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Yield of and nutrient-water use by maize exposed to moisture stress and K fertilizers in an *inceptisol* of West Bengal, India

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ABSTRACT

Potassium (K) is important for both qualitative and quantitative traits of maize. However, role of this macronutrient is often being ignored, and is often applied as an optional nutrient, with no proper fertilizer recommendation. Present experiment focused on the role of K fertilization in determining soil K fractions, maize yield, K and water use by maize under different irrigation regimes. Result revealed that K-fertilization significantly improved available soil K, fractions of K (especially non-exchangeable, mineral and total fractions), maize yield, K uptake and water use efficiency. Imposition of moisture stress up to 50% available soil moisture deficit (ASMD) significantly increased all the aforementioned parameters over the no stress situation, while irrigation available at 75% ASMD reduced them significantly. Soil K fractions, under different K fertilizations and irrigation schedules, decreased with the increase in soil depth upto 90 cm. Only exception was non-exchangeable soil K which remained stable across soil depths. The relationship among different K fractions and available soil K was estimated. Available K was observed to have strongest correlation with water soluble and exchangeable K in all possible irrigation regimes. Path analysis studies revealed that water soluble K exerted highest direct effect on changes in maize grain yield and K uptake followed by exchangeable, non-exchangeable and mineral K under irrigation availability at 25 and 50% ASMD. However, exchangeable K exerted highest direct effect on maize grain yield at 75% ASMD.

1. Introduction

India has made significant progress in maize (*Zea mays* L.) cultivation during past 60 years. The increase in maize area, production and productivity in the country from 1954 to 2014 is about 5.2 million ha, 21.2 million tonnes and 1.9 t ha^{-1} (Agricultural Statistics at a Glance, 2014). Hybrid maize requires high input, especially nutrients. Nitrogen (N), phosphorus (P) and potassium (K) remain the major ones for increased and sustained productivity. Potassium has often been given less importance because of the myth that it is already present in soil in large amount (Qiu et al., 2014). The reality is something different that the intensive rice-based cropping system made serious depletion of soil K in the entire Indo Gangetic plains (IGPs) of south Asia despite originally high K contents (Singh et al., 2004). The reason may be harvesting of straw along with grain of rice, maize etc. in these systems (Timsina and Connor, 2001).

Potassium is a primary osmotic in maintaining low water potential of plant tissues (Assmann and Shimazaki, 1999; Bahrani et al., 2012), regulated stomatal closure and increased water use efficiency (Wiebold and Scharf, 2006), conferred resistance to biotic and abiotic stresses. The element has been reported to improve the yield attributes; grains yield (Nesmith and Ritchie, 1992) and crop quality (Pettigrew, 2008) of maize.

Irrigation is also an important input governing the growth, yield and nutrient uptake of maize. The grain yield and yield components of maize was markedly affected by irrigation (Rivera-Hernandez et al., 2010; Moser et al., 2006). Any shortage of water during critical crop growth stage from tasseling to grain filling can drastically reduce grain yield (Eck, 1986). Several yield attributing traits were observed to be genuinely affected by moisture stresses imposed at various growth

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stages (Moser et al., 2006; Ansari et al., 2006).

Forms of potassium in soil may also indicate or calibrate the appropriate fertilizer K rate (Qiu et al., 2014) and irrigation schedule (Zhang et al., 2011). Sparks et al. (1980) measured increases in water soluble K; Havlin et al. (1984) and Wood and DeTurk (1941) reported increase in exchangeable K and non-exchangeable K, respectively after K addition to soil. Some factors, such as – clay content, cation-exchange processes, Ca, Mg, and NO_3 content in soil and leachates, etc. are involved in determining the potassium content in soils and in soil water after K-fertilization. Potassium ions are easily adsorbed by clay minerals. As the stream channel sediments have considerable amount of clay minerals, concentration of K^+ ions in stream water is reduced until some flood events that can cause erosion of clay minerals (Siwek et al., 2017). Dobermann et al. (1996) concluded that interaction of K^+ with other cations like Ca^{2+}, Mg^{2+} etc. is also important. Excessive (Ca + Mg)/K ratio may contribute to K deficiency due to the stronger K adsorption to cation exchange sites reducing the K activity in the soil. Such preferential adsorption of K^+ over Ca^{2+} or Mg^{2+} by the clay fraction has also been observed by Parfitt (1992). Leaching of mobile anion like NO_3 is correlated with leaching of cations like K, Ca and Mg. As Ca and Mg are present in the soil solution in greater amounts than K, the former two are usually the major cations leached (Kayser and Isselstein, 2005). Several reports are there to comprehend the K fertilization effects on soil K pools, *albeit* effect of irrigation either alone or in combination with K fertilization is still like a black-box.

The major constraints lying with maize cultivation and good production are climatic conditions resulting in drought/excess water associated with increased pressure of diseases/pests and cultivation mainly under rainfed conditions on marginal lands with inadequate irrigation. Thus, the emerging issues are how the water and potassium alliance helps increasing the maize productivity; and also how soil potassium dynamics, as influenced by potassium fertilizer and simulated moisture situations, make maize plants coping up moisture stress. The present study has been conceived to look into the changes of soil K fractions (available, water soluble, exchangeable, non-exchangeable, mineral and total) with K fertilization and simulated irrigation situations and effect thereof on yield and efficiencies of maize to use nutrient and water.

2. Materials and methods

2.1. Study area

Field experiments were conducted during two consecutive winter seasons of 2013–14 and 2014–15 at Gayeshpur, Nadia, West Bengal, India situated at 23°26.010′N latitude and 88°22.221′E longitude and 12.0 m above the mean sea level.

The climate of the region is humid-tropic, with hot summer and moderately cool winter. Average weekly maximum and minimum temperature fluctuated between 21.2–39.8 and 6.9–25.2 °C during year 1, while 23.1–41.3 and 9.2–26.6 °C during year 2. In general, there was a gradual drop in temperature from November to January, which favoured the growth and development of maize hybrids. Avearge weekly maximum and minimum relative humidity prevailed between 83 and 98 and 25–68% during year 1, while 80–95 and 35–62% during year 2. The average weekly rainfall during the experimental period (November to March) was recorded 91.4 and 54.7 mm during year 1 and year 2, respectively. Fig. 1a and b depicts the meteorological parameters *viz.* weekly temperature ($T_{\max}$ and $T_{\min}$), rainfall, relative humidity ($RH_{\max}$ and RH_{min}) and bright sunshine hours of the experimental period during both the years. The soil of the experimental field is characteristically an *aeric haplaquept*, sandy clay loam in texture with good drainage and water holding capacity. The pre-experimental physico-chemical properties and fertility status of the experimental soil are appended in Table 1.

2.2. Experimental details

The experiment was laid out in a strip-plot design. It is a two factor design in which greater precision is allowed in measuring the interaction effect sacrificing the degree of precision on main effects. It is accomplished by dividing the experimental area into three plots, namely the vertical strip, horizontal strip and intersection. The vertical and horizontal strips are perpendicular to each other, without having any relationship between their sizes. However, the intersection plot is the smallest. In this experiment, the design had three irrigation schedules (irrigation at 25, 50 and 75% available soil moisture deficit or ASMD) in the vertical strip and four levels of potassium fertilization (0, 50, 100 and 150 kg K ha^{-1}) in the horizontal strip, replicated thrice. The plots were 4 m long and 3 m wide with 0.45 m bunds leaving 1.5 m irrigation channel between two strips. Field capacity and permanent wilting point were first measured with pressure plate apparatus (Model 1600, SOIL MOISTURE EQUIPMENT CROP, Santa Barbara, Ca, USA). The profile soil water content from soil surface (0 cm) to 30 cm depth was measured gravimetrically (oven dry basis). The change in profile soil water storage (S, cm) was determined from the successive soil water sampling measurements. During irrigation scheduling, volumetric water content was measured with THETAPROBE soil moisture sensor in Frequency Domain technique. When THETAPROBE reads 30%, 50% and 70% depletion of the volumetric water content in 30 cm soil depth, irrigation was provided.

Land was ploughed four times with the help of tractor + cultivator, and two times with tractor + rotavator. Then the clods, stones and weeds were removed from the experimental field. Planking was done to break clods and level the field after final tilling. The field was properly levelled and required number of plots and irrigation channels were prepared by manual labour as per the layout plan for the experiment.

Before we start the experiment, there was no specific recommended dose of fertilizer (RDF) for hybrid maize for that location. The recommendation from Indian Institute of Maize Research (IIMR) was consulted (IIMR, 2017) while fixing the RDF for N and P (200 kg N and 60 kg P_2O_5 ha^{-1}) for that location. The entire amount of phosphorus (through single super phosphate), potassic fertilizer (through muriate of potash, as per treatments) and 40% of RDF of total nitrogenous fertilizer (through urea) were applied at final land preparation. The rest amount of the nitrogenous fertilizer was applied in two equal splits at 40 days after sowing or DAS (knee-high stage) and at 85 DAS (pretasseling stage), respectively. Seeds of maize hybrid cv. P 3522 were sown at 25 kg ha^{-1} during last week of November in both the years of experimentation. Seeds were dibbled at 3–5 cm depth, with 2 seeds at each position. Spacing of 60 cm × 30 cm (density of about 55,555 plants/ha) was maintained by thinning and gap filling. The weed control was accomplished by hand weeding (twice at 40 and 60 DAS) to control the most dominant weed species identified as *Chenopodium album*. Besides hand weeding, pre-emergence treatment with the metribuzin (sencor 480 soluble concentrate or SC) at 1 kg a.i. ha^{-1} in 600 L of waters was done. Crops in both the years were absolutely free from insect or disease attack.

Crops were harvested during third week of April during both years. Harvesting was done when husks turned yellow, silks got a brownish discoloration, and grains became hard. Then husks were removed from the cobs and dried in sun for 7–8 days. After proper sun-drying, grains were removed from the cobs with local made hand-sheller.

Plants from the demarked net plot area were harvested and tied in bundles after removing all the matured cobs from them. Grains, after deshelling, dried properly to reduce the moisture content at 14.0%. Weight of grains was recorded as kg/plot and then converted into t ha^{-1}. Water use efficiency (WUE) in kg ha^{-1} mm^{-1} was calculated by dividing plant dry matter yield (kg ha^{-1}) to actual evapotranspiration (mm) (Scott, 2000).