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Evaluation of improved tea (*Camellia sinensis* L.) genotypes to differential drip-irrigation levels in Tanzania

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Abstract

*A study was carried out to establish optimal drip irrigation level for yield, shoot density and water use efficiency (WUE) on tea (Camellia sinensis L.) crop. Thirty-one improved tea genotypes and five irrigation treatments (I_0 - I_4 =100%) were investigated for 2-seasons at Ngwazi Tea Research Station, Tanzania. A Randomized Complete Block Design was adopted with irrigations arranged in split-plot in 3 replications. Genotypes and irrigations were assigned as main- and sub-plots respectively. Irrigation was scheduled based on a simple soil water balance equation. Evapotranspiration was calibrated using daily evaporation B-Pan data. Under I_4 =100%, TRFK 303/577 (19) had significantly higher yield (2037kgmtha^{-1}). Under I_1 = 25%, TRFK 303/259 (18) recorded highest shoot density (207shoots m^{-2}). Under I_0; TRIT 201/43 (4) and TRFK 303/259 (18) produced significantly higher yields of 1136 and 1138kgmtha^{-1} respectively. Significantly higher shoot density (159shoots m^{-2}) and yield (1570kgmtha^{-1}) were registered during 2014/15 and 2015/16 respectively. Yield and shoot density had significant positive correlation r = 0.99***. Yield r = 0.73*** and shoot density r = 0.70*** significantly positively correlated with WUE. Yield-drip irrigation relationship described significant quadratic function with average R^2 = 0.54* in 2014/15 and linear function with higher and significant R^2 = 0.98*** in 2015/16. Yield-WUE relationship explained linear function with very weak R^2 = 0.04in 2014/15, in 2015/16 the relationship was linear with higher significant R^2 = 0.72***. Compared to I_4 =100%, irrigating tea at I_1= 25% in 2014/15 improved yield by 1.4% and saved water by 74.6%. Irrigating tea at I_1= 25% during 2015/6 improved tea yield by 37.9% and saved water by 68.3%.*

Keywords: Deficit irrigation, yield, shoot density, water use efficiency.

Introduction

Tea (Camellia sinensis L. (O.) Kuntze) is a grown crop mainly for commercial purpose worldwide. In Tanzania, tea contributes to over 50 000 USD annually, equivalent to over 0.12% of the national GDP[1]. The crop provides employment to over 50 000 households, especially the smallholders. Over 2million families earn their living through tea production and processing[2]. Among the important cash crops in the country, tea ranks between 4th and 5th.

Tea growing environments in Tanzania vary, ranging from the climatic, edaphic to biotic conditions[3]. The conditions interact differently affecting tea crop growth. Tanzania produces over 33 000 metric tons annually of the processed tea[1]. Over 70% of this quantity is produced at the Southern Highlands (SH). Over 80% of the produced annual tea is realized during wet season (Oct/Nov to April/May). The other 20% is realized during the long dry season (May/June to Sept/October). The dry spell at the Southern Highlands is divided into cool - (May/June to July/ Mid-August) and warm dry (Mid-August to Mid-Nov)[3]. While the condition restricts shoot growth; both yield[4,5] and quality[6] are mainly influenced by soil water deficit (SWD). Yield losses of up to 25% of processed tea are reported due to drought stress mainly during long dry season at the Southern Highlands of Tanzania[3].

Several approaches have been adopted in Tanzania to mitigate drought stress in tea crop mainly through sprinkler irrigation; through such approaches cultivars responsive to sprinkler irrigation have been identified and recommended for adoption by tea growers'[3]. Identification of cultivars tolerant to drought stress has been well advanced[4,7]. However, one of the key short coming of sprinkler irrigation is observed mainly on uncontrolled water loss[8].

Global climate reports indicate the decline in water resource, posing significant challenges to many crops in the country[9], tea inclusive. For tea crop there is prediction that previously potential tea areas are turning into marginal areas[10,11]. To serve the declining water resource on tea crop especially under water scarce resource, tea growers opt to maximize crop production per unit water used instead of per unit land area[12]. Also, it is suggested adoption of genotypes responsive to drip irrigation[3,4]. Based on two independent studies in Tanzania, there is a gain in tea yield of 50% -52% using drip irrigation on mature tea crop[7,12].

Information on identified responsive tea genotypes to deficit irrigation on yield and shoot density, especially of recently 29 - developed genotypes are scarce. Therefore, the present study focused on the establishment of optimum irrigation rate on tea yield, shoot density and water use efficiency (WUE) in drought prone areas of Tanzania.

Materials and methods

Description of study areas and planting of tea genotypes: The study was conducted from 2014/15 to 2015/16 at Ngwazi Tea Research Station (NTRS), Southern Highlands of Tanzania in Mufindi District (8°32'S, 35°10'E and altitude of 1840m asl). The experiment was set in formerly established tea farm No.17 in March, 2005. The soils were described as sandy clay loamy with optimal organic matter (2.3%) and pH (H_2O) of 4.3 within 0 to 90cm depth. This was slightly below the optimal range of pH 4.5 - 5.5 for tea[13]. The climatic weather is as detailed by Tea Board of Tanzania[1] is presented herein Tables - 1 and 2.

Genotype Treatments: A total of 31 - tea genotypes were evaluated, comprising different varietal types i.e. Chinery, Assam, Cambod and their hybrids (Table-3). Fertilizer was applied at 250kgNha^{-1}year^{-1} in two splits[15]. Other agronomic management practices were done according to TRFK[13]. A complete randomized block design (CRBD) with five irrigation levels (I_0 – I_4) arranged in split-plot in 3-replications was adopted. Irrigation levels (I_0 – I_4) and genotypes (1 – 31) were assigned as main- and sub-plots, respectively.

Table-1: Soil Physico-chemical characteristics of the tea experimental site at Ngwazi Tea Research Station (NTRS) in Tanzania in 2014-2015.

Soil parameters	Physical properties	Chemical properties	Remarks[§]
Cation Exchange Capacity (CEC) (cmol kg^{-1})	-	14.76	Medium
N (%)	-	0.18	Low
Available K^+ (cmol kg^{-1})	-	0.69	Medium
Available P (ppm)	-	15.37	Medium
Mg^{2+} (cmol kg^{-1})	-	0.91	Medium
Organic Matter (%)	-	2.39	Medium
pH	-	4.3	Acidic
Sand (%)	46.2	-	-
Silt (%)	18.3	-	-
Clay (%)	35.5	-	-
Textural Class	Sandy Clay Loam	-	-

§=Interpretation according to Landon[14].

Table-2: Recorded Weather at Ngwazi tea Research Station during 2014/15 and 2015/16.

Month	2014/15[a]				2015/16[b]			
	Temperature (°C)			Precipitation (mm)	Temperature (°C)			Precipitation (mm)
	Max	Min	Mean		Max	Min	Mean	
April	-	-	-	-	21.6	14.1	17.9	112.0
May	-	-	-	-	19.6	10.9	15.3	20.0
June	-	-	-	-	19.9	9.4	14.7	0
July	-	-	-	-	19.7	9.2	14.5	0
August	-	-	-	-	20.5	9.5	15.0	0
September	20.8	10.3	16.4	0	22.6	10.2	16.4	0
October	23.9	11.9	18.4	22	24.7	12.3	18.5	0
November	24.7	12.7	19.0	3.8	24.9	13.0	19	24.0
December	24.4	12.8	18.7	102	24.1	13.3	18.7	31.2
Mean	23.5	11.9	Total:	127.8	22.0	11.3	Total:	187.2

[a]= Experiment irrigated from September to December; [b]= Experiment irrigated from April to December.

Irrigation treatments: Water for irrigation was pumped from the Natural Lake Ngwazi using electrical pump (3-phase Motor; 175HP; 415V, CATCO, U.K). Water was delivered to storage plastic tank (5000lts capacity) approx. 800m fixed at 2m height from ground. Scheduling of drip irrigation was based on the soil water balance equation as detailed in FAO[10]. The amount of water for each irrigation level was estimated from the sunken evaporation pan (B-pan) located 300m from the experimental site at Ngwazi meteorological station (Figure-1). The experimental plots were irrigated whenever E-Pan recorded 75mm of the evaporated water (TRIT, 2007). Five irrigation treatments were studied labelled I_0 = no-drip irrigation (Control), I_1 = 25%, I_2 = 50%, I_3 = 75% and full-irrigated (I_4 = 100%), each represented 25% reduction soil water deficit, 50% reduction soil water deficit, 75% reduction soil water deficit and 100%, the latter being full soil water deficit replacement (at field capacity), respectively.

Evapotranspiration (mm): Scheduling of drip irrigation treatments and calibration of daily and cumulative potential soil water deficit (SWD)(mm) was estimated using the soil water balance equation for tea below[7];

$$\text{Soil water deficit (mm) SWD} = SWD_{i-1} - R_i + E_{pan} \quad (1)$$

Where: SW_{Di-1} represented the soil water deficit during the previous $(_{i-1})^{th}$ day; R_i = precipitation and E_{pan} = evaporation from the sunken evaporation pan (B-pan) measured during the i^{th} day in mm using the Automatic IMETOS©R Meteorological station installed within 300m distance from experiment N17 at Ngwazi Tea Research Station (NTRS). Since tea bushes were mature (11yrs.) with almost 100% crop ground cover, the estimated water loss from the soil surface was assumed almost negligible. Whenever 75mm of water evaporated from the evaporation B-Pan, it was considered time to irrigate tea crop (Kipangula, Pers. Comm.).

Prior to imposing the drip irrigation treatments, the experiment was uniformly irrigated to harmonize the experimental soil moisture content. The differential drip irrigation treatments were commissioned from 1st September to 17th December 2015 during first dry season and 1st May to 31st December 14th 2016 during second season, when irrigation was stopped and wet season (rainfall) set in.

Data collection: Shoot density (shoots m^{-2}): Data on shoot density were collected and estimated based on Nyabundi K.W. et al.[18]. Shoots count was carried out a day before harvesting green leaf for yield determination. Shoots were counted using a $0.2m^2$ wooden grid randomly thrown at a frequency of five grids per plot over the tea plucking table. The fresh mass of the shoots from each plot was weighed at each harvest and average of shoots was calibrated from each plot and converted into number of shoots per m^2 [16,17] as shown below:

$$\text{Shoot density } (m^{-2}) \ \frac{\text{Number of shoots}}{\text{Land area } (m^2)} \quad (2)$$

Mean yield (kgmtha^{-1}): Yield data were collected from harvested green leaf (2 leaves + a bud). Weight of harvested green leaf from each plot was measured and expressed in gram or kg per plot. Harvested green leaf was converted into annual made tea yields (kgmtha^{-1}) by multiplying with a 0.225 outturn factor[14].

Figure-1: Experimental setup of drip irrigation at Ngwazi Tea research Station (NTRS) (2014/15-2015/16).

Table-3: List of 31-Tea Genotypes Evaluated under Drip irrigation (I_0–I_4) at Ngwazi Tea Research Station during 2014/15 and 2015/16 [16,17].

Genotype	Source of origin	Varietal Type
TRFK 11/4	Kenya local selection	Assam
TRFK 12/19	Kenya local selection	Assam
TRIT 201/16	Tanzania local selection	Assam/ Chinery hybrid
TRIT 201/43	Tanzania local selection	Assam
TRIT 201/44	Tanzania local selection	Assam
TRIT 201/47	Tanzania local selection	Assam/ Chinery hybrid
TRIT 201/50	Tanzania local selection	Assam
TRIT 201/55	Tanzania local selection	Assam/ Chinery hybrid
TRIT 201/73	Tanzania local selection	Assam/ Chinery hybrid
TRIT 201/75	Tanzania local selection	Assam/ Chinery hybrid
TRIT 201/82	Tanzania local selection	Assam/ Chinery hybrid
TRFK 301/4	Kenya local selection	Cambod
TRFK 301/5	Kenya local selection	Cambod
TRFK 301/6	Kenya	Cambod
TRFK303/1199	OP progeny TRFK 6/8	Assam/ Chinery hybrid
TRFK 303/178	OP progeny TRFK 6/8	Assam
TRFK 303/216	OP progeny TRFK 6/8	Assam
TRFK 303/259	OP Progeny TRFK 6/8	Assam
TRFK 303/577	OP progeny TRFK 6/8	Assam/ Chinery hybrid
TRFK 31/8	Kenya	Assam
TRFK 371/2	Kenya	Assam
TRFK 371/3	OP progeny AHP S15/10	Assam
TRFK 371/6	OP progeny AHP S15/10 in Kenya.	Assam
TRFK 371/8	OP progeny AHP S15/10	Assam
TRFK 381/5	BB35 × BB2	Assam
TRFK 400/10	Kenya	Assam
TRFK 400/4	OP progeny AHP S15/10	Assam
TRFK430/63	TRFC × EPK TN 14/3	Assam/ Chinery hybrid
TRFK 430/7	TRFCA SFS 150× EPKTN14/3	Assam/ Chinery hybrid
TRFK 6/8	Kenya local selection	Assam
SFS150 (Ck-2)	Malawi local selection	Assam

Water use efficiency (WUE): The Water use efficiency (WUE) is defined as ratio of yield to evapotranspiration (ET) or yield obtained per unit of applied water from irrigation including that of from precipitation[8]. In tea crop the productivity of tea is quantified in terms of weight of 'made tea' per unit land area per year. Therefore, WUE measures the productivity of applied water irrigation. WUE of tea is influenced by water availability, nitrogen application and season[3]. During wet season, WUE is higher than in cool dry season and the response of WUE to irrigation increases with increasing nitrogen fertilizer. The WUE values were adopted to determine productivity of irrigation among treatments[19] and calculated according to[8];

$$WUE(kg.ha^{-1}.mm^{-1}) = Yield\ (kg.ha^{-1})/total\ applied\ water(mm) \quad (3)$$

In case of a perennial crop, tea inclusive, this period will cover beginning when the first irrigation treatments were imposed until when it was stopped following the set in of wet season.

Data analysis: Obtained data were analyzed both in separate and combined analysis (ANOVA) using statistical software Version 15[20]. Means for genotypes, irrigations, seasons and their interactions were separated using the Duncan Multiple Range Test (DMRT) at probability level of $p \leq 0.05$. The statistical model was adopted as described below;

$$Y_{ijkl} = \mu + R_i + I_j + \varepsilon_{ij} + G_k + (G*I)_{jk} + \varepsilon_{ijkl} \quad (4)$$

Where: Y_{ijk}= Response variable: Observation in the i^{th} replication, j^{th} irrigation, k^{th} genotype and l^{th} plot. μ = the general mean; R_i, I_j and G_k = effects of i^{th} replication, j^{th} irrigation and k^{th} genotype, respectively. ε_{ij} = random error for factor A; $(G*I)_{jk}$ =interaction effect; ε_{ijkl} = error for factor B.

Results and discussion

Analysis of variance: Both separate and combined analysis (ANOVA), showed significant ($p \leq 0.001$) effects of irrigation, genotypes and season on both tea yield and shoot density traits. This suggested that there is opportunity to select or identify optimum irrigation level, suitable genotype and season for yield and shoot density in tea production. The effects of genotype × irrigation, genotype × season and irrigation × season interactions on yield and shoot density were significant ($p \leq 0.001$), suggesting differential responses of genotypes among irrigation levels and seasons and that irrigation effects also depended on season. The significance of genotype × season interaction, also suggested that the genotypic performance varied among seasons due to differences in climatic conditions and genotypes. Thus, specific combinations of factors need to be identified for optimum expressions. In a similar clonal tea study[7] reported significant combined effects on irrigation, genotypes, seasons and their respective interaction on yield. However, non-significant G × I effect on tea yield also have been reported[21]. Such contrasting findings could be attributed to different set of populations/genotypes and environments that were evaluated.

Applied Irrigation Water and Evapotranspiration (ET) (mm): During 2014/15, the applied irrigation and evapotranspiration had similar trend of increase as in 2015/16 (Table-4). This was probably as a result of relatively higher minimum and maximum temperatures together with low precipitations during the two seasons (Table-4) which could have influenced higher ET. Similar results on silage maize (*Zea mays* indentata Sturt.) were reported[22]. Irrigating tea crop at I_1=25% increased an estimated ET by 69.6% and 64.4% in 2014/15 and 2015/16, respectively (Table-4). Reducing soil water deficit by 75% (I_3), increased an estimated ET by 27.9% and 17.9% in 2014/15 and 2015/16, respectively (Table-4). The irrigation × season interaction was highly significant ($p \leq 0.001$) on yield and shoot density, suggesting that irrigation levels responses varied inconsistently with season. Similar variation in irrigation level responses were reported with seasons under sprinkler irrigation system both on tea yield and shoot density[4].

Table-4: Effect of drip irrigation and evapotranspiration treatments on water use efficiency (WUE) and yield response during 2014/15 and 2015/16**.**

Season	Irrigation treat (mm)	Evapotranspiration (mm)	Applied irrigation (mm)	Yield (kgmtha^{-1}) ¥	WUE (kg m^{-3})
2014/15[a]	I_0	127.8	-	300	-
	I_1	214	167	425	2
	I_2	391	344	393	1
	I_3	507	460	427	0.8
	I_4	704	658	419	0.6
Mean	-	454	407.3	393	1.1
Sed (±)	-	-	-	28.4	-
L.S.D ($p \leq 0.05$)				56	-
CV (%)	-	-	-	7.2	-
2015/16[b]	I_0	187.2	-	1096	-
	I_1	197	165	1336	6.8
	I_2	277	245	1481	5.3
	I_3	455	423	1785	3.9
	I_4	554	521	2153	3.9
Mean	-	370.8	338.5	1689	5.0
Sed (±)	-	-	-	6.8	-
L.S.D (±) ($p \leq 0.05$)				13.4	-
P-value				0.05	-
CV (%)	-	-	-	0.4	-

¥=kgmtha^{-1} stands for kilogram made tea per hectare. [a]= experiment irrigated from September to December; [b]= experiment irrigated from May to December.

Yield ($kgmtha^{-1}$): Higher yields in 2015/16 compared to 2014/15 (Table-4) could be as a result of variation in climatic weather during the two seasons. The mean minimum (11.3°C) and maximum (22.1°C) temperatures were relatively optimal with high precipitations (187.1mm) in 2015/16. In addition, adequate drip irrigation water was applied and well distributed from May to Mid-December, causing more water availability to tea crop in all treatments. On the other hand, the 2014/15 was relatively warmer (11.9°C and 23.1°C) with low precipitation (127.1mm) leading to high water evaporative demand which affected tea yields during 2014/15[23].

During 2014/15, the experiment was irrigated only for relatively short duration (4-months) from September to December, indicating this was insufficient quantity of water to adequately meet the required soil moisture among the irrigation treatments.

Water use efficiency (kgm^{-3}): The WUE ranged from 0.6 to 2.0kgm^{-3} during 2014/15 and from 3.9 to 6.8kgm^{-3} in 2015/16 (Table-4). During both seasons, the WUE values decreased with increased applied drip irrigation water. Higher WUE values were obtained at deficit water supply I_2 = 25% level, while, the least WUE at fully drip irrigated level I_4 = 100% during both seasons. The results suggested that during the seasons higher levels of irrigation provided more than necessary required moisture, hence was less economical.

Higher WUE values at I_1 = 25% was due to increased promotion of Absicic Acid (ABA) causing decreased stomata conductance, therefore, increased water use efficiency (WUE)[24]. Decreased stomatal conductance is explained to reduce water loss more than the quantity of carbon fixation[25]. In contrast, applied fully irrigated treatment (I_4 = 100%) influenced more water and nutritional uptakes which maintained favourable tea plant growth status.

Effects of drip irrigation (I) for yield and shoot density: Yield increase at I_4 = 100% (Table-5) was due to sufficient available soil moisture content during the entire growing period[22]. Higher water availability is likely to have caused optimum transpiration and higher growth of the aerial tea plant parts[26]. However, the results contradict the report by Kigalu[11]. The author reported highest tea yields at I_2 = 50% at Kibena Tea Company (KTC). The variation could be attributed to soils types. At KTC soils are described as clay loam with high organic matter and high water holding capacity; whereas, at Ngwazi site, the soils are sandy clay loam with medium to high organic matter (OM). The clay soils at KTC is likely to affect tea growth through poor drainage. Soils at Ngwazi provides good drainage and controlled effect of excess water in the soils (Makweta, Pers. Comm).

Statistically there were similar shoot densities at I_1= 25%, I_2 = 50%, I_3 = 75% and I_4 = 100% (Table-5). This implies that the tea crop at the test location need only I_1 = 25% of moisture level, thus economical supply of moisture should be applied. Lower shoot density at (I_0), was due to reduced photosynthetic capacity (assimilation of CO_2) and stomata conductance (gs) causing stomata closure and reduced transpiration rate[26,27]. Water stress at (I_0) also reduced shoot density through restriction of tea shoot growth[2] leading to high water evaporative demand[28]. During adequate of irrigation water i.e. no water deficit, greater numerical shoot density was recorded at I_4 = 100% (149shoots m^{-2}), the condition influenced higher shoots initiation and extension mainly due to favourable air temperature[24]. In tea plant, air temperature is described to positively associate with rates of shoots initiation.

Table-5: Main effect of irrigation regimes on yield and shoot density.

Irrigation regime (mm)	Yield ($kgmtha^{-1}$)¥	Shoot density (Shoots m^{-2})
I_0 = No irrigation	698	118
I_1= 25%	878	148
I_2 = 50%	937	139
I_3= 75%	1102	140
I_4 = 100% (Fully irrigated)	1284	149
Mean	980	139
Sed (±)	15.8	16.0
LSD (±) ($p \leq 0.001$)	31.1	22.0
P-value	0.05	0.05
CV (%)	1.6	11.5

¥=$kgmtha^{-1}$ stands for kilogram made tea per hectare.

Main-effect of genotypes for yield and shoot density: The differences among tea genotypes for yield could be an attribute to genetic composition (Table-6). This creates an opportunity for tea breeders to exploit the variability in the course of improving yield in tea populations. Similar conclusion was made on sprinkler- and drip-irrigated clonal tea studies by so many researchers[1,4,11]. Genotype TRFK 303/577 (19) gave significantly highest mean yield of 1564$kgmtha^{-1}$. Similar results were reported by Nyabundi *et.al*[17] on same tea genotype TRFK 303/577 (19). Highest mean yield for mature tea genotype TRFK 303/577 (19) may be linked to genetic and physiological factors. Being a Chinery type, higher yielding may be associated with small size, dark green coloured leaves with semi erect to erect posture which could have intercepted higher light intensity to influence higher photosynthesis rate and yield[24]. The significantly highest mean shoot density (184shoots m^{-2}) recorded for TRFK 303/259 (18) could be an attribute to genetic makeup.

Table-6: Main-effect of genotypes for yield and shoot density.

Genotype	Yield ($kgmtha^{-1}$) ¥	Shoot density (shoots m^{-2})
TRFK11/4	683u	107p
TRFK 12/19	803q	142g-k
TRIT 201/16	628v	108p
TRIT 201/43	1103g	137i-l
TRIT 201/44	619v	122no
TRIT 201/47	1055ij	162b-e
TRIT 201/50	712t	117op
TRIT 201/55	1045j	142g-k
TRIT 201/73	975m	155d-g
TRIT 201/75	748s	122no
TRIT 201/82	847p	156c-f
TRFK 301/4	1340b	172b
TRFK **301/5**	1029k	149f-i
TRFK 301/6	1056ij	125l-o
TRFK 303/1199	1182f	148f-i
TRFK 303/178	743s	123no
TRFK 303/216	966m	151e-h
TRFK 303/259	1291c	184a
TRFK 303/577	1564a	167bc
TRFK 31/8	768r	145f-j
TRFK 371/2	904o	127k-n
TRFK 371/3	1080h	137i-l
TRFK 371/6	803q	124m-o
TRFK 371/8	1007l	140h-k
TRFK 381/5	1196e	135i-m
TRFK 400/10	938n	127l-o
TRFK 400/4	1216d	130j-n
TRFK 430/63	1063i	146f-j
TRFK 430/7	1009l	125l-o
TRFK 6/8	701t	124m-o
SFS150(CK)	1306c	165b-d
Mean	980	139
Sed (±)	7.2	7.5
P-value	0.05	0.05
CV (%)	2.8	14.4

¥=$kgmtha^{-1}$ stands for kilogram made tea per hectare. Means followed by the same letter indicate no differences according to Duncan Multiple Range test (DMRT) at the probability level of 0.05.

Main-effect of seasons on yield and shoot density: Recorded highest yield during 2015/16 than in 2014/15 (Table-7) may be an attribute to differences in climatic conditions. Differences in minimum and maximum temperatures were reported between seasons which caused variation in maize crop performance[23]. The weather during 2015/16 was relatively lower with min. (11.3°C) and max. (22.1°C) temperatures and relatively higher precipitation (187.1mm). During 2015/16, applied irrigation provided a large sufficient water irrigation to all treatments from May to November months, the condition which assured adequate availability of water for normal tea growth. Similar observations were reported in corn (*Zea mays* L.), where due to weather variation more corn yield was recorded during 2004 than in 2003[29].

Similarly, higher shoot density in 2014/15 (Table-7) could be ascribed to compensatory plant growth effects which upon commencement of irrigation in September (peak of dry season) it directly influenced the initiation of dormant tea shoots within the plucking table following the unfavorable cool dry weather[24,30]. In tea, under insufficient water supply or water stress, shoot density is less affected than shoot weight[24]. However, yield was not increased because the governing conditions did not influence immediate shoot expansion and extension which ultimately affects shoot weight per unit area, hence the tea yield[24].

Table-7: Main-effect of seasons on yield and shoot density.

Season	Yield ($kgmtha^{-1}$)¥	Shoot density (shoots m^{-2})
2014/15[a]	390	159
2015/16[b]	1570	119
Mean	980	139
Sed (±)	10.1	7.5
LSD ($p \leq 0.05$)	19.9	2.6
CV (%)	1.0	5.4

¥=$kgmtha^{-1}$ stands for kilogram made tea per hectare. [a] = experiment irrigated from September to December; [b]= experiment irrigated from May to December.

Interaction effect between genotypes and irrigation levels on yield: The interaction effects between genotypes and drip irrigation revealed significantly highest yield (2037$kgmtha^{-1}$) response for genotype TRFK 303/577 (19) at I_4 = 100% (Table-8). Several previous findings reported similar results[4,11,31]. Variation in yield response to differential drip irrigation can be due to differences in genetic composition among tested tea genotypes. Considering the differences responses among genotypes to varying moisture regimes, thus, Genotypes TRIT 201/43 (4) and TRFK 303/259 (18) displayed significantly higher yield responses at non-irrigated treatment (I_0). This could be due to higher genotypic ability to diverge a large fraction of dry matter to leaves (sink) and less proportion to tea structural roots[4]. It is suggested that, such genotypes use advantage of full ground canopy (100%) cover to conserve water from reduced water loss through evaporation[26]. Also, well-established tea root structure at mature age aids to extract stored water from deep in the soil. Clonal genotype S 15/10 is reported to have out-yielded other five genotypes based on its ability to partition more dry matter to leaves (sink)[4]. Therefore, the present results provide a scope for identification and selection of improved tea genotypes responsive to fully and deficit soil moisture conditions.

Table-8: Interactions of genotype × Irrigation (G*I) on yield (kgmtha^{-1})$^{¥}$.

Genotype \ Irrigation	I_0	I_1	I_2	I_3	I_4
TRFK11/4	451p	606w	678r	787qr	893q
TRFK 12/19	545m	677s	634t	987m	1171n
TRIT 201/16	400r	567x	607u	511t	1060o
TRIT 201/43	1137a	834p	1027h	1226gh	1291kl
TRIT 201/44	478o	617v	467v	551t	979p
TRIT 201/47	543m	1013i	1222e	1331e	1259lm
TRIT 201/50	672i	609vw	606u	704s	968p
TRIT 201/55	711h	1035h	724q	1233g	1520ef
TRIT 201/73	693h	994k	903l	1242fg	1039o
TRIT 201/75	514n	651t	930k	837pq	805r
TRIT 201/82	426q	616v	762s	1142ij	1407i
TRFK 301/4	775g	1049g	1424a	1697b	1755b
TRFK **301/5**	649j	952mn	999i	1093jk	1452gh
TRFK 301/6	850e	945n	1148d	1014lm	1318jk
TRFK 303/1199	803f	927o	1189c	1389d	1600d
TRFK 303/178	487o	628v	742p	877o	981p
TRFK **303/216**	600k	1112e	730q	923no	1463gh
TRFK 303/259	1137a	1300b	1023h	1297ef	1698c
TRFK 303/577	970b	1476a	1404b	1933a	2037a
TRFK 31/8	935c	751r	969j	760r	426t
TRFK 371/2	705h	773q	757o	1052kl	1229m
TRFK 371/3	911d	1002j	844m	1172hi	1473g
TRFK 371/6	773g	652t	781n	750rs	1058o
TRFK 371/8	641j	966l	1094f	910o	1423hi
TRFK 381/5	924cd	1059f	1130e	1219gh	1628d
TRFK 400/10	555lm	522z	1075g	1277e-g	1263lm
TRFK 400/4	853e	1191d	1095f	1408d	1538e
TRFK 430/63	667i	983k	930k	1241fg	1488fg
TRFK 430/7	572l	956m	1027h	1148i	1341j
TRFK 6/8	458p	540y	907l	973mn	627s
SFS150 (CK)	788fg	1216c	1410b	1499c	1616d
Mean	698	878	937	1102	1284
P-value	-	-	0.05	-	-
CV (%)	1.8	0.6	0.8	3.4	2.4

¥=kgmtha-1 stands for kilogram made tea per hectare. Means followed by the same letter indicate no differences according to Duncan Multiple Range test (DMRT) at the probability level 0.05.

Interaction effect between genotypes and irrigation levels on shoot density: The genotypes × irrigation interaction effects were significant on shoot density trait (Table-9). Significantly highest shoot density (207 shoots m^{-2}) was recorded for genotype TRFK 303/259 (18) at I_1 = 25%. Such genotype indicated higher ability to partition a larger proportion of dry matter during dry season in shoots (sinks) than in the root zone[1]. This may be similar reasoning for same genotype under non-irrigated treatment (I_0). In contrast, significantly higher shoot density at irrigation treatment I_4 =100% for genotypes TRFK 301/5 (13) and TRFK 303/216 (17) can be due to sustained available water throughout the growing seasons which favoured normal growth of tea shoots. Thus, there are genotypic differences on shoot density that make it possible to identify tea cultivars with high shoot density under moisture stress (e.g. TRFK 303/259 (18) and under ample moisture regime (e.g. TRFK 301/5 (13) and TRFK 303/216 (17).

Table-9: Interactions of genotype × irrigation (G*I) on shoot density (shoots m^{-2}).

Genotype \ Irrigation	I_0	I_1	I_2	I_3	I_4
TRFK11/4	90i-k	102j	105k-m	101hi	141ef
TRFK 12/19	115d-i	153c-f	168b-d	123f-i	151de
TRIT 201/16	105e-k	122g-j	105k-m	104hi	102g
TRIT 201/43	135cd	131e-i	128f-l	147d-g	141ef
TRIT 201/44	84k	130e-i	111i-m	130e-h	156c-e
TRIT 201/47	124c-g	182ab	169b-d	177a-c	156c-e
TRIT 201/50	103f-k	102j	124g-m	105hi	149d-f
TRIT 201/55	111d-i	150c-g	129f-l	175a-d	144d-f
TRIT 201/73	103f-k	192a	166b-d	159a-d	147d-f
TRIT 201/75	99h-k	141c-i	102lm	114hi	155c-e
TRIT 201/82	129c-e	161b-d	662s	179ab	169b-d
TRFK 301/4	159ab	187ab	163c-e	174a-d	178a-c
TRFK 301/5	121d-h	148c-h	152c-f	126e-i	200a
TRFK 301/6	121d-h	141c-i	135f-i	120g-i	109g
TRFK 303/1199	128c-e	149c-g	155c-f	150c-f	160c-e
TRFK 303/178	92i-k	147c-h	99m	128e-i	148d-f
TRFK 303/216	112d-i	165bc	132f-k	154b-e	200a
TRFK 303/259	174a	207a	191ab	162a-d	184ab
TRFK 303/577	120d-h	199a	**197a**	174a-d	147d-f
TRFK 31/8	168a	149c-g	173a-c	110hi	124fg
TRFK 371/2	103f-k	153c-f	113h-m	130e-h	136ef
TRFK 371/3	135cd	154c-e	106k-m	152b-e	139ef

Genotype \ Irrigation	I_0	I_1	I_2	I_3	I_4
TRFK 371/6	114d-i	152c-f	107j-m	105hi	141ef
TRFK 371/8	106e-k	138c-i	150c-g	165a-d	140ef
TRFK 381/5	118d-h	125f-j	136f-i	152b-e	142ef
TRFK 400/10	100g-k	115ij	138e-i	118hi	153de
TRFK 400/4	126c-f	142c-i	123g-m	116hi	143ef
TRFK 430/63	124c-g	134d-i	137e-i	**185a**	150d-f
TRFK 430/7	86jk	126e-j	140e-h	131e-h	143ef
TRFK 6/8	116d-h	119h-i	134f-j	114hi	136ef
SFS150(CK)	146bc	181ab	191ab	169a-d	138ef
Mean	118	148	139	140	149
P-value	0.05	0.05	0.05	0.05	0.05
CV (%)	12.4	11.4	11.9	12.1	10.1

Means followed by the same letter indicate no differences according to Duncan Multiple Range test (DMRT) at the probability level 0.05.

Correlations of yield and shoots density with Water use efficiency (WUE) stabilities: Results for correlations between yield and shoot density (r = 0.725***) (Table-10) was expected because shoot density is one of the key tea yield components[3,17,30]. Tea shoot density contributes 80% - 89% of tea yield variations[17,30]. The relation indicates the importance of shoot density in determining tea yield[17]. This implies that, tea genotypes with higher mean yield also present higher shoot densities. Therefore, this offers a scope for either concurrent improvement of tea yield with shoot density or through improved shoot density alone[30]. Correlations between tea yield with WUE (r = 0.994***) and shoot density with WUE (r = 0.701***) in that order were significantly and positively correlated (Table-10). Thus, increased WUE is pertinent for increased yield and shoot density of tea crop. Based on independent reports on wheat crop, yield and shoot density was increased at less quantity of water[32]. Thus, this presents opportunity of breeding high water use efficient tea genotypes. Under limited water resource, winter wheat genotypes with high WUE are reported to use less water[33]. That is, genotypes are able to integrate higher rate of carbon per unit water used leading to accumulation of more biomass.

Yield–evapotranspiration relationship: The yield-evapotranspiration quadratic function in 2014/15 (Figure-2) also are reported by scientists[3,7] under sprinkler and drip irrigation systems, respectively. The regression showed that significant average increase in coefficient of determination of R^2 = 0.583* in tea yield was on average proportional to the increment of ET. The regression also indicated that tea amounting to 260kgmtha^{-1} could be produced without water irrigation due to effect of available sufficient residual moisture in the soil[23]. Yield-ET indicated that small irrigation application increased crop ET, more or less linearly beyond which it turns to curvilinear. This was as a result of lost water upon attaining maximum ET[29].

Table-10: Correlation of yield and shoots density with Water use efficiency stabilities.

	Yield	Shoot density	WUE
Yield	-		
Shoot density	0.725***	-	
WUE	0.994***	0.701***	-

***=significant at p≤ 0.001; Degrees of freedom = n -2 = 463.

Strong positive linear relationship of R^2 = 0.948*** in 2015/16, indicated tea yield increased with evapotranspiration (ET) showing no point of maximum attainment for further increased yield with ET. Maximum yield point may not be specified due to lack of excessive irrigation application during 2015/16. The slope showed the tea yield increased with evapotranspiration at the rate of 2.448kg ha^{-1} mm^{-1} during 2015/16 (Figure-2). However, higher clonal genotypes response of 7.2 kg ha^{-1} mm^{-1}

to drip irrigation are reported by Kigalu[7]. The variation could be due to differences in tested genotypes and soil types in the present study. Such relationship also is widely reported in other crop species such as; maize (*Zea mays* L.)[19] and Alfalfa (*Medicago sativa* L.)[31].

At Ngwazi site, the dry period is divided into cool (April/May-July/August) and warm dry (Sept-Dec.) seasons. Between the two seasons, 2014/15 the tea crop was irrigated with drip water only during warm dry season (Sept-Dec.), leaving the crop to suffer from drought stress during cool dry season. But, during 2015/16, the crop was gradually and consistently supplied with water during the entire cool and warm dry periods favouring normal tea crop growth.

Yield-water use efficiency relationship: The tea yield-WUE relationship during 2014/15 and 2015/16 (Figure-3) were associated with WUE under drought and freely available water conditions. According to Edwards *et.al*[25] and Nir *et.al*[27], under water-limited condition, higher WUE during 2014/15 could be attributed to enhanced plant leaf chlorophyll level which positively affects CO_2 fixation and contributes to better tea plant performance. In other words, under water limited condition tea genotypes use available limited water conservatively which influence higher stomata conductance (Wg) causing better tea plant performance. However, this may depend on whether the tea genotype is either susceptible or tolerant to drought stress. Similarly, due to well-watered condition, tea genotypes seems not to use water conservatively causing low stomata conductance (Wg) keeping good tea plant performance[25]. During 2014/15, tea plants were under stressful condition (drought) which possibly used the limited available moisture more conservatively to maintain normal tea growth. Ultimately, this influenced a relatively low tea yield-WUE R^2 = 4.1%. In contrast, due to more freely available drip irrigated water, tea plants during 2015/16 did not utilize the freely available water conservatively leading to negatively strong yield-WUE association with higher R^2 = 78.1%. At hormonal level, under water-limited condition, tea genotypes response involves accumulation of Absicic acid (ABA) hormones which regulate specific gene expression for chemical signals which initiates stomatal closure a crucial water-conserving response for adaptation to drought stress[34].

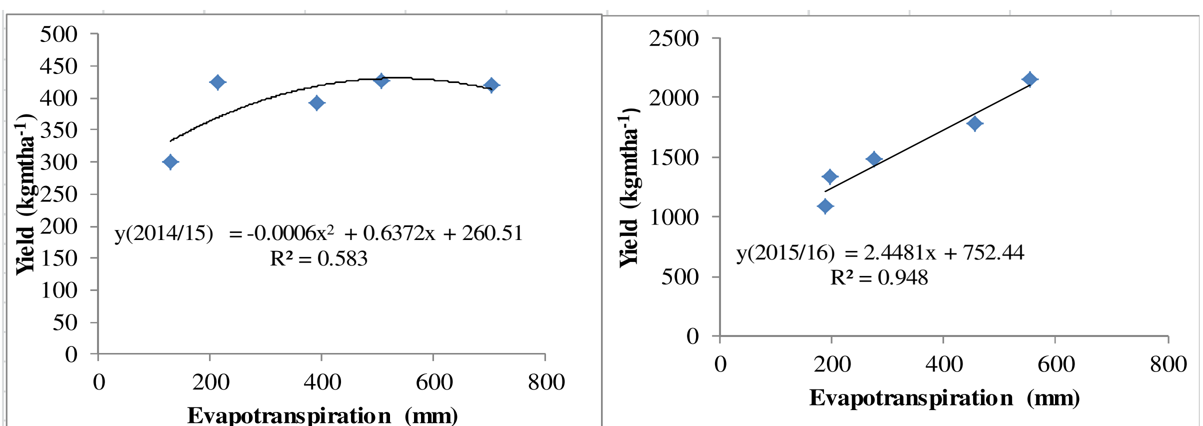

Figure-2: Relationship between Yield (kgmtha^{-1}) and evapotranspiration mm) for tea crop at Ngwazi Tea Research Station (NTRS) during 2014/15.

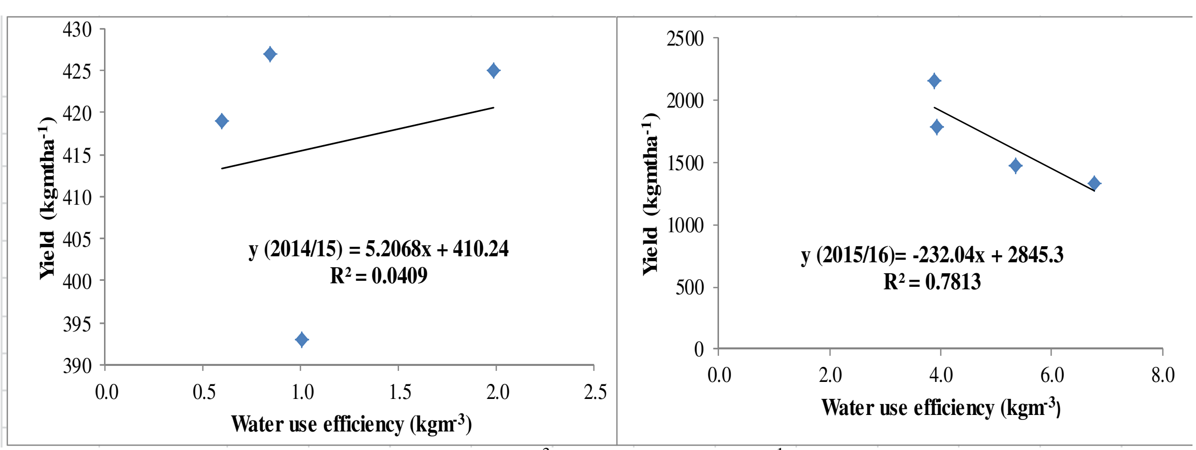

Figure-3: Relationship between water use efficiency (kgm^{-3}) and yield (kgmtha^{-1}) for tea crop at Ngwazi Tea Research Station (NTRS) during 2014/15.

Conclusion

Applied drip irrigation levels significantly affected both tea yield and shoot density traits. Deficit drip irrigation levels decreased tea yield and to a lesser extent shoot density. From the present study, applying drip irrigation at full treatment (I_4=100%) contributed to significantly higher tea yields. However, application of drip irrigation at I_1 (25% reduction of moisture stress) resulted to comparable yields with I_4 (100% reduction of moisture stress). For shoot density significant difference was evident between no-irrigation (I_0) with the rest of irrigation regimes (I_1 (25%) - I_4 (100%). Irrigation × Genotype interaction indicated genotype TRFK 303/577 (19) had highest tea yield at full-drip irrigation treatment (I_4=100%), while TRFK 303/259 (18) was promising for shoot density both at no-irrigated (I_0) - and deficit drip irrigation I_1 = 25%. Under limited water resource (I_0), genotypes TRIT 201/43 (4) and TRFK 303/259 (18) revealed significantly highest tea yields. Yield showed significant positive association (r = 0.725***) with shoot density. Also, significant positive correlation (r = 0.994***) was found between tea yield with water use efficiency (WUE). Shoot density with water use efficiency (WUE) presented significant positive associations (r = 0.701***). Yield - Evapotranspiration described positive quadrant with average R^2 = 0.583* in 2014/15 and linear with significant R^2 = 0.983*** in 2015/16 relationship. Yield-WUE relationship was linear and very weak (R^2 = 0.041) in 2014/15, but strongly negative and linear (R^2 = 0.781***) during 2015/16.

Recommendation: i. Tea genotype TRFK 303/577 (19) can be considered for commercialization in areas where water may not be a limiting factor. ii. Genotype TRFK 303/259 (18) can be considered for tea shoot density and yield production in areas where water availability can be a limiting factor. iii. Genotype TRIT 201/43 (4) can be recommended for yield production where water can be a limiting factor. iv. Genotypes TRFK 303/259 (18), TRFK 303/577 (19) and TRIT 201/43 (4) can be incorporated in tea breeding programmes for generation of improved tea genotypes on shoot density, yield and WUE. v. For maximum yield production it is recommended to irrigate tea at full drip irrigation level (I_4 = 100%). vi. In areas with moisture stress, high yields can be obtained using 25% reduction of moisture deficit (I_1).

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