European Journal of Agronomy 91 (2017) 34–43

Contents lists available at ScienceDirect

European Journal of Agronomy

journal homepage: www.elsevier.com/locate/eja

Plant growth regulator and its interactions with environment and genotype affect maize optimal plant density and yield

Weiqiang Zhang[a], Chunxin Yu[a], Kai Zhang[a], Yuyi Zhou[a], Weiming Tan[a], Lizhen Zhang[b], Zhaohu Li[a], Liusheng Duan[a,*]

[a] State Key Laboratory of Plant Physiology and Biochemistry, Engineering Research Center of Plant Growth Regulator, Ministry of Education, College of Agronomy and Biotechnology, China Agricultural University, No 2 Yuanmingyuan West Road, Haidian District, Beijing 100193, China

[b] College of Resources and Environmental Sciences, China Agricultural University, No 2 Yuanmingyuan West Road, Haidian District, Beijing 100193, China

ARTICLE INFO

Keywords:
DA-6
Ethephon
Lodging percentage
G*E*M interaction
Morphology
Yield components

ABSTRACT

Increasing planting density is important to raise maize yield, however, high density often leads to an increase risk of lodging due to dense canopy and weak stem. Maize yield and optimal plant density are increased by applying plant growth regulator compound of ethephon and DA-6, however, we do not know if this compound would interact with location and genotype. In this study, a novel plant growth regulator, as the synthesis of ***N***, ***N***-diethyl − 2 − hexanoyl oxygen radicals − ethyl amine (2-ethyl chloride) phosphonic acid salt (DHEAP), combining the effects of ethephon and DA-6 in one chemical, was developed and tested at three locations, five plant densities (6.75, 8.25, 9.75, 11.25 and 12.75 plants m^{-2}) and three cultivars in 2014–2015. This study aimed to quantify the interactions between environment, genotype and management (Appling DHEAP and plant density) on lodging-related optimal plant density and yield. DHEAP significantly increased grain yield by 10.7% due to the increases of kernel weight by 3.2% and kernel number per ear by 4.4%. On average across genotypes and environments, applying DHEAP increased optimum plant density by 6%. The optimal plant density interacted with cultivar, DHEAP and environment. Applying DHEAP reduced lodging percentage by lowering ear height. The yield-lodging relationship was affected by genotype and location. We concluded that maize yield could be enhanced by optimizing plant density, applying DHEAP and cultivar selection, but climatic and environmental differences of locations should be considered.

1. Introduction

Crop yield is often interactively determined by genetic characteristics (G), environment (E) and management (M) (e.g. plant density and other cultivation techniques) (Sangoi et al., 2002; Tokatlidis et al., 2011; Shi et al., 2016). High population density results in a risk of lodging and reduces grain yield by 5–25% in maize (Norberg et al., 1988; Ma et al., 2014a; Bian et al., 2016). Globally, the current modern hybrids of cereal crops improve yield potential by allowing farmers to increase planting density (Tokatlidis, 2013; Hernández et al., 2014; Lindsey et al., 2015; Li et al., 2015) as well as applying plant growth regulator (Zhang et al., 2014).

Maize (*Zea mays* L.) is an important cereal crop for the sources of food, feed, and fuel (Leff et al., 2004; Zhang et al., 2014). In China, there are 37 million ha maize growing in three major producing regions in 2014, 31% in Northeast, 23% in North China Plain and 16% in Southwestern (Fig. 1). As a major agronomic goal, optimal plant population density differs with ecological regions (Sangoi et al., 2002; Ren et al., 2016; Tokatlidis, 2013). In current farmers' practice, plant population density of maize is 6.75 plants m^{-2} at Yellow-Huai River Plain and Northeast China. Applying plant growth regulator (PGR) increases optimal plant density from 6.0 to 7.5 plants m^{-2} in Harbin, Northeast China by reducing lodging (Zhang et al., 2014). Limited knowledge exists on if the PGR effects for enhancing optimal plant density would depend on ecological environments and genotypes.

Optimal plant density is corresponding to site-specific environment, e.g. soil fertility and precipitation. Uneven distribution of precipitation in particular in the flowering phases may aggravate water lodging and limiting optimal plant density and yield (Wang et al., 2011; Ren et al., 2016; Yin et al., 2016; Ma and Maystadt, 2017). It is likely the optimal plant density with applying PGR differed with locations, years and cultivars (Zhang et al., 2014; Qin et al., 2016; Shuai et al., 2016).

* Corresponding author.
E-mail addresses: zmaizer@163.com (W. Zhang), duanlsh@cau.edu.cn (L. Duan).

http://dx.doi.org/10.1016/j.eja.2017.09.008
Received 25 April 2017; Received in revised form 16 September 2017; Accepted 18 September 2017

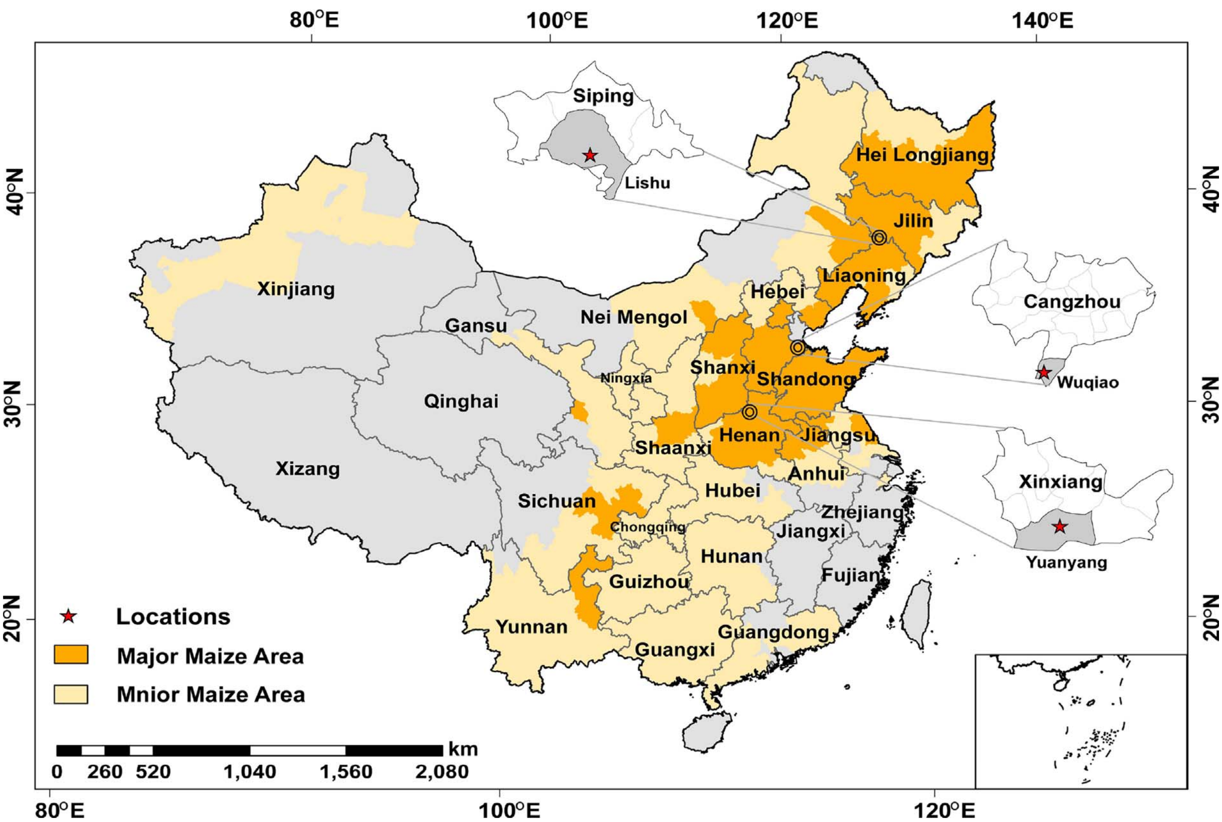

Fig. 1. Map of major maize growing regions and the locations of experimental sites (red stars) in China. Data was from National Statistical Bureau of China in 2008–2014. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

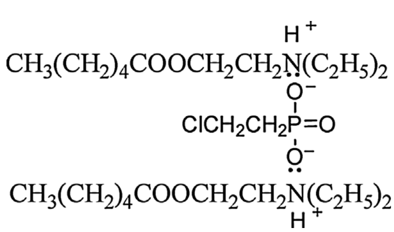

Fig. 2. Molecular structure of the new synthetic plant growth regulator DHEAP, which combines functional group of ethephon and diethyl aminoethyl hexanoate (DA-6).

Lodging is an important adversity affecting maize yield and quality especially under dense populations (Tokatlidis et al., 2011; Zhang et al., 2014; Bian et al., 2016). Maize root lodging occurs by root soil integrity, but stalk lodging usually due to the bending or breaking of the lower internodes (Ye et al., 2015; Xu et al., 2017). New varieties with short plant and low position of ear setting are commonly applied to alleviate maize lodging in high plant density (Ma et al., 2014b; Shi et al., 2016; Xue et al., 2016). Low ear height in modern maize hybrids showed to be better adapted to high density (Sangoi et al., 2002; Duvick 2005). But excessively low ear position easily leads to crop failure to pollination and decrease harvest index (Zsubori et al., 2002; Flint-Garcia et al., 2003; Xue et al., 2017). Ear height and plant height increase linearly with plant density in maize (Li et al., 2015).

Low ear height and short plant can also be obtained by applying plant growth regulators. By applying ethephon and DA-6, the center of gravity height decreases and rind penetration strength and number of vascular bundles in stalk are increased (Xu et al., 2017), thus reduces maize lodging percentage (Zhang et al., 2014; Ye et al., 2015). Plant growth regulators have been successfully applied to optimize plant morphology, reduce lodging and increase yield when optimal short

Table 1
Weather data of experimental locations during maize growing season in 2014 and 2015.

Month	Mean air temperature (°C)					Precipitation (mm)					Sunshine hours (h)					Wind speed (m s^{-1})				
	Yuanyang		Wuqiao		Lishu	Yuanyang		Wuqiao		Lishu	Yuanyang		Wuqiao		Lishu	Yuanyang		Wuqiao		Lishu
	2014	2015	2014	2015	2015	2014	2015	2014	2015	2015	2014	2015	2014	2015	2015	2014	2015	2014	2015	2015
May	25.8	24.2	22.1	20.5	17.2	14.6	16.8	52.8	50.0	37.3	229	206	310	294	236	3.8	6.1	3.4	2.8	5.1
Jun.	26.6	26.2	25.0	25.6	21.6	13.2	67.1	48.0	35.5	53.0	179	163	168	207	160	1.3	4.7	2.3	2.5	4.5
Jul.	28.5	27.0	27.2	27.2	24.5	183	72.8	129	118	16.5	190	179	180	209	165	0.9	1.9	1.2	1.3	2.1
Aug.	25.4	25.5	25.2	25.5	23.0	53.6	109	81.8	176	60.4	171	168	197	227	184	0.2	0.3	1.3	1.5	1.8
Sep.	21.1	21.3	20.7	20.9	17.8	280	51.6	48.5	40.8	35.0	135	117	124	208	193	0.1	0.2	1.0	1.2	1.6
Total[a]	25.4	25.0	24.5	24.8	20.8	530	301	307	370	202	676	627	668	851	937	0.6	1.8	1.5	1.6	3.0

[a] Precipitation and sunshine are monthly sums, while air temperatures and wind speed are monthly mean in maize growing season.