cárcova *et al*. 2000; Cárcova and Otegui 2007). Plant water deficits during flowering and early kernel growth reduce the yield potential of maize by decreasing KN per ear. Developmental failure after fertilization is an important component of this kernel loss (Schussler and Westgate 1991a, b). KW depends on the potential kernel size established early in grain filling and on the plant capacity to provide assimilates needed to fulfill this potential during grain filling stage (Borrás and Westgate 2006). The individual KW accumulation is controlled by the kernel growth rate and by the duration of linear grain-filling (Borrás and Gambín 2010). It has been suggested that the assimilate availability per kernel during the early growth stage determines its potential sink capacity and is closely related to the kernel growth rate during the linear grain-filling period (Andrade *et al*. 1999; Gambín *et al*. 2006; Borrás and Gambín 2010). The duration of linear grain-filling is related to the environmental conditions during the grain-filling stage for a given hybrid. The variation of KW among different floret positions of the maize ear was substantial. The variation was mostly related to the changes in kernel growth rate and to the duration of linear grain-filling under the condition of insufficient assimilates supply (Chen Y J *et al*. 2013). Thus, better understanding of early grain