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Balanced nutrition increases yield of pearl millet under drought

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ABSTRACT

Improving the climate resilience of crops is particularly important in the semi-arid tropics (SAT) where variability and uncertainty of precipitation is expected to increase under climate change with detrimental impacts on the vulnerability of livelihoods of small farm holders. This study analyses a long-term strategic experiment datasets from fifteen experiments (1981–1995) managed under different fertility levels at International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru and on-farm balanced nutrition management trials (2010–2012) in Karnataka, India to evaluate the pearl millet performance in contrasting seasons with improved agronomic management. Long-term climate variability and yield trends were analyzed using ICRISAT's weather datasets. On-farm data analysis revealed that majority of farmers' field soils were deficient in organic carbon, available phosphorous, sulphur, zinc and boron at all the locations studied. Pearl millet grain yield and above ground dry matter was improved significantly with balanced nutrient application (NPK + S + Zn + B) in farmers' field which were critically deficient in the soil nutrients. Even in comparatively drier years, application of balanced nutrient significantly increased grain yield and aboveground dry matter which provides resilience against drought through enhanced water productivity. Long-term experiments conducted in ICRISAT showed that nitrogen application increased grain yield and above ground dry matter in pearl millet however seasonal variability had a greater effect on yield than cultivars and applied N. Pearl millet yield was positively associated with August maximum temperature and negatively with seasonal precipitation. September precipitation >125 mm which coincided with grain filling stage reduced grain yield. Benefit:cost analysis showed that balanced nutrient application of pearl millet is an economically sustainable option across the seasons. Pearl millet can be an important component of climate resilient agriculture in low production environments when managed with improved agronomic practices.

1. Introduction

Pearl millet (*Pennisetum glaucum* L.) is most widely grown type of millet and an important food and forage crop in Africa and Asia. Pearl millet has an ability to offset the effects of severe water and nutrient stress firstly by being able to withstand high temperatures (Ong, 1983) and by having sensitive and adaptive tillering capability (Ong and Monteith, 1985; Singh et al., 1998). The tillering ability can effectively restart growth after long periods of drought by producing new tillers which can at least mature to harvestable grain. Therefore, pearl millet is traditionally a component of the dryland systems grown on marginal soils which receive 150–750 mm of precipitation per year. Its importance is expected to increase under climate change scenarios for developing resilient cropping systems because of its suitability to the extreme limits of hot and dry climate.

Pearl millet has genetic variability for various morphological traits, yield components, adaptation and quality traits from the local landraces to hybrids that offer a wide range in plant-type from low- to high-tillering habit to early- and medium-duration cultivars (Bidinger et al., 1994). It is believed that hybrids require more N fertilizer compared to local landraces because their yields are generally higher (Joshi and Kalla, 1986). However, the response of different varieties to N fertilizer is variable over the years as grain yields may increase or decrease (O'Leary et al., 2008). And also crop responses to N depend on many factors, but particularly on yield potential and availability of residual soil N, water and other nutrients (S, Zn, B). Therefore response of pearl millet for grain varies widely among N studies with optimum rates from 0 to greater than 150 kg ha^{-1} N (Gascho et al., 1995). It is claimed that the high-yielding varieties and hybrids use nitrogen more efficiently (Wani et al., 1990). Based on the response to nitrogen application, it is estimated that for every 1 kg N applied, the hybrids

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or improved varieties return 10–15 kg of grain at 30–60 kg ha^{-1} N (Maman et al., 1999). However, 40 kg ha^{-1} N was found to be profitable for most of the pearl millet growing regions, but higher nitrogen levels (60–80 kg ha^{-1}) are recommended in areas with assured precipitation such as Gujarat and Uttar Pradesh. Much less is known, however concerning the effects on nitrogen use efficiency (NUE) and its components in pearl millet. Genotypic differences in N uptake and utilization have been found in many cereals e.g. wheat (Cox et al., 1985; Gooding et al., 2012a), corn (Chevalier and Schrader, 1977), and sorghum (Maranville et al., 1980). There is clear requirement to understand and harness genetic effects to improve NUE in pearl millet especially in SAT areas where farmers are resource poor and fertilizer availability is a concern. Genotypic diversity for grain yield and nitrogen use efficiency in pearl millet have been reported by Wani et al. (1990). However, contribution of uptake and utilization efficiency to overall nitrogen use efficiency have not been reported earlier.

A large yield gap exist between farmers practice and attainable yield of crops in SAT because of inappropriate crop, soil and water management at farm level, combined with persistent land degradation. Crop yields in SAT are sub-optimal and 5 folds lower than researchers field (Wani et al., 2009) because high spatial and temporal precipitation variability is coupled with poor nutrient status in the soils (Wani et al., 2009, 2011, 2012; Saharawat and Wani, 2013). Pearl millet is grown in such soils, generally without the application of fertilizer N and micronutrients. However little attention has been paid to importance of soil test based balanced nutrition (NPK + S + Zn + B) of pearl millet in SAT. Plant nutrients have interdependent metabolism within the plant system; uptake of nutrients is affected even if one nutrient is limiting. Nitrogen assimilation is affected with sulphur deficiency (Zhao et al., 1999) and S application is necessary to achieve maximum efficiency of applied N fertilizers (Fazli et al., 2008). Proper N fertilization and Zn application also has positive effect on grain Zn concentration (Gooding et al., 2012b; Cakmak et al., 2010) whereas excessive phosphorous interferes with Zn uptake and induces Zn deficiency (Mousavi, 2011). Phosphorous application can improve water use efficiency of crops under limited moisture conditions (Pyne et al., 1992). It is now well documented that wide range of SAT soils are deficient in micronutrients (Sahrawat et al., 2013) therefore it is important to promote soil test based nutrient management for judicious use of resources and to enhance fertilizer use efficiency.

As the frequency of extreme climatic events has increased (IPCC, 2007), it is important to evaluate the crops for their resilience against fragile environments as well as sustaining yields and soil fertility with better water and nutrient management. Long-term experiments in ICRISAT reveal that with appropriate land, water and nutrient management crop productivity increase as well soil quality improves along with increased Carbon sequestration of 330 kg C ha^{-1} $year^{-1}$ (Wani et al., 2009). Here, the purpose of balanced nutrient management in farmers' field is to harness the attainable yield potential of crops, reduce the injudicious use of fertilizers leading to environmental and soil degradation and improving livelihoods. Therefore, the objectives of this study were to compare the performance of pearl millet with balanced nutrition management against current farmers practice in contrasting seasons. Secondly, a meta-analysis of fifteen years unpublished data (ICRISAT) for four pearl millet cultivars to determine the response of genotypes to N fertilizer rates and quantify the effect of seasonal variations on pearl millet yield. The overall aim of this paper is to evaluate the effect of balanced nutrient management to bridge the existing yield gaps through enhanced productivity on farmers' fields and explore the possibility of genotypic variability for nitrogen use efficiency in pearl millet.

2. Materials and methods

2.1. On-station trial

2.1.1. Crop husbandry and experimental design

Fifteen field experiments conducted between 1981 and 1995 compared the performance of four genotypes of Pearl millet under different fertility regimes. All experiments were conducted on the same site at the ICRISAT centre, Patancheru (near Hyderabad), India (17.5N, 78.5E, 545 m altitude) on an Alfisol which are characterized by N and P deficiency, coupled with low organic matter. Before initiating the experiment soil (0–500 mm) was tested for soil textural, chemical and water retention properties (Table 1). The experiment was a split plot design with four replications; genotypes as main plot and N fertilizer levels as sub plots. Fertilizer treatments included: no N application, 20 kg N ha^{-1} as urea + 9 kg P_2O_5 ha^{-1} as single super phosphate, 40 kg N ha^{-1} + 18 kg P_2O_5 ha^{-1} were broadcasted as basal dressings. Untreated seeds were drilled on a single day within each year between end of June to first fortnight of July at a depth of 50 mm, with a row spacing of 0.75 m and plant spacing of 0.1 m. Weeding and intercultural operations were undertaken as and when required. Crop was harvested in the last week of September. Weather data was recorded at automated meteorological station at the site.

2.1.2. Plant material

GAM 73 is dwarf elite line from Senegal and a source of major d2 dwarfing gene (Rai and Rao, 1991). The d2 dwarfing gene has been extensively used to reduce plant height in high yielding pearl millet hybrids in the United States, India and Africa. Ex-Bornu is an important landrace population from the Bornu region of northeast Nigeria, which is extensively used as parental material in breeding programmes in India. Ex-Bornu is tall and matures in 90–95 days. 700256 was a tall African landrace and matures in 90–95 days. BJ 104 is most popular and widely cultivated pearl millet hybrid in India. BJ 104 is medium tall with good basal tillering, red nodal joints, medium long cylindrical ear heads and matures in 75–82 days.

2.1.3. Agronomic assessments

At harvest above ground plant samples were harvested. The panicles were separated and threshed. Fresh stover yield was recorded and a sub sample was collected and milled. The sub sample biomass and grain was dried at 70 °C for 72 h. Nitrogen concentration was determined for the vegetative tissues and grain samples using Technicon Auto analyser. The destructive samples allowed the interpretation of effects on grain N uptake in terms of above-ground crop N uptake and partitioning of N to developing grain from vegetative tissues (NHI).

2.1.4. Nitrogen use efficiency calculations

Nitrogen use efficiency (NUE) is defined as the ability of a crop to produce grain from available N (Moll et al., 1982; Kindred and Gooding, 2004). NUE can be derived by two components: first is the ability of the crop to take up nitrogen from the soil (nitrogen uptake efficiency; NUpE) and the second is the ability of the crop to produce grain from the nitrogen in the canopy, i.e. nitrogen utilization efficiency to produce grain (NUtEg). Nitrogen uptake efficiency can be expressed as the total amount of nitrogen in the above ground crop at maturity divided by the available soil mineral N (NO_3^{2-} + NH_4^{+}) plus nitrogen applied as fertilizer. N utilization efficiency can be expressed as grain yield divided by total aboveground N uptake (Gooding et al., 2012a). The destructive plant samples allowed the calculation of NUpE of the above-ground crop; the N utilization efficiency to produce grain (NUtE).