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Water and Fertilizer Use Management for Improving Smallholder Farmers' Tomato Production in the Dry Savanna Agro Ecology of West Africa

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We evaluated tomato yield and fertilizer nitrogen (N) use efficiency under two watering systems and two N forms. Six treatments were used: hand watering (HW) with no fertilization (T1), dripping bucket irrigation (DBI) with no fertilization (T2), DBI with 200 kg of N15P15K15 + 100 kg of ordinary urea (OU) ha^{-1} (T3), HW with 200 kg of N15P15K15 + 100 kg of OU (T4), DBI with 200 kg of N15P15K15 + 100 kg of urea in the form of super granule (USG) (T5) and HW with 200 kg of N15P15K15 + 100 kg of USG (T6). Yield was responsive to fertilization, watering system and N form. OU increased yield by 72.40% under DBI (30.20 t ha^{-1}) versus yield for HW. USG allowed yield increase of 172% for the DBI (33.28 t ha^{-1}) in comparison with yield under HW. Yield under HW was 30% lower with USG (12.25 t ha^{-1}) than with OU. Under DBI, yield was 10% superior when USG was used (33.28 t ha^{-1}) over the yield with OU. The DBI system provided a better use of N than HW, with much greater N agronomic efficiency index with USG.

Introduction

Improving smallholder farmers' livelihoods demands that water resources available to them and small amounts of other inputs particularly fertilizer they can afford to buy be efficiently used. Vegetable cropping plays a key role in sub-Saharan Africa (SSA) because it represents an asset to backing-up farmers' incomes from other crops (de la Peña and Hughes 2007) and to enhancing food security and children education (IFDC 2014). Vegetables are the best resource for overcoming micronutrient deficiencies and provide smallholder farmers with much higher income and more jobs per hectare than staple crops (AVRDC, 2006). In resource-poor rural communities especially in SSA, vegetable production is undertaken by farmers through water source constraints (Abramson *et al.*, 2011) and traditional practices based on hand watering. Such practices have the drawback of increasing working time due to frequent soil crusting, important amount inputs use because they are regularly washed away by the watering system, stressing the plant and damaging flowers/fruits. This results in low yields with minimal benefit (FAO, 2006). Alternative practices are therefore needed to reverse the downward trend in vegetable production in the region for the sake of food security and poverty alleviation.

The maintenance of nutrients and water at optimum levels within the rhizosphere of plants is a primary factor for achieving higher yields, and increased fertilizer and water use efficiencies. However, the world now faces very serious global warming problem and therefore, concern of newer and more efficient irrigation methods is in demand. At the same time, adequate fertilization both in time and through application methods to maintain optimum nutrient supply for optimum growth and development of the crop are also equally important towards the higher productivity. Low-cost drip irrigation (LCDI) has emerged as a means to address these challenges through increased water use efficiency, labour savings, and higher economic returns (Ngigi *et al.,* 2005; Polak *et al.,* 2003). A recent study (Woltering *et al.*, 2011) quantified the time savings and economic gains associated with drip irrigation for smallholders. Fertilizers should be applied in a form that becomes available in synchrony with crop demand for maximum utilization of nutrients from fertilizers to enhance productivity (Boyhan *et al.,* 2001). Recent research efforts in West Africa (Detchinli and Sogbedji 2015; IFDC 2013) demonstrated that deep placement of fertilizer N in the form of urea super granule (USG) proved superiority over the ordinary urea form of N in terms of crop yield and associated economic profitability and nutrient use efficiency for maize cropping. Although LCDI has emerged as an alternative to more costly conventional drip systems, studies comparing the performance of LCDI with either conventional drip irrigation systems or the most popular careful hand watering used in the region are scarce. Furthermore, no research efforts have been performed using the USG-based fertilizer deep placement technology in vegetable cropping in the region.

The objective of this study was to quantitatively assess the effect of watering and fertilization practices on tomato yield and N use efficiency under tomato cropping. The aim was to identify approaches that improve smallholder farmers' vegetable based production.

Materials and Methods

Study area

The study was conducted in the Sudan Savanna agro ecological zone of northern Togo (10-11°N, 0-1°E). The dominant soil type was a rhodic ferruginous sol that is sandy-clayed at the top horizon and clayed-sandy or sandy-clayed at the horizon of alteration (DRPDATS, 2013). Organic matter widely varied from 0.8 to 1.6%, the pH ranged from 5.8 to 6, and total N and P and sum of exchangeable bases were 0.08%, 0.095 ppm and 7 to 20 meq, respectively.

The rainfall regime is monomial with annual rainfall typically ranging from 1000 to 13000 mm and occurring generally from May to October. The off-season covers the period from November to April during which vegetable cropping is undertaken. Yearly average minimum and maximum temperature values are 22 and 35°C with highest values in March and November (33 and 38°C, respectively) and lowest values in January and August (15°C and 17°C, respectively) (DRPDATS 2013). The family-based fields used in the study were under continuous unfertilized maize or sorghum crops.

Soil, crop and watering management

A 2-off season period (2013-2014) experiment was established with two watering regimes crossed with three fertilization schemes leading to six treatments in three replicates each. The experiment was settled in thirty farmer-family fields selected in the study area (savanna region of Togo). The applied six treatment were as follow: (i) farmer's based hand watering (HW) with no fertilizer application (T1), (ii) dripping bucket irrigation (DBI) system with no fertilizer application (T2), (iii) DBI system with application of 200 kg of N15P15K15 + 100 kg of prilled, ordinary urea (46% N) corresponding to $N_{76}P_{30}K_{30}$ ha^{-1} (T3), (iv) HW with application of 200 kg of N15P15K15 + 100 kg of prilled, ordinary urea (46% N) corresponding to $N_{76}P_{30}K_{30}$ ha^{-1} (T4), (v) DBI system with application of 200 kg of N15P15K15 + 100 kg of urea (46% N) in the form of super granule (USG) corresponding to $N_{76}P_{30}K_{30}$ ha^{-1} (T5) and (vi) HW with application of 200 kg of N15P15K15 + 100 kg of urea (46% N) in the form of super granule (USG) corresponding to $N_{76}P_{30}K_{30}$ ha^{-1} (T6). The $N_{76}P_{30}K_{30}$ ha^{-1} is a recommendation by the national agricultural extension services in Togo and the two forms of urea-N fertilizer used in the experiment are presented in figure 1. The DBI system is a small scale design (for up to 500 m²) with buckets of 200 litres (filled with water by hand) releasing water to crops through a dripping system by simple gravity. The bucket is kept a 1.2 m above the soil surface and is equipped with two dripping pipes that feed each two 15 m - long rows of tomato plants on a point-placed water basis for each plant. The DBI system design and its in-field setting are presented in figure 2.

The site in each farmer family field was manually ploughed and 18 plant beds (15 m x 1.80 m) for the six treatments with three replicates each were laid out in a completely randomized design. Fertilizer $N_{76}P_{30}K_{30}$ ha^{-1} rate was applied three weeks after tomato planting as recommended by the national agricultural research and extension services in the region. In each off-season of each of the two years, all fertilizers were manually point-placed at approximately 8 cm depth. Tomato (Tropimech, the most used variety) was planted in November at a density of 74,000 plants ha^{-1}, weeded as needed and the harvest ended in March-April.

Data collection and analysis

Tomato fresh fruit yield was determined under each treatment by harvesting all the plants from each plant bed. The GENSTAT statistical software package was used to run the analysis of variance (ANOVA) on the yield data sets and the Duncan test at 5% was used to discriminate among mean tomato yields. Mean tomato fruit yield data were used to calculate the N agronomic efficiency Index using the approach of Fathi (1996) represented by the following equation:

N agronomic efficiency Index = (A-B) / C (1)

Where A is yield of plant that obtains a fertilizer, B is yield of plant that obtains a minimum amount of fertilizer and C is the consumed fertilizer.

Results and Discussion

Tomato fresh fruit production

Tomato yield data are presented in table 1. Mean yield typically ranged from 8 to 34 t ha^{-1}. Across treatments, mean yield were 18.78 and 18.86 t ha^{-1} for the first and the second seasons, respectively, indicating that there was no seasonal effect on the data. Tomato yield was responsive to fertilization scheme, watering system and their interactions, being on average lowest (8.83 and 10.85 t ha^{-1}) with no fertilizer and ranging from 12.25 to 33.28 t ha^{-1} when fertilizer was applied. This indicates that in the region, improvement in tomato production is subject to mineral fertilizer use.

Under no fertilizer treatments, seasonal mean yield for DBI (10.85 t ha^{-1}) was 23% superior over the HW system (8.83 t ha^{-1}) (Table 1). With the use of ordinary (prilled) urea, mean yield increased by 72.40% under DBI (30.20 t ha^{-1}) as compared with yield for the HW system (17.52 t ha^{-1}). The use of USG resulted in yield increase of 172% for the DBI (33.28 t ha^{-1}) in comparison with yield under the HW system (12.25 t ha^{-1}). These trends of the data set clearly demonstrate the superiority of the DBI system over the HW system in terms of fresh tomato fruit yield. This finding of our study corroborated several other research results. Kaniszewski and Dysko (1988) reported lowest tomato yield with hand watering in comparison with micro-jet and dripping irrigation systems and von Westarp *et al.,* (2004) in their study on cauliflower concluded that low cost drip irrigation and hand watering are both viable options to increase food production in water scarce, small-scale farming in Nepal, with a greater performance of the drip irrigation system.

Seasonal mean tomato yield under HW was 30% lower when fertilizer N was applied in the form of USG (12.25 t ha^{-1}) as compared with yield associated with the use of ordinary (prilled) urea (17.52 t ha^{-1}). The data set showed that under DBI, yield was 10% superior when USG was used (33.28 t ha^{-1}) over the yield obtained using prilled urea (30.20 t ha^{-1}). This shows that on the basis of N fertilizer form, both N forms (USG and prilled urea) performed well under the DBI system with a greater performance of USG, but USG led to severe yield depression under the HW system indicating that using this form of N is not advised for the traditional HW practice. Studies comparing the performance of the USG and ordinary forms of N fertilizer in vegetable cropping are lacking. However, Detchinli and Sogbedji (2015) in a maize crop based experiment in West Africa found that N fertilizer in the USG form proved superiority over the ordinary urea form under low (30 kg ha^{-1}) and high (90 kg ha^{-1}) N rates of application. Furthermore, studies by Tarfa and Ahmed (2011) in Nigeria and IFDC (2014) in Ghana under irrigated rice cropping reported higher rice yields with the USG than those with ordinary urea.

Nitrogen agronomic efficiency index

The N agronomic efficiency index values are presented in table 1. In contrast to tomato yield, mean N agronomic efficiency index values experienced seasonal variation across treatments, being 13% higher in the second season (311) than in the first season (274). With the use of ordinary (prilled) urea, mean index increased by 122% under DBI (420) as compared with index for the HW system (189). The use of USG resulted in index increase of 558% for the DBI (487) in comparison with index under the HW system (74). Similar to yield data, the N agronomic efficiency index data show that the DBI system provided a better use of the N fertilizer than the HW system.

Mean N agronomic index under HW was 154% higher when fertilizer N was applied in the form of ordinary urea (189) as compared with index using USG (74). The data set showed that under DBI, index was 16% superior when USG was used (487) over the index obtained using prilled urea (420). This shows that on the basis of N fertilizer form, both N forms (USG and prilled urea) performed well under the DBI system with a greater performance when USG was used, but

USG resulted in very low N agronomic efficiency index under the HW system. Besides the lowest index value of 74 recorded from the HW system with USG, seasonal mean index values from this study ranged from 189 to 487 which reasonably agreed with tomato N agronomic efficiency index values of 185 to 275 published by Badr *et al.*, (2012) and 142 to 441 reported by Djidonou *et al.*, (2013).

Table.1 Mean tomato yield and N fertilizer agronomic efficiency index

Treatment	Yield (t ha^{-1})			N agronomic efficiency index		
	Season 1	Season 2	Mean	Season 1	Season 2	Mean
T1	9.50a[¶]	8.16a	8.83a	-	-	-
T2	11.22b	10.48b	10.85b	-	-	-
T3	29.30c	31.10c	30.20c	393a	448a	420a
T4	18.20d	16.84d	17.52d	189b	189b	189b
T5	32.65e	33.90e	33.27e	465c	509c	487c
T6	11.80b	12.70f	12.25f	50d	98d	74d
Mean	18.78	18.86	18.82	274	311	292

¶ Means within the same column followed by the same letter are not significantly different at $\alpha = 0.05$

Fig.1 Urea super granule, USG (left) and ordinary urea, OU (right)

Fig.2 Small scale design (for up to 500 m²) with buckets of 200 liters releasing water to plants through a dripping system

In the light of the results from the field experiment, off-season tomato production in the Savanna region of northern Togo should not be undertaken without mineral fertilizer application. Traditional hand watering practice may be used together with N fertilizer in the form of prilled urea. Hand watering is not recommended when the urea super granule form of N is applied because such a watering system-fertilizer combination led to drastically low yields and N agronomic efficiency index. The dripping bucket irrigation system proved capable of substantially improving tomato yield and N agronomic efficiency index under both prilled urea and urea super granule forms of N, with a greater performance when urea super granule is used.

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