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# Enhancing grain yield, biomass and nitrogen use efficiency of maize by varying sowing dates and nitrogen rate under rainfed and irrigated conditions

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ABSTRACT

The prime objective of the study was to investigate the effect of sowing date and nitrogen application rates on maize dry matter, grain yield and nitrogen use efficiency under rainfed and irrigated condition. The field experiment was a randomized split plot design with three replicates. Sowing date was taken as the main plot and nitrogen rate was considered as the subplot under both irrigated and rainfed conditions. Two planting dates were considered, namely; timely and late sowing scenarios. The nitrogen rates considered were 0 ($N_0$), 75 ($N_{75}$), 100 ($N_{100}$) and 125 ($N_{125}$) kg ha$^{-1}$ and 0 ($N_0$), 60 ($N_{60}$), 80 ($N_{80}$) and 100 ($N_{100}$) kg ha$^{-1}$ of urea for irrigated and rainfed maize, respectively. Grain yield and other yield parameters (kernel number, and cob number), plant dry matter weight, agronomic efficiency (AEN), partial factor productivity of nitrogen (PFPN), and nitrogen use efficiency (NUE) were measured. The results revealed that sowing on recommended date with higher nitrogen rate significantly increase grain yield and yield components. The sowing dates clearly exhibited 16.14%, and 15.99% loss of average grain yield of rainfed maize for the years 2012 and 2014, respectively. 9.79%, and 11.98% average grain yield loss from the irrigated maize during the years 2013 and 2014, was observed under late sowing condition compared to timely sowing time, respectively. On an average, grain yield for $N_{100}$, $N_{80}$, and $N_{60}$ were 292%, 249%, and 149% higher than that of $N_0$, under the rainfed maize, respectively. Grain yield for $N_{125}$, $N_{100}$, and $N_{75}$ were 340%, 271% and 204% were higher than that of $N_0$ under irrigated maize. The increase in nitrogen rate from $N_0$ to $N_{100}$ under rainfed and $N_0$–$N_{125}$ under irrigated maize suggested a decrease in NUE, AEN and PFPN values, respectively. Additionally, the lower AEN and NUE values showed that a further reduction in N application rate was possible. The study also revealed that a combination of sowing dates with appropriate nitrogen rates could increase grain yield and NUE.

## 1. Introduction

Maize (*Zea mays* L.) is one of most important food grain throughout the world, accounting for 9% of total food grain production in the country and is the third most important cereal crop in India after rice and wheat (Panda et al., 2004). The total production of maize yield has increased globally, to 311.8% in the year 2010 from 168.5% during the year 1961 (Qian et al., 2016). The increase in yield could be ascribed to variety improvement and agronomic managements, such as, increase in plant density, fertilizer application rate and planting time (Qian et al., 2016).

Nitrogen (N) fertilizer plays a vital role in optimizing the trade-off between grain yield and profit (Jin et al., 2012). Hence, effective management of nitrogen fertilization is a leading challenge for enhancing maize productivity, and environmental sustainability (Ma et al., 2006). Nitrogen is a major nutrient for crop production as it directly affects the dry matter production by influencing the leaf area and photosynthetic efficiency; hence an optimum rate of application of nitrogen is necessary to prevent retardation of plant growth and yield (Tafteh and Sepaskhah, 2012). N deficiency inhibits growth of a plant and also decreases the shoot to root ratio (Steer and Harrigan, 1986). Besides this, N deficiency also reduces the radiation use efficiency, radiation interception, dry matter partitioning, and growth of reproductive organs (Marschner, 2012). Moreover, N deficiency delays both reproductive and vegetative phenological development, reduces leaf emergence rate, grain yield, and yield components (Shahrokhnia

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and Sepaskhah, 2016). On the other hand, higher rate of nitrogen combined with low nitrogen use efficiency will have adverse effect on the environment such as, soil acidification, environmental pollution and decreased soil microbial activity (Chen et al., 2014; Zhu et al., 2016). Hence, the reduction of *N* fertilizer inputs and improved *N* use efficiency are essential for the sustainable production of maize. Thus, a balance between crop nitrogen and yield efficiency needs to be taken care of. Zhu et al. (2016) stated that increasing *N* fertilizer application has been a major management strategy to obtain high grain and biomass yields. Therefore, for sustainability of agroecosystem, both the crop yield, and nitrogen use efficiency need to be balanced (Jin et al., 2012).

Planting date is an important management practice used to adjust the timing and occurrence of crop phenological phases according to environmental conditions for crop development (Maton et al., 2007; Bonelli et al., 2016). Cirilo and Andrade (1994) and Bonelli et al. (2016) reported that changes in planting date can alter crop growth rate and the length of crop phenological phases which effects potential grain yield and its components. These alterations are particularly significant in cool-temperate short season environments, where solar radiation and temperature change considerably in the beginning and at the end of the maize cropping season (Wilson et al., 1995). Caviglia et al. (2014) reported that when maize was sown in early spring (September-mid to October), in comparison to the late sowing where the damage by stem borer was observed. Sorensen et al. (2000) stated that any delay in sowing time reduced the synchronization of peak solar radiation and maximum green leaf area index for maize hybrid varieties. Reductions in yield due to early or late planting are well documented in the literature (Johnson and Mulvaney, 1980; Sorensen et al., 2000; Tsimba et al., 2013a; Tsimba et al., 2013b; Caviglia et al., 2014; Bonelli et al., 2016; Zhou et al., 2017). Otegui et al. (1996) stated that early planting results in reduced intercepted photosynthesis rate (IPAR) due to delayed leaf area development, while higher temperatures under late planting situations reduce the IPAR which affects the crop development, thereby the yield is decreased (Tsimba et al., 2013b). In temperate and cool-temperate environments, late maize sowing causes a delay in crop flowering and increase in length of grain filling period to the end of the crop stage. Thus, as sowing date is delayed in these environments, both the critical period for grain set and the grain filling period are subjected to a progressive deterioration of photo-thermal conditions for the crop growth. In accordance, delay in maize sowing date can reduce the number of grains (Tsimba et al., 2013a; Bonelli et al., 2016).

The present study was conducted to illustrate the variation in maize yield, plant biomass, kernel number and *N* use efficiency under different planting dates and two irrigation conditions (irrigated and rainfed) with different rates of nitrogen. The objective of the study was to estimate the effects of sowing dates and *N* fertilizer rate on aboveground biomass, grain yield, grain *N* content, *N* use efficiency, and total *N* uptake under irrigated and rainfed conditions. The abbreviations used in the paper are shown in Appendix A.

## 2. Material and methods

### 2.1. Experimental location

The field experiments were conducted at the experimental farm of Agricultural and Food Engineering Department, Indian Institute of Technology, Kharagpur, India (22.33° N latitude, 87.33° E longitude and altitude 48 m). The soil of this region is classified as the lateritic type having medium sandy loam texture (Satapathy et al., 2014; Halder et al., 2016). Table 1 shows soil parameters at different layers of soil (Satapathy et al., 2014).

### 2.2. Meteorological conditions

The climate of the location (Kharagpur) is classified as sub-humid with an average temperature ranging from 21 to 32 °C. The area receives an average rainfall of 1200–1500 mm annually. The weather data was measured using an automated weather station located at the experimental farm of the Institute. The daily and hourly monitored weather variables were temperature, rainfall, wind speed, relative humidity, sunshine hour and saturation vapor pressure. Other micrometeorological parameters such as solar radiation, psychometric constant, latent heat of vaporization etc. were computed using the measured weather data while the solar radiation was estimated using the recorded sunshine hour (Allen et al., 1998). Fig. 1(a–c) shows the daily value of temperature (maximum and minimum) (°C), solar radiation ($MJ\ m^{-2}d^{-1}$), rainfall (mm) for the year 2012, 2013 and 2014 respectively. Maximum temperature ranged between 40 and 45 °C and minimum temperature 7–10 °C for the year 2012, 2013, and 2014 respectively (Fig. 1). The experimental farm had maximum rainfall during the end of June to mid of September (Fig. 1).

### 2.3. Crop experimental details

Four field experiments on maize crop were conducted for two sowing dates (timely and delayed) and four nitrogen fertilization rates were maintained under two irrigation conditions (rainfed and irrigated) in an area of 1470 $m^2$. The field experiment was a randomized split plot design with three replicates, and the crop was sown at a depth of 5 cm with 30 cm × 20 cm spacing.

#### 2.3.1. Rainfed crop experiment

Two field experiments were conducted under the rainfed condition of maize (year 2012 and 2014) sown on 10 June (*P1*) and 25 June (*P2*) and subsequently, harvested after 90 days (8th and 23rd September) (Roy et al., 2006). Maize of hybrid variety *Bio-22027* was selected for the experiment. Nitrogen treatment were done at 0 ($N_0$), 60 (*N60*), 80 ($N_{80}$), and 100 ($N_{100}$) kg $ha^{-1}$ respectively (Lenka and Jena, 2001; Roy et al., 2006). The experiment was designed following the split-plot technique and the crop was sown at a depth of 5 cm with 30 cm × 20 cm spacing. Nitrogen was applied in three splits: 50% at sowing time, 25% after 25 days of sowing, and 25% after 50 days of sowing respectively.

#### 2.3.2. Irrigated crop experiment

Two field experiments on maize crop were conducted under irrigated conditions in the year 2013 and 2014, respectively. The maize seed was sown on 5th and 25th of January 2013 and 2014 (medium duration) respectively, and subsequently, harvested after 90 days (5th and 26th April) (Directorate of maize research, 2012). Maize hybrid (*Tx367)* (medium duration) was selected for the experiment. Nitrogen treatment was maintained as 0 ($N_0$), 75 ($N_{75}$), 100 ($N_{100}$), and 125 ($N_{125}$) kg $ha^{-1}$, respectively (Lenka and Jena, 2001). Furrow irrigation was used for the entire experiment.

*2.3.2.1. Irrigation scheduling.* Irrigation scheduling was done based on the available soil moisture content. Daily soil water content was measured with a Time domain reflectometry (TDR TRIME, IMKO Gmbh, Germany) (Imko GmbH, 2000) by setting the instrument in a manual mode (Noborio, 2001). The access tubes were installed vertically upto a depth of 1 m (10 cm above the soil surface and 90 cm into the soil) in the middle of each plot and the probe was inserted into access tubes at different depths (20, 40, 60, and 90 cm) for measuring the soil water content, respectively. Irrigation amount was measured using a water meter (Srivastava et al., 2016). All the plots were irrigated with a measured amount of water upto the root zone depth. Fig. 2(a–d) represents the irrigation amount date wise for the maize crop for the year 2013 and 2014 respectively.