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Phenology and yield performance in upland rice under varying water supply

Thesis prepared for the Degree Master of Science

Organic Agriculture and Food systems M.Sc.

Kristina Alina Klinkhammer

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Supervisor: Prof. Dr. Folkard Asch

Co-Supervisor: Prof. Dr. Georg Cadisch

Declaration

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Kristina Alina Klinkhammer

Born on 14.02.1991

Matriculation number: 574772

hereby declare on my honor that the attached Master thesis has been independently prepared solely with the support of the listed literature references and that no information has been presented that has not been officially acknowledged.

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Co-Supervisor: Prof. Dr. Georg Cadisch

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ABSTRACT

Rice consumption is currently increasing while rice production in drought prone areas is restricted to the limited amount of water. Many regions in SSA (Sub-Saharan Africa) seem to be marginally suitable for rice cultivation with natural rainfall amount and distribution. A more productive minimal water management is urgently needed to enable sufficient rice cultivation and to ensure food security. This study was conducted to investigate the impact of different water amounts and distribution on phenological development and yield performance of different upland rice cultivars. In a field trial in semi-arid Dodoma region, four NERICA varieties, four NERICA parents, IAC165 and one “Supa” genotype were tested under simulated unimodal Dodoma rainfall pattern (DO) and bimodal Morogoro rainfall pattern (MO). Furthermore, effects of supplementary irrigation in form of live saving irrigation and water management in form of simulated tied-ridges and weeding measures were tested. Phenological plant development, LAI (leaf area index), LRI (leaf rolling index), biomass and grain yield performance were observed while PAW (plant available water) was monitored during the experiment. Phenological observation showed that panicle initiation was delayed under rainfall scenarios for most varieties compared to plants with sufficient water conditions. Flowering appearance and ripening was dependent on genotype and mostly not affected by water treatments. Water shortage caused plant dying in MO and DO during the vegetation period and ended up in lower biomass accumulation and grain yield. Grain yield generally increased with higher water supply. Average NERICA yield under fully irrigated conditions was 2.34 t ha^{-1} while yield performance was 1 t ha^{-1} and less with 417.1 to 427.3 mm Dodoma rainfall. Late flowering SupaIndia cultivar did not perform grain yield under Dodoma rainfall. Morogoro treatment resulte 482.4 to 605.4 mm and gained yield of 1.83 ± 0.13 t ha^{-1} for SupaIndia. Irrigation supplements and water management increased yield for Dodoma treatments. Live saving irrigation in Dodoma with 20 to 50 % additional water input showed an increase in grain yield up to 572.24 % for NERICA17. The composition of yield components was not significantly changed with different water supply. HI (harvest index) was lowest for Dodoma rainfall and Dodoma rainfall plus tied-ridging simulation with 0.25 ± 0.20 and 0.25 ± 0.18 respectively. HI was lowest for SupaIndia. In conclusion, water management can improve yield performance and enable sufficient production in drought prone areas also without high external water sources.

Keywords: *Phenological development, BBCH, Supplementary irrigation, Minimal water management, NERICA*

CONTENT

TABLES AND FIGURES

ABBREVIATIONS

°C	Degree Celsius
µS	Microsiemens
ANCOVA	Analysis of covariance
ANOVA	Analysis of variance
ARI	Agricultural Research Institute
AWC	Available water capacity
bar	1 bar = 10^5 Pascal (Pa)
BBCH	Biologische Bundesanstalt, Bundessortenamt und Chemische Industrie
BEAF/	Beratungsgruppe Entwicklungsorientierte Agrarforschung/ Consultative
CGIAR	Group on International Agricultural Research
C	Carbon
Ca	Calcium
cc	Volume unit equate to 1 milliliter
CEC	Cation exchange capacity
CEC_{pot}	Potential cation exchange capacity
cm	Centimeter
cm^3	Cubic Centimeter
CW	Clean weeding
CWR	Crop water requirement
DAS	Days after sowing
Deg	Degree
DM	Dry matter
DM_B	Biomass dry matter
DM_W	Weed dry matter
DO	Dodoma
EC	Electrical conductivity
ET_0	Grass evapotranspiration
ET_C	Crop evapotranspiration
FAO	Food and Agriculture Organization
Fb	Fractional beam radiation
FC	Field capacity
FDR	Frequency domain reflectometry
FI	Full irrigation
FM	Fresh matter
FW	Farmer´s weeding

g	Gram
GIZ	Gesellschaft für Internationale Zusammenarbeit/ German Corporation for International Cooperation
h	Hour
ha	Hectare
HI	Harvest index
K	Potassium
K_2O	Potassium oxide
K_C	Crop coefficient
$K_{C\ end}$	Crop coefficient in end phase
$K_{C\ ini}$	Crop coefficient in initial phase
$K_{C\ mid}$	Crop coefficient in middle phase
kg	Kilogram
km	Kilometer
LAI	Leaf area index
LRI	Leaf rolling index
LSI	Life saving irrigation
L	Liter
m	Meter
m^2	Square meter
ml	Milliliter
Max	Maximum
MC	Moisture content
Mg	Magnesium
Min	Minimum
mm	Millimeter
mmol	Millimol
MO	Morogoro
mol	Mole
N	Nitrogen
Na	Sodium
NERICA	New Rice for Africa
O	Oxygen
Ø	Direction
P	Phosphorus
P_2O_5	Phosphorous pentoxide
Pa	Pascal

PAR	Photosynthetically active radiation
PAW	Plant available water
pH	Negative decade logarithm to base 10 of the H^+ concentration
PWP	Permanent wilting point
R^2	Coefficient of determination
rH	Relative humidity
s	Second
S	Sulphur
SD	Standard deviation
SE	Standard error
Sig.	Significant
SLA	Specific leaf area
SSA	Sub-Saharan Africa
TDR	Time domain reflectometry
TGW	Thousand grain weight
TR	Tied-ridges
TSP	Triple Super Phosphate
Vol. %	Volume percent
WARDA	West Africa Rice Development Association
WUE	Water use efficiency
WUEB	Biomass water use efficiency
WUEG	Grain water use efficiency
Y_{act}	Actual grain yield
Y_{pot}	Potential grain yield
z	Zenith angle
τ	Tau
χ	Leaf area distribution
%	Percent

BACKGROUND

This study was conducted in cooperation with the Africa Rice Center (WARDA); a CGIAR partner, and financially supported by BEAF (Ger: *Beratungsgruppe Entwicklungsorientierte Agrarforschung*) by GIZ (German Corporation for International Cooperation; Ger. *Gesellschaft für Internationale Zusammenarbeit*).

The experimental field trial was carried out within the GlobE research project “Trans-SEC- Innovating Strategies to safeguard Food Security using Technology and Knowledge Transfer: A people-centered Approach” funded by BMBF (*Bundesministerium für Bildung und Forschung*).

1 INTRODUCTION

Rice is one of the most important stable food crops (Hirano et al., 2008) and a basic food security component for more than half of the world (Dai et al., 1995). Seck et al. (2012) mentioned rice as the most rapidly increasing food source in Africa. From 2012, the rice consumption in Sub-Saharan Africa (SSA) is expected to increase 5 % per year. This enormous growth requires either more import or higher production (Seck et al., 2013). Drought and water scarcity are the major threats in global rice production, especially in semi-arid regions. Precipitation is not influenceable but a crucial factor for local rice production and a limiting factor in SSA. In semi-arid regions in East Africa, rainfed cropping systems are prone to water shortage induced by low precipitation amount and rainfall distribution (Seck et al., 2013). Irrigation management is a controversial topic in these areas since water availability is limited (Borrell et al., 1997). Drought during dry season and flooding during wet season on the central plateau in Tanzania are considered as natural hazards (Ricepedia, 2013). Besides total precipitation, rainfall variability is a major parameter in crop cultivation (Mahoo et al., 1999). According to Seck et al. (2012), seasonal drought prone areas are not suitable for water intensive rice cropping systems. Matsumoto et al. (2014) suggested that the minimum water requirement for upland rice is 311 to 600 mm during cropping period, depending on the variety. With different environmental conditions, land suitability for rice cultivation differs (Figure 1).

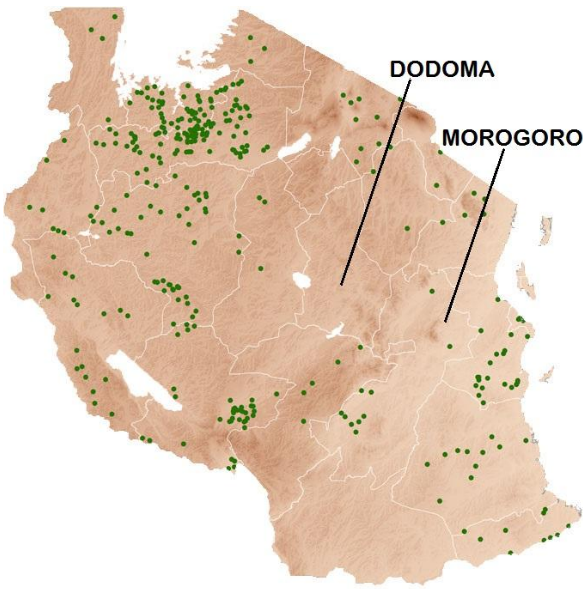


Figure 1. Map of Tanzania and districts borders with allocation of highest rice production areas. Each green dot represents a rice cultivation area of 1,000 ha (AfricaRice, 2013).

The semi-arid Dodoma region has unimodal rainfall with a wet season from October to April characterized by erratic rainfall patterns (Mahoo et al., 2015). Due to high rainfall variability, growing season usually starts in December and ends in May with an average precipitation amount of 429 mm during the growing season (Mahoo et al., 2015). Due to rainfall distribution and amount, Dodoma region seems to be marginal suitable for rice cultivation. One of the high potential agricultural regions in Tanzanian mainland is Morogoro region (Ministry of Agriculture Food Security and Cooperatives Tanzania, 2014), characterized by bimodal rainfall. Nevertheless, Mahoo et al. (1999) revealed an average precipitation of 445 mm during long rainy season and 327 mm during short rainy season with varying dry spells during the cropping period which are also marginal suitable for rice production (Seck et al., 2012; AfricaRice, 2013).

A productive cultivation method for rainfed upland rice in semi-arid regions in SSA is needed to fulfill the increasing rice and nutrient demand. Although some regions in Tanzania appear unfavorable for growing rice, water use efficiency of present rainfall has to be enhanced. Minimal water management can be seen as an opportunity to improve plant growth but has to be proven for rice cultivation in Dodoma and Morogoro. Knowledge about minimal water requirements and methods to increase yield performance with minimal external water input are necessary to ensure food security in these regions. A deeper understanding of plant development and water influence on yield components and yield generation presents the basis to improve agricultural techniques and genetic material. When required water amounts for rice production and most effective water usage stages are known, water saving methods, water harvesting (Hatibu and Mahoo, 1999) and minimal water management can lead to a sustainable and productive food production in semi-arid areas.

In irrigated lowland, rice cultivars such as IR64 and SARO5 are usually grown with grain yields from 2.5 to 4.0 t ha^{-1}. Upland rice production in Tanzania is currently reliant on landraces such as “Supa” cultivars. Grain yield of 0.8 to 1.0 t ha^{-1} are gained (Ricepedia, 2013). The Africa Rice Center, being part of the CGIAR system, is currently working on the introduction of new rice seed varieties into upland rice systems in many African countries such as Tanzania. NERICA (“New Rice for Africa”) is combining African (*Oryza glaberrima*) and Asian (*Oryza sativa*) rice species and their characteristics to find a rice genotype as high-yielding as *O. sativa* but adapted to African conditions (Somado et al., 2008). Advantages of NERICA varieties include high yield potential and short growth cycle enabling adaption to limited water availability in areas with short rainy season (Ricepedia, 2013). Moreover, some NERICA varieties show improved weed competitiveness, higher resistance against pests and diseases and higher nutrient content (Somado et al., 2008). In WARDA (West Africa Rice Development Association) field experiments in West Africa, NERICA upland rice varieties gained grain yields up to 6 t ha^{-1} (Africa Rice, 2008). WARDA analyzed the effects of drought stress in eleven NERICA varieties, NERICA parents and 87 non-NERICA varieties. Drought was implemented for 21 days starting 45 days after sowing. Drought stress significantly reduced number of tillers, number and weights of fertile panicles and grain yield ($p<0.05$). NERICA1 and 4 did not show yield reduction under drought stress. NERICA3, 5, 7, 8, 9 and 12 showed a higher yield than average yield in stressed plants (Somado et al., 2008). However, local farmers prefer rice cultivars that are known as traditional and local varieties but show low yield potential.

Drought resistant and high-yielding rice genotypes showing short growth cycles appear as an opportunity to counteract unbalanced rainfall distribution and to enable adequate grain yield production in semi-arid regions. A genotype based comparison under different rainfall conditions is necessary to analyze adaption and to identify the most suitable upland rice variety for each region resulting in sufficient grain yield.

This M.Sc. study was conducted in Dodoma region, Tanzania. The aim of this study was the analysis of yield performance in upland rice under simulated Dodoma and Morogoro rainfall conditions. Reasons for yield performance were revealed by comparing rainfall distribution and phenological development considering the crucial stages for yield components determination. Furthermore, it was investigated if minimal water management systems and methods can counteract potential yield losses during drought spells. Thus, supplementary irrigation in from of life saving irrigation and minimal water management in form of simulated tied-ridging were tested in combination with non-weeding and clean-weeding measures. As genetic revolution becomes more and more important in rice cultivation, 10 upland rice genotypes have been analyzed and compared in terms of phenological development and yield performance under satisfying irrigation and their adaption to the two East African regions. Results should lead to identification of the most suitable adapted variety for local farmers.

In addition, yield performance was analyzed under simulated Morogoro rainfall conditions and additional life saving irrigation, tied-ridges simulation and weeding to compare development differences and yield responses between erratic rainfall in Dodoma and bimodal rainfall in Morogoro with rainfall peaks at different plant development phases.

In theory, tied-ridging or furrow-diking is a possibility to use rain more efficiently by surface-runoff reduction (Krishna, 1989; Hitibu and Mahoo, 1999). Thereby it presents an opportunity to contribute to practicability of low-input rainfed crop production systems, also in semi-arid areas (Wiyo et al., 2000). Wiyo et al. stated that besides an erosion control measure, tied-ridging can be seen as a useful tool for water harvesting. It is known that yield is affected by tied-ridges (Wiyo et al., 2000). Objective of this study was to evaluate tied-ridges as improvement for agricultural production without external water input. Can the higher soil water content caused by simulated run off reduction ensure a sufficient rice production and lead to higher yield performance in Dodoma and Morogoro region?

Water availability to plants is not only dependent on water input; evapotranspiration and competition are further influencing factors (Tanner and Sinclaire, 1983). Agronomic practices, such as weed control, are the most common methods to reduce evaporation and thereby improving soil water holding capacity in Dodoma region (Hatibu and Mahoo, 1999). Findings of Hatibu and Mahoo revealed that weeding which is done twice or triple is a common farmer´s practice in local farming systems. Can frequently executed weed reduction by clean weeding reduce water evaporation, enhance soil water content and increase the effect of tied-ridging? Does grain yield profit from clean weeding compared to common farmer´s weeding practice?

Life saving irrigation is frequently discussed as supplementary irrigation method with minimal external water input in semi-arid regions (Prakasa Rao et al., 2001; Zaman, 2003; The World Bank, 2006). Is life saving irrigation as a minimal water management suitable to produce upland rice in Dodoma and Morogoro at satisfying yield levels? How much external water is needed to compensate drought spells?

This study was carried out during dry season 2015, rainfall and tied-ridges effects were simulated. Life saving irrigation and tied-ridging simulation can also be considered as different water supply levels. How much water is absolutely indispensable to result in satisfying yield in different rice genotypes and have different water distributions (by Dodoma and Morogoro rainfall as source) an effect on it? Which genotype benefits most from minimal external water input? Which genotypes are suitable for the two rainfall simulations?

2 DATA AND METHODS

2.1 Location

The experimental field trial was carried out at the Agricultural Research Institute (ARI) Makutupora in Dodoma, Tanzania. The station is located at S5° 58' 41.509" E35° 46' 5.873", 22 km north of Dodoma, 1091 m above sea level in Dodoma district. The field experiment was conducted from 9th of May till 7th of October 2015 during dry season.

2.2 Experiment

2.2.1 Experimental Design

The experiment was designed to investigate the effects of varying water supply and availability on 10 different rice varieties. In total 10 different water supply and weeding treatments were tested. The design was a randomized block design. The whole field was divided into two blocks to minimize site effects due to slope and different soil conditions. The experimental area included 20 plots, 10 plots in each block (Figure 3, top).

A drip line system was installed before the experiment started (Figure 2). This system was chosen due to its opportunity of applying specific amounts of water per plant hill and low water wasting as this study is supposed to contribute to a water saving rice production. Every plot was equipped with a separate drip line system for individual water supply enabling individual water supply. One plot in each block was assigned for one of the 10 treatments.

Each plot measuring 3.75 m x 5.40 m was divided into two subblocks to minimize site effects. Each subblock contained 10 subplots measuring 0.75 m x 1.20 m with 10 different rice varieties. Positions of treatments within blocks and varieties within subblocks were randomized.

Figure 2. Experimental field with installed irrigation system before sowing (left) and after sowing and labelling (right).

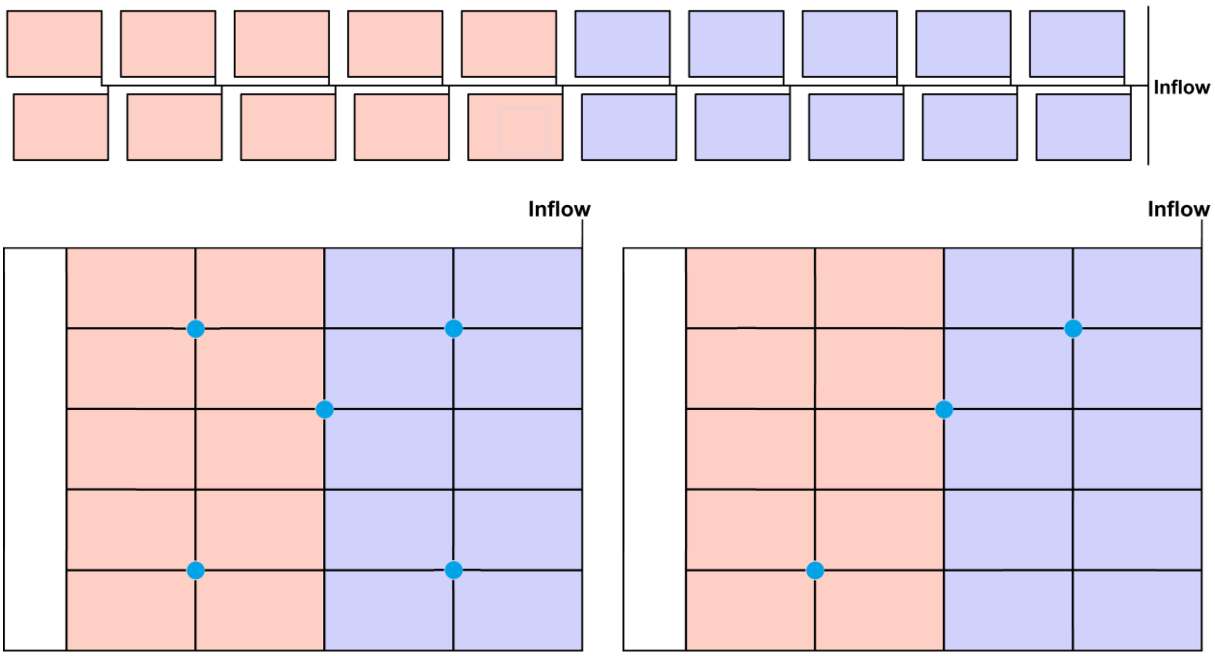


Figure 3. Field layout of experimental trial: plot arrangement (top) and subplot arrangement (bottom) in 2 blocks (red and blue). Blue dots mark positions of soil moisture access tubes which were installed within one plot for LSI plots (bottom, left) and other plots (bottom, right).

This design resulted in four replications for each variety in each treatment and 400 subplots in total. Due to the irrigation system with 25 cm drip line distance and 30 cm dripper distance 12 drippers were located in a subplot enabling 24 plant hills per subplot. Plants were sown on each side of a dripper with distance of about 6.25 cm to the drippers. To prevent interactions between varieties within a plot, every subplot was surrounded by 16 border plant hills of the same variety (Figure 4). All eight plant hills in the center of the subplots were numbered (Figure 4). The numbering of central plants within the plot was done in the same order for each subplot. In this thesis, all 16 border line plant hills of each subplot will be mentioned as “border plants” and these plants were not used for data collection. The eight central plant hills surrounded by the border lines hereinafter referred to as “harvest plants” were used for parameter analyses, BBCH stages determination and harvest.

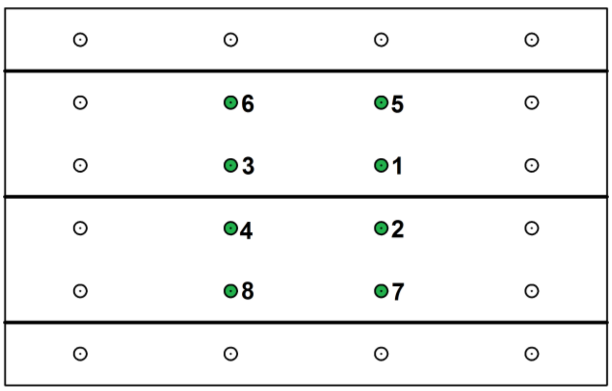


Figure 4. Scheme of a subplot with 24 plant hills. Lines illustrate drip lines, white dots represent border line plants and green dots the central harvest plants. Numbering represents the order for choosing plant hills for harvest.

2.2.2 Rice varieties

The Africa Rice Center (AfricaRice) introduced 18 different upland NERICA varieties until today. For this investigation, 10 rice varieties were tested including four NERICA varieties, four parent varieties of NERICA, one international variety and one "Supa" landrace as local check variety (Table 1). Seeds were provided by AfricaRice.

Table 1. Summary of tested upland rice varieties.

Variety	Selection criteria	Pedigree
NERICA4	NERICA	WAB 450-IBP-91-HB
NERICA7	NERICA	WAB 450-IBP-20-HB
NERICA14	NERICA	WAB 880-1-32-1-2-P1-HB
NERICA17	NERICA	WAB 881-10-37-18-13-P1-HB
CG14	Parent of NERICA1 to 18	
WAB56-50	Parent of NERICA 12 to 14	
WAB56-104	Parent of NERICA 1 to 11	
WAB181-18	Parent of NERICA 15 to 18	
IAC165	Internationally used variety	
SupaIndia	Locally used landrace	

Figure 5. Rice plant of IAC165 under full irrigation on day 14 after sowing.

Figure 6. Rice plant of CG14 under full irrigation on day 14 after sowing.

Figure 7. Plant and of CG14 (left) and IAC165 (right) under full irrigation on day 97 after sowing.

2.2.3 Treatments

To identify the general phenological development and yield performance of the 10 upland rice genotypes, genotypes were cultivated under fully irrigated (FI) conditions as control plots. In order to define the necessary daily irrigation amount to satisfy the crop water requirements (CWR), the crop evapotranspiration (ET_c) was determined according to the FAO Irrigation and Drainage Paper No. 56 (Allen et al., 1998).

$$ET_c = ET_0 \, x \, K_c \quad (1)$$

ET_c: crop evapotranspiration
ET_0: grass evapotranspiration
K_c: crop coefficient

ET_0 is the reference grass evapotranspiration (Allen et al., 1998) and based on long term climatic data (1980-2010) which were determined by the weather station of Dodoma airport. The crop coefficient (K_c) represents the crop characteristics and soil evaporation and was divided into $K_{c\ \mathrm{ini}}$, $K_{c\ \mathrm{mid}}$, and $K_{c\ \mathrm{end}}$ displaying the different water requirement situations during initial, middle and end plant growth stages, respectively. Calculations were done according to FAO guidelines (1998, 1990) and K_c values were used for calculations in 10 day intervals. To identify the CWR, ET_c was corrected by leaching requirements and irrigation efficiency. The daily irrigation amount was then computed taking into account plant spacing and discharge rates. Irrigation took place every day with minimal daily irrigation amounts.

Dodoma and Morogoro (Figure 8) rainfall pattern were chosen to compare upland rice performance under unimodal and bimodal rainfall conditions. For Morogoro, average annual precipitation ranges between 600 mm and 1800 mm (Ministry of Agriculture Food Security and Cooperatives Tanzania, 2014). Mahoo et al. (1999) revealed an average precipitation of 445 mm (*Masika*) during long rainy season (October to January) and 327 mm (*Vuli*) during short rainy season (March to May) with varying dry spells during the cropping period. Dodoma climate is characterized by one rainy season from November until April with average annual precipitation of 570 mm and around 429 mm during the growing season (December to May).

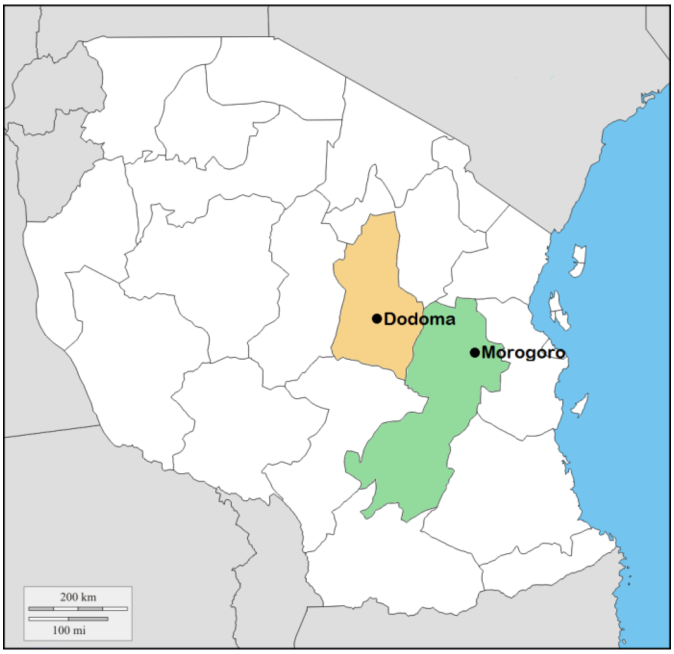


Figure 8. Location of Dodoma and Morogoro regions in Tanzania. The two rainfall scenarios presented in this thesis are based on average daily precipitation in these East African regions from 1980 to 2010 (adapted after www.d-map.com).

The different rice varieties were tested under irrigated conditions simulating the rainfall scenarios: a) rainfall as typical for the Dodoma region (DO) and b) rainfall as typical for the Morogoro region (MO). For simulation of these rainfall scenarios, the average precipitation amount for Dodoma and Morogoro was calculated for each day of the growing season. Basis for this calculation were weather data from 1980 to 2010. Since surface runoff water does not enter the soil surface and therefore does not contribute to the soil water balance, the simulated rainfall had to be corrected by surface runoff as surface runoff does not occur in a drip line field trial. The exact irrigation amount for rainfall events without surface runoff was calculated for each day on the basis of an investigation on tied-ridging effects on soil water status (Wiyo et al., 2000). Formula and calculation method was designed by Wiyo et al.:

$$\begin{aligned} &If\ R_i > R_w \qquad && RO_i = \frac{COEF}{100} \times (R_i - R_w) \\ &if\ R_i \leq R_w \qquad && RO_i = 0 \end{aligned} \tag{2}$$

$COEF$: percentage of rainfall converted to surface runoff = 46.2 %

R_i: input of rain (mm)

R_w:minimum amount of rainfall required to cause surface runoff = 3.3 mm

RO_i: Surface runoff

In addition, the effect of tied-ridging the field (TR) as a water conservation measure was tested by eliminating run off losses of rainfall for Morogoro and Dodoma. TR is a method of water harvesting and does not require external water input in practice. As the field trial for this study was conducted during dry season and water was supplied by a dripper system, elimination of surface runoff was simulated. For both rainfall simulations, tied ridges simulations were applied as advanced rainfall simulation. The exact irrigation amount was the actual daily rainfall used for rainfall irrigation but this time including the surface runoff.

Since weeds often constitute a major problem in upland rice systems, weed control was tested in combination with tied-ridging water supply for both regions and the control irrigation. In these three treatments, clean weeding was done frequently during the whole experiment. Other treatments were weeded twice during the experiment (after emergence and after row closure) as it is a common procedure in Dodoma local farming (Hatibu and Mahoo, 1999). Therefore the different weeding treatments will be considered as clean weeding (CW) and farmer´s weeding (FW).

In addition to the straight forward simulation of long term rainfall patterns in the region, plant condition based life saving irrigation (LSI) was provided for both rainfall events to estimate the amount of water needed as supplemental irrigation if the crop had been threatened by drought spells. For this water treatment, plants of respective plots were checked every morning before irrigation. Supplemental irrigation was applied with 50 % of the water amount of control plots (FI) of the same day if plants were threatened.

This results in the following ten treatments:

1. DO: Simulated rainfed conditions for Dodoma
2. MO: Simulated rainfed conditions for Morogoro
3. DOTR: Simulated rainfed conditions for Dodoma + simulated tied-ridging supplement
4. MOTR: Simulated rainfed conditions for Morogoro + simulated tied ridging supplement
5. DOLSI: Simulated rainfed conditions for Dodoma + life saving irrigation during drought spells
6. MOLSI: Simulated rainfed conditions for Morogoro + life saving irrigation during drought spells
7. DOTR + CW: Simulated rainfed conditions for Dodoma + simulated tied-ridging supplement + additional clean weeding to remove potential water users during the season
8. MOTR + CW: Simulated rainfed conditions for Morogoro + simulated tied ridging supplement + additional clean weeding to remove potential water users during the season
9. FI: Optimal fully irrigation with minimal amounts per day
10. FI + CW: Optimal fully irrigation with minimal amounts per day + clean weeding

For all simulated rainfall events, tied-ridging including rainfall events and full irrigation, the daily irrigation water amount was computed into irrigation duration according to irrigation efficiency, plant spacing, and discharge rate. Every plot was then supplied with the specific daily water amount by irrigation with the specific duration. To analyse LSI, TR and TR + CW treatments in contrast to pure rainfall scenarios, these treatments were hereinafter referred to as “advanced rainfall scenarios”.

The irrigation started on 9th of May, 2015, during dry season in Dodoma simulating the 29th of December. Due to technical problems in local water supply, irrigation was not possible on day after sowing (DAS) 84, DAS 114 and DAS 120 for all plots.

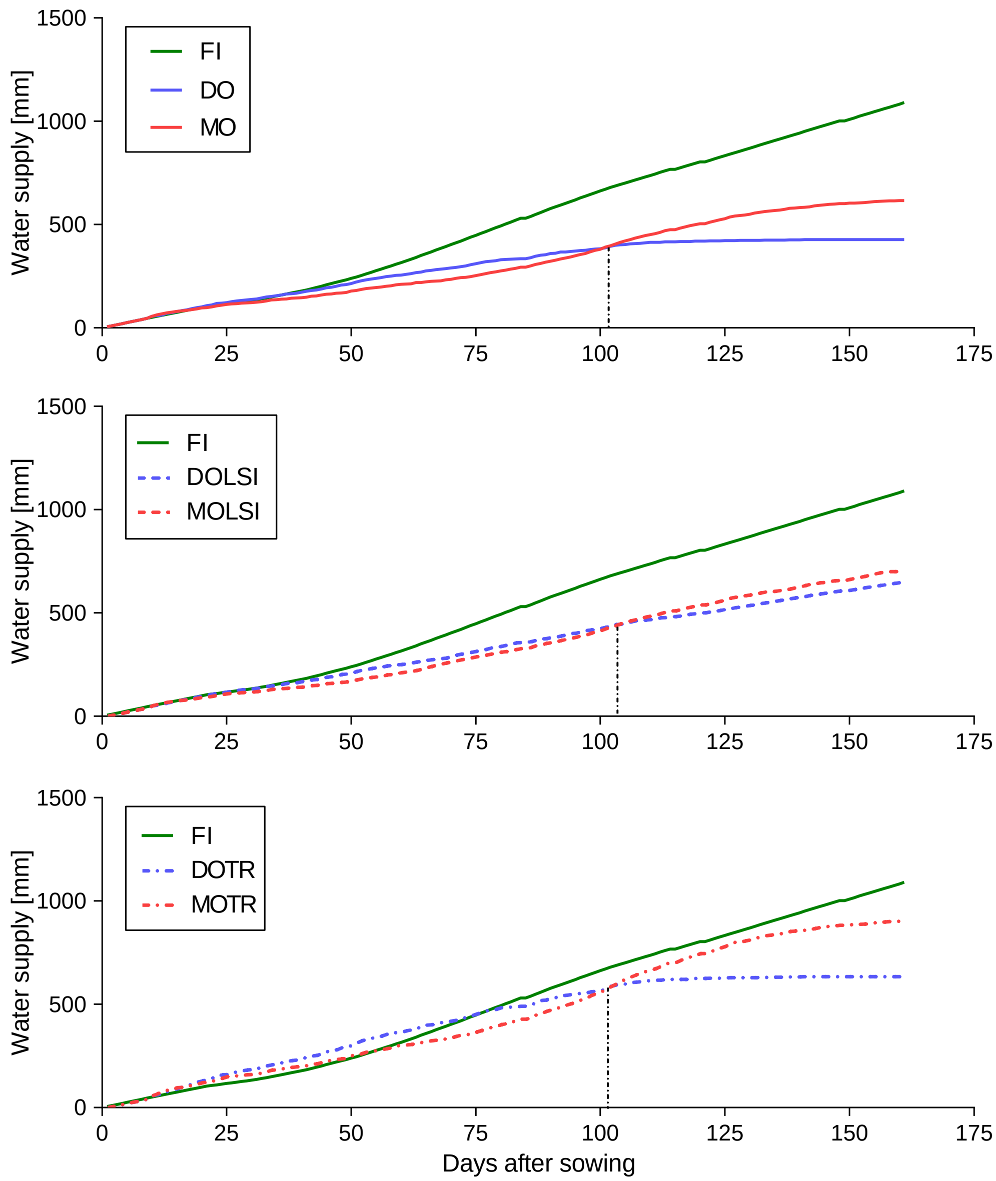


Figure 9. Accumulated irrigation amounts during whole vegetation period for simulated rainfall for Dodoma (DO) and Morogoro (MO) regions with supplementary life saving irrigation (LSI) and tied-ridging simulation (TR). TR simulation was computed after Wiyo et al., 1999. Vertical lines mark the interference of DO and MO lines.

2.3 Environmental conditions

2.3.1 Soil characteristics

The investigation took place in Makutupora, Dodoma district in Tanzania, during dry season 2015. Soil samples were taken for the trial area in April and May 2015 before the experiment started. The samples were analysed by the analytical laboratory for Soil Chemistry and Pedology at Hohenheim University, Germany. The soil was classified as Rhodic Cambisol (Blume et al., 2009).

Table 2. Mean physiochemical soil properties and soil characteristics for field trial area on Makutupora research station (n=3). Data were provided by the Soil Chemistry and Pedology at Hohenheim University, Germany.

Depth cm	**pH** (1:1)	**EC** (1:1) µS	**P** ppm	**K** ppm	**Sand** %	**Silt** %	**Clay** %	**Soil Type**
0-10	7.0	58.4	16.7	413.7	59.2	8.0	32.4	sandy clay
10-30	6.6	61.3	5.2	295.2	52.2	6.7	41.3	sandy clay
30-60	7.6	55.3	2.5	472.3	45.7	24.9	30.6	clayey sandy loam
60-90	7.5	59.0	5.0	621.8	47.3	16.4	38.1	clayey sandy loam
90-120	6.6	101.2	1.4	204.2	45.0	24.7	31.8	clayey sandy loam
120-150	7.0	87.0	1.3	133.3	46.1	31.9	25.7	clayey sandy loam

Depth	**Exchangeable cations**				**CEC_{pot}**	**Sum of cations**
cm	Na mmol kg^{-1}	K mmol kg^{-1}	Ca mmol kg^{-1}	Mg mmol kg^{-1}	mmol kg^{-1}	
0-10	0.3	13.0	44.5	18.2	106.5	76.0
10-30	1.2	10.4	44.6	18.5	116.3	74.8
30-60	3.2	14.6	41.4	25.2	124.1	84.4
60-90	2.0	19.9	46.8	22.1	131.4	90.8
90-120	5.0	6.7	45.2	26.7	125.8	83.7
120-150	6.3	4.8	64.3	30.7	154.8	106.0

Table 3. Field capacity (FC), permanent wilting point (PWP) and available water capacity (AWC) for different soil layers and mean over all depths (n=3). Data were provided by a Ph.D. project within the Trans-SEC-project.

Parameter	Soil depth				
	0-10 cm	10-20 cm	20-30 cm	30-60 cm	Mean
FC	25.30	28.33	28.07	30.47	28.04
PWP	13.68	15.32	15.17	16.47	15.16
AWC	11.62	13.02	12.90	14.00	12.88

Physiochemical soil properties for single soil layers are presented in Table 2. The soil was a clayey sandy loam and sandy clay soil with averagely 48.6 % sand, 18.5 % silt and 32.9 % clay. A bulk density of 1.38 $g \cdot cm^{-3}$ was measured. The pH values ranged from 6.6 to 7.6 depending on soil depth. The amount of organic N in 0 to 30 cm, 30 to 60 cm and 60 to 90 cm depth was 0.05, 0.04 and 0.03 %, respectively; the amount of organic C was 0.42, 0.29 and 0.24 %, respectively.

Additionally, field capacity (FC), permanent wilting point (PWP) and available water capacity (AWC) were determined to define the hydrological balance (Table 3).

$$Usable\ field\ capacity = field\ capacity - permanent\ wilting\ point \quad (3)$$

2.3.2 Climatic conditions

The experiment was conducted during dry season to minimize risks of external water sourcing. The agricultural research station Makutupora was equipped with a recording weather station (DELTA-T automatic weather station (WS-GP2)) next to the field area since 2014. The devices recorded temperature (°C), relative humidity (rH; %), photosynthetically active radiation (PAR; µ mol m^{-2} s^{-1}), wind speed (m s^{-1}), wind direction (Deg.) and wind gust (m s^{-1}) in 10 minute intervals. Monthly average data are presented in Annex A. Daily minimal, maximal and mean temperature and humidity are shown in Figure 10. The precipitation amount during the whole experimental period was 0 mm.

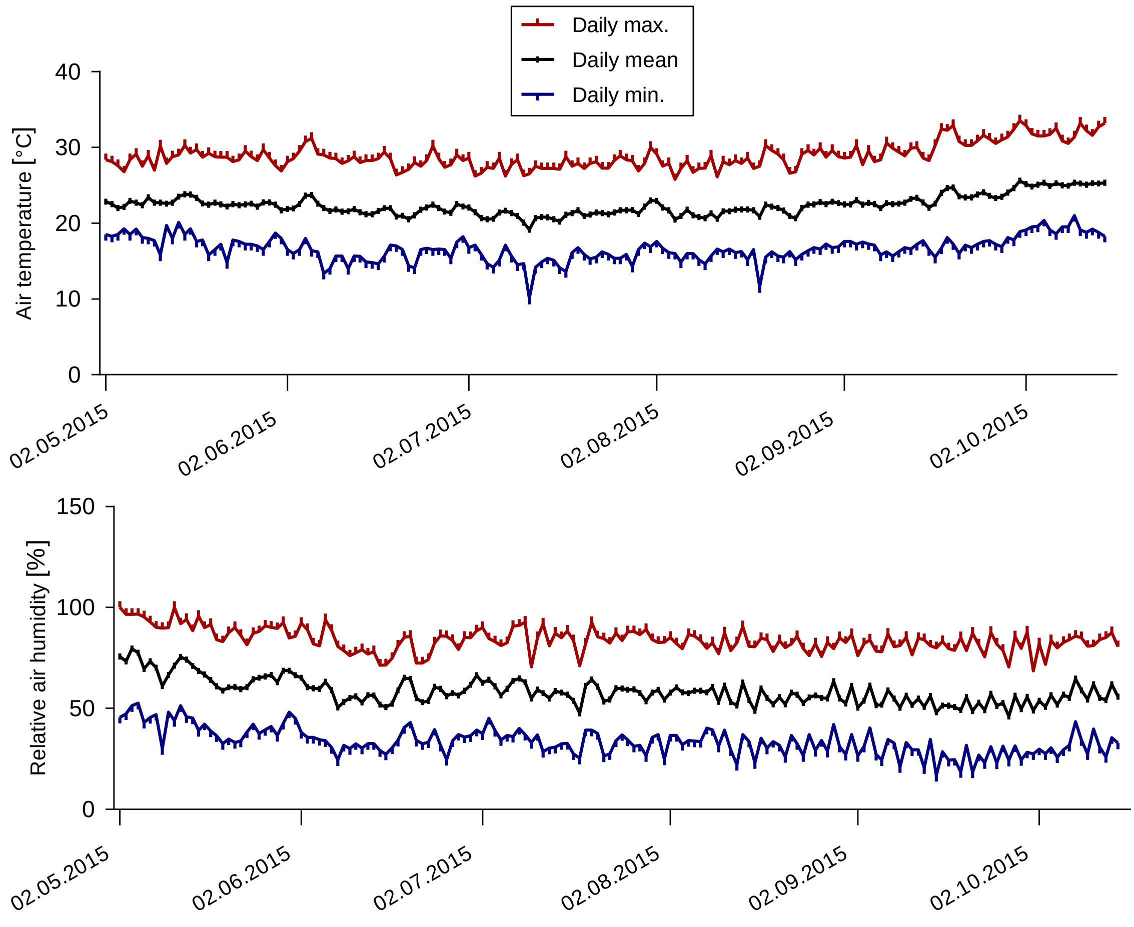


Figure 10. Daily minimal, maximal and mean temperature and relative humidity at Agricultural Research Institute Makutupora for whole experimental period.

2.4 Crop management

2.4.1 Sowing and Thinning

Before sowing, the whole field was hoed and levelled manually. The drip line system was installed before the experiment started.

Sowing was done on 9th of May, 2015. Seeds were sponsored and germination rate was tested by AfricaRice. The required number of seeds per hill was based on the germination rate (Table 4). Sowing was done manually by dibble technique (Figure 12). Sowing depth was 2-3 cm (Dunn et al., 2015). First fertilizer application was done basal during sowing into the sowing hole (section 2.4.2).

The number of plant hills per subplot was given by the irrigation system installation with 25 cm drip line distance and 30 cm dripper distance. Plants were sown on each site of the drippers. In total, 24 plant hills were planted for each subplot with a plant distance of approximately 12.5 cm, 6.25 cm distance to drip lines. Row distance was according to the dripper distance 30 cm (Figure 4).

Additional plant nursery fields were planted for each variety at the end of the field to ensure good transplantation opportunities (Figure 11). The nursery area was prepared for basin irrigation. Water was applied by hand every morning.

Table 4. Germination rate for investigated rice varieties and resulting seed amount per hill. Germination was tested and data were provided by Africa Rice Center.

Variety	Germination rate %	Seeds hill^{-1}
NERICA4	100	6
NERICA7	60	8
NERICA14	100	6
NERICA17	75	8
CG14	100	6
WAB56-50	90	6
WAB56-104	90	6
WAB181-18	40	10
IAC165	90	6
SupaIndia	60	8

Figure 11. Plant nursery area for plant transplantation at the end of the field (left) and subplot with wetting pattern for 12 drippers and emerging rice plants in 24 plant holes (right).

The aspired number of rice plants per plant hill was two. Thinning of emerged plants was done from 15 DAS to 60 DAS. Simultaneously missing plants per hill were augmented (Figure 12). Transplantation was done in the evening hours, when risk of heat drought and radiation stress was low for transplanted seedlings. A time table of transplantations for each variety is provided in the appendix (Annex B). Additional water was applied manually by cup to transplanted hills. This water supplements were necessary for transplanting success and were not included in water calculations and balances as not every plant per plot received the same amount.

Due to emergence rate and quantity of seeds, the number of nursery seedlings for genotypes WAB181-18 and SupaIndia was not sufficient for four subplots. Therefore one replication had been cleared for these two genotypes.

Figure 12. Sowing with farmer´s practice (left) and manual thinning and transplanting technique (right).

2.4.2 Fertilizer and pesticide application

First fertilizer application was done during sowing as a basal dressing. Yara Mila complex fertilizer (23 – 10 - 5), Potassium Nitrate (13 - 0 - 46) and Triple Super Phosphate (0 - 44.5 - 0) were used (Table 5). Fertilizers were applied directly into the planting hole for each plant hill.

Urea was applied two times during vegetation period as top dressings. Urea was dissolved in water and the solution was applied per watering can. The exact date for urea application was determined by visual assessment of the nutritional status of the plants (Table 5).

Table 5. Fertilizer application during the experiment.

Time of application days after sowing	**Product** (N – P_2O_5 - K_2O)*	**Application** (kg ha^{-1})	**Method**
0	Yara Mila Complex (23 - 10 - 5)	200.0	In planting hole, covered, then seed spreading
0	Potassium Nitrate (13 - 0 - 46)	43.5	In planting hole, covered, then seed spreading
0	Triple Super Phosphate (0 - 44.5 - 0)	18.2	In planting hole, covered, then seed spreading
37	Urea (46 - 0 - 0)	18.2	In solution by watering can
66	Urea (46 - 0 - 0)	18.2	In solution by watering can

*numbers in brackets identify the amount of N, P_2O_5 and K_2O in kg per 100 kg of the specific fertilizer

Pest control measures were carried out on DAS 66 and DAS 74 to control pests like African rice gall midge and stem borers (Table 5). Pesticides were applied via backpack sprayer.

Table 6. Pest control measures during the experiment.

Time of application days after sowing	**Product**	**Active ingredient**	**Dose** (mL L^{-1})	**Method**
66	Supercron 720EC	Profenofos	0.5	by foliar sprayer
74	Ninja 5EC	Lambdacyhalothrine	2.0	by foliar sprayer

2.4.3 Weeding and tillage

Weeding was divided into farmer´s weeding (FW) practice and clean weeding (CW) treatments. FW practice was defined as clean weeding (total remove of all weeds with roots) procedure that is done twice as common method for soil moisture conservation in Dodoma region (Hatibu and Mahoo, 1999). FW was done for all plots on 13 DAS after emergence to maintain normal plant growth and on 62 DAS after row closure.

CW was defined as clean weeding procedure in higher frequency than in FW. For CW including treatments all weeds were removed additionally during the whole experimental period. The desired status was the continuous absence of any weed within these treatments.

In general, weed control was done manually directly after irrigation. The handling was carried out with care to ensure absence of root residues in the field. During FW weeding on 62 DAS and 123 DAS (after harvest), total FM of weeds was recorded for NERICA4, NERICA14 and IAC165 subplots and samples of 100 g FM were taken for further DM analysis.

As soil compaction occurred due to small plot size and high pressure during measurements tillage was necessary to ensure usual plant growth and water infiltration pattern. Soil loosening was done for upper soil layers manually with wooden sticks on 70 DAS. Attention was paid to maintain a healthy root system.

2.4.4 Loss control

This investigation took place at ARI Makutupora during dry season. Except for other projects at ARI station, vegetation around the field was dried and depleted. Bird and rodent losses became a severe problem which increased during the experiment while environment became dryer. The field was guarded from sunrise to sunset during germination and from grain filling until harvest by manual bird protection.

2.5 Data collection

2.5.1 Soil water content

Soil moisture in soil depths of 10, 20, 30 and 40 cm was measured by PR2 probe (Profile Probe, Type PR2, Delta-T Devices Ltd., Cambridge, UK), a FDR (Frequency domain reflectometry) device. Additionally, surface soil moisture (5 cm soil depth) was measured by SM300 soil moisture sensor (Soil Moisture and Temperature Sensor, Delta-T Devices Ltd., Cambridge, UK), a TDR (Time domain reflectometry) device. Therefore, 40 cm long access tubes were installed in the plots to provide information about soil moisture in different soil layers during the experiment. In order to provide representative data, three tubes per plot were installed in a diagonal line though the plot. To report the soil moisture of LSI plots more in detail, LSI plots were equipped with five access tubes arranged crosswise (Figure 3). In total, 68 tubes were placed in the whole field. To minimize influence of tubes to the root zone of harvest plants, tubes were set at corners of subplots of different varieties right in the middle of four rice plants. To ensure reliable information about soil water content, attention was paid that tubes were vertical, free of dirt and closed between measurements.

Soil water content was measured twice a week. Values were recorded in vol %. To compute accurate soil moisture values, recorded values were adjusted by calibrating the SM300 and the PR2 probe. Therefore soil moisture content was determined one day by oven dried soil volume samples. Soil samples were taken and analyzed within the framework of a PhD project. Values of soil moisture samples and soil moisture measured by TDR and FDR devices resulted in calibration curves used in this experiment. Calibration curves are shown in the appendix (Annex C).

The soil moisture content was used to identify the amount of soil water usable for plants. The plant available water (PAW) was calculated for each measuring day during the experiment and for each surface layer, respectively.

$$Plant\ available\ water = measured\ soil\ moisture - permanent\ wilting\ point \tag{4}$$

PAW values were used to create an accumulated PAW stress index. Negative PAW values identify soil water deficit that might cause plant water stress. During these phases water was not available for plants. All negative values were accumulated and data were standardized by number of soil moisture measuring dates and days from sowing to harvest (Annex D).

2.5.2 Leaf Rolling Index

As this study should contribute to reveal the relation of water availability on rice physiology drought responses were reported to relate stress with water supply. Since rice is susceptible for drought, leaf rolling was frequently observed as stress indicator due to water shortage (O´Toole and Cruz, 1980; Turner et al, 1986). Leaf rolling index (LRI) was determined for three plants in each subplot weekly. Subjective values for leaf rolling were evaluated in a scale from one to nine for three harvest plants. The harvest plants were chosen according to allocated numbers for harvest priority in each subplot (Figure 3). Leaf rolling was determined in the morning to reduce rolling changes with changing radiation and temperature.

LRI values were used to create an accumulated rolling stress index. Due to named literature, higher LRI should identify higher water stress. All LRI values were accumulated for the whole growing period and corrected by the number of measuring dates (Annex D). Then rolling stress values were standardized by number of soil moisture measuring dates and days from sowing to harvest.

2.5.3 Phenological development and plant growth

All plots were frequently inspected to determine the phenological growth stages. The BBCH is a measurement of phenological growth stages (Lancashire et al., 1991). The BBCH growth stages such as emergence, tillering, stem elongation, booting, heading, flowering, milk ripening, ripening and senescence were recorded with this scale for each plot at least once per week. A detailed BBCH scale used during the field assessment is provided in the appendix (Annex E). Number of living plant hills and number of plants per BBCH stage were recorded during each reckoning. With these data, dates of entering each BBCH stage were evaluated. One subplot was considered as reaching one growth stage if 50 % of living harvest plant hills entered this stage.

Figure 13. Phenological development stage of emergence (left), heading (middle) and flowering (right) in irrigated upland rice.

2.5.4 Leaf area index

Leaf area index (LAI) is a measure of total one-sided plant leaf area per unit of ground area (He, Guo, & Wilmshurst, 2007). Since LAI is related to canopy biomass, plant growth, density and heterogeneity, it also provides information about microclimate and water loss. LAI was measured for NERICA4, NERICA14 and IAC165 in all treatments every week; one variety was measured per day. The LAI was measured non-destructively and calculated by Plant Canopy Analyzer LAI2000 (LI-COR Biosciences, Lincoln, Nebraska, U.S.). This device enables simultaneous above and below canopy PAR readings as a basis for LAI calculations (LI-COR, 1992). Calculation of LAI is based on the following parameters: zenith angle (z), fractional beam radiation (Fb), Tau (τ) and leaf area distribution parameter ($_{X}$). One sensor mode was used with one above canopy and four below canopy readings in two replications for each subplot (ABBBB ABBBB). For creating a representative value per subplot, the four below canopy readings were arranged in a diagonal line covering the central plot area (Figure 14). The view cap of 45° was chosen due to local light conditions. Measurements took place from 5 pm to 6.30 pm. The data were downloaded and handled by the file viewer FV2200 2.1.1 Software (LI-COR Biosciences, Lincoln, Nebraska, U.S.).

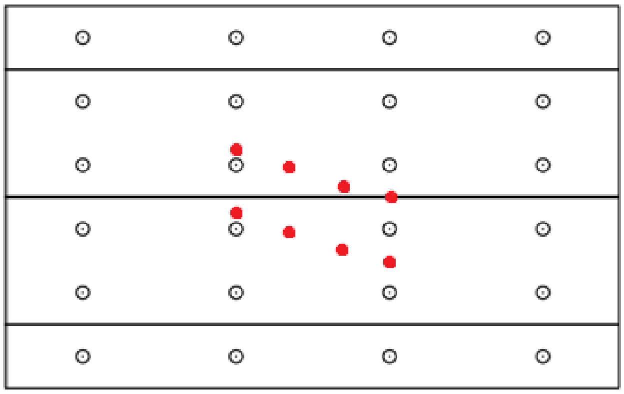


Figure 14. Scheme of leaf area index measure spots for LAI2000 device within a subplot. Thick lines illustrate drip lines, black dots represent plant hills and red dots represent LAI measure spots for two times four below canopy readings.

2.5.5 Harvest and yield parameters

According to Fageria (2007), yield performance is strongly influenced by yield components. To recognize the different relations of components per variety and treatment number of tillers, numbers of panicles per plant hill and panicle lengths were determined for one plant per subplot once per week. At harvest, final panicle number, average panicle length, panicle DM and filled and unfilled seeds per panicle were recorded.

Harvest date was determined separately for each treatment-variety combination. All four replicates were harvested at the same day (Table 7). One plot was harvested when 80 to 100 % of living plant hills reached ripeness stage. In total, six plant hills per subplot were harvested. At harvest, one single plant hill and five plant hills of the harvest plants were harvested by hand directly above soil surface. The hills were chosen according to the numbering of the eight central harvest plants within the subplot (Figure 4). If one hill within the harvest scheme was an empty hill, the scheme skipped to the next hill. Panicles were separated from stem and leaves. Panicles of the single harvested plant and the five plants were handled separately as samples. Stem and leaves of all six plants were handled together as total above ground biomass sample. All samples were packed in paper envelopes.

Table 7. Harvest dates in days after sowing for different upland rice varieties under different irrigation and weeding treatments.

Harvest date in days after sowing										
	Variety									
Treatment	CG14	IAC165	NERICA4	NERICA7	NERICA14	NERICA17	SupaIndia	WAB56-104	WAB181-18	WAB56-50
DO	119	119	116	121	119	119	152	119	119	119
DOLSI	121	121	116	131	119	121	152	119	121	119
DOTR	119	119	116	131	119	119	152	116	119	116
DOTR + CW	119	121	116	131	121	121	152	119	119	119
FI	121	119	116	131	119	121	152	116	121	119
FI + CW	119	121	116	142	119	121	152	119	121	119
MO	119	119	116	131	119	121	152	116	119	119
MOTR	119	119	116	131	121	119	152	119	119	119
MOTR + CW	121	121	116	142	119	121	152	121	121	121

Seeds of the five plant hills were separated from the panicle stems and FM was determined with an analytical balance (Sartoirus Entris Analytical Balance ENTRIS64-1S, Sartorius, Göttingen, Germany). All following weighing measurements were done with the same balance. For dry matter (DM) measurements, the seeds were oven dried at 105 °C for 72 h (Chen, 2003) and weighed afterwards.

DM of five plant hills was then used to compute the potential rice grain yield in g m^{-2} (Y_{pot}). Water content was determined with FM and DM of seeds with wet basis seed moisture content according to (ASABE, 1988) and adjusted to 14 % reference moisture content. A moisture content of 14 % was chosen as reference according to International Rice Research Institute corresponding to a moisture equilibrium at a vapour pressure of 3200 Pa and a temperature of 29 °C (San Martin et al., 2001). As the seed mass represented five plants, potential grain yield in g m^{-2} was grossed up. Actual performed grain yield (Y_{act}) in g m^{-2} was determined with percentage of living plant hills.

$$MC\ \% = (DM\ x\ FM)\ x\ 100 \tag{5}$$

MC: moisture content

DM: dry matter, water removed mass

FM: fresh matter, mass before drying

The biomass and panicle stem samples were sundried in direct sunlight and wind circulation to avoid mould and rotting processes. Later, all samples were oven dried at 70 °C for 72 h (Frank et al., 2004), weighed (s.a.) and dry matter for biomass (DM_B) was determined as described for grain yield. Actual performed biomass in g m^{-2} was determined with the percentage of living plant hills. The separately harvested single plant hill panicles were used for yield component analysis. Panicles per plant hill and filled and unfilled seeds per panicle were counted. Length and FM per panicle were measured respectively. The panicles were oven dried at 105 °C for 72 h and total DM was determined.

Y_{act} and DM_B per m^2 where used to calculate the harvest index (HI) using the first HI formula by Donald from 1962 (Hay, 1995):

$$HI = \frac{\mathrm{Y_{act}}}{(\mathrm{Y_{act}} + \mathrm{DM_B})} \tag{6}$$

2.5.6 Weed samples

During FW weeding, total FM of weeds was recorded for NERICA4, NERICA14 and IAC165 for each subplot. For each recorded subplot, a sample of 100 g was pooled. If the total FM was less than 100 g, the total weed amount was taken for this sample. All weed samples were dried in an oven at 105 °C for 72 h (Chen, 2003). Dry matter of weeds (DM_W) was quantified as for grain yield and biomass and the total DM_W for each subplot of the three varieties were calculated.

2.6 Statistical analysis

In order to make the effects of varying water supply and weeding treatments on the investigated parameters of the 10 varieties more comparable, data were normalized by calculating relative values. Relative values were derived by relating all parameter data to the mean parameter value for the four FI plots for the respective variety:

$$X \,\%\, of\ control = (X_{Treatment} / X_{control})\ x\ 100 \qquad (7)$$

$X_{Treatment}$: investigated parameter value and

$X_{control}$: mean value of the same parameter under FI conditions

Microsoft EXCEL 2010 (Microsoft Corporation, 2010, Redmond, U.S.) was used for data editing and organization. Statistical analyses were computed with *IBM SPSS Statistics 23.0* (IBM Corporation, 2015, Armonk, U.S.). By using ANOVA and ANCOVA procedures, significant treatment and genotype effects were identified as well as treatment and genotype interactions. Significances were determined by Tukey-tests with α=0.05 and LSD-tests with α=0.05. Linear regressions and other graphs were created with *GraphPad Prism 6.0 software* (GraphPad Software Inc, 2016, San Diego, U.S.). Linear regression analysis revealed trends and differences for single parameters.

Values presented in this thesis are given as mean ± standard error (SE) if not specified differently.

3 RESULTS

3.1 Water availability

3.1.1 Soil moisture content

This study focussed on upland rice growth and development behaviour related to water availability depending on water supply and weeding measures. The most crucial factor to understand the effect of investigated treatments is the soil moisture content within the soil during whole cropping period. Therefore soil moisture content was continuously monitored.

The soil moisture pattern was affected by DO and MO rainfall conditions. As expected, soil moisture was higher under higher daily irrigation amount and lower during drought spells when water was withheld. For all DO including treatments soil moisture was decreased compared to FI plots during cropping season in all layers (Figure 15). In contrast, MO treatment data showed increased soil moisture during cropping season. These results matched with the different water supply treatments and daily amounts shown in Figure 1. Rainfall simulations DO and MO caused the lowest moisture levels in all layers. Advanced water supply treatments such as tied-ridging, life saving irrigation and weeding measures resulted in higher values for DO and MO, respectively. For soil layers of 20 cm and deeper, soil moisture content in all treatments mostly was higher than in FI plots except for DO plots.

Surface moisture had the widest varying range during the experiment. Although moisture content in all deeper soil layers varied around 30% and less from FI control values, surface moisture varied from 21.9 % to -100 % in DOTR plots for DO including treatments (Figure 15; left) and -73.7 % in MO plots to 32.2 % in MOTR + CW plots for MO including treatments (Figure 15; right). Thereby, results showed no significant differences between TR and TR + CW treatments for both rainfall scenarios.

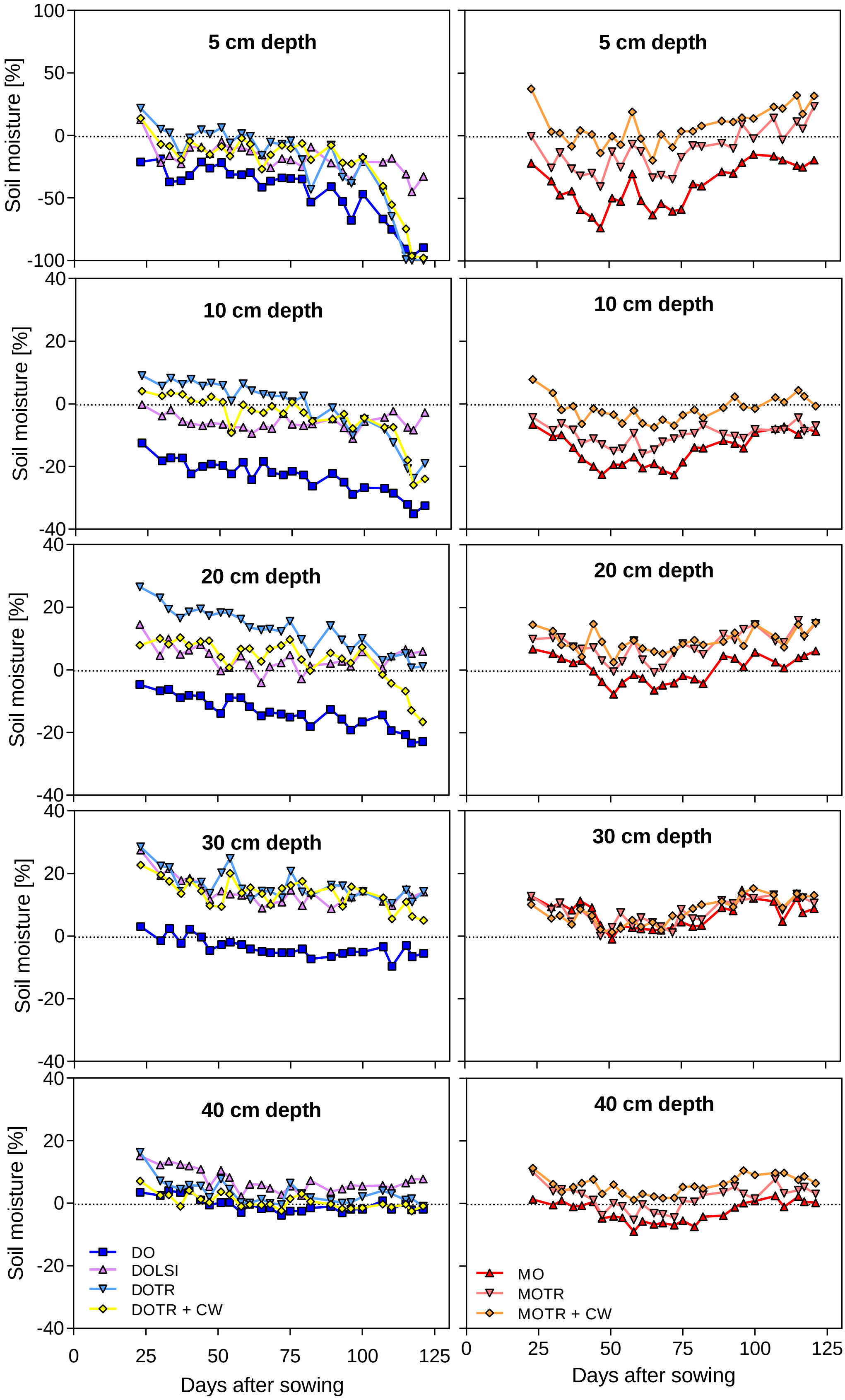


Figure 15. Soil moisture development in five different soil depths measured by PR2 for Dodoma (DO, left) and Morogoro (MO, right) rainfall plots and simulated tied-rides (TR), life saving irrigation (LSI) and clean weeding (CW) in percentage deviation to the fully irrigated plots.

Additionally, effects of clean weeding measures in comparison to farmer´s weeding measures were analyzed. Therefore, soil moisture content of CW treatments was related to FW treatments (in MOTR, DOTR and FI) for each measuring day (Figure 16).

When soil moisture in FW increased due to higher water supply, soil moisture in CW also increased. Linear regression curves showed positive interception values for 5, 10 and 40 cm soil depth. When soil moisture content was low, CW treatment caused higher moisture values compared to FW. Although weeds can maintain soil water by reduced soil water evaporation, reduced biomass production and transpiration by total weed removal seemed to have higher influence on soil moisture content. In higher soil moisture contents as 15 % and higher, CW had no effect on soil moisture compared to FW. In total, results showed no clear effect of clean weeding on soil moisture content.

Table 8. Equation for linear regressions of soil moisture in different soil layers in clean weeding plots (CW) related to farmer´s weeding plots under fully irrigated conditions (FI) and Dodoma (DOTR) and Morogoro (MOTR) rainfall simulation with simulated tied-ridging effect. For regressions, CW is taken as the dependent variable (y).

Linear regression:			
5 cm (surface)	FI:	$y = 0.63x + 6.10$;	R^2=0.53
	DOTR:	$y = 0.74x + 3.92$;	R^2=0.89
	MOTR:	$y = 0.70x + 8.54$;	R^2=0.50
10 cm depth	FI:	$y = 0.48x + 8.39$;	R^2=0.39
	DOTR:	$y = 0.78x + 4.16$;	R^2=0.85
	MOTR:	$y = 0.91x + 3.59$;	R^2=0.62
20 cm depth	FI:	$y = 0.72x + 5.47$;	R^2=0.71
	DOTR:	$y = 0.93x - 0.29$;	R^2=0.82
	MOTR:	$y = 0.80x + 4.52$;	R^2=0.68
30 cm depth	FI:	$y = 0.86x + 4.53$;	R^2=0.46
	DOTR:	$y = 0.77x + 3.91$;	R^2=0.59
	MOTR:	$y = 1.01x - 0.17$;	R^2=0.79
40 cm depth	FI:	$y = 0.83x + 3.30$;	R^2=0.44
	DOTR:	$y = 0.80x + 2.78$;	R^2=0.51
	MOTR:	$y = 0.48x + 8.97$;	R^2=0.41
All depths	FI:	$y = 0.81x + 3.22$;	R^2=0.70
	DOTR:	$y = 0.80x + 3.08$;	R^2=0.89
	MOTR:	$y = 0.89x + 3.31$;	R^2=0.76

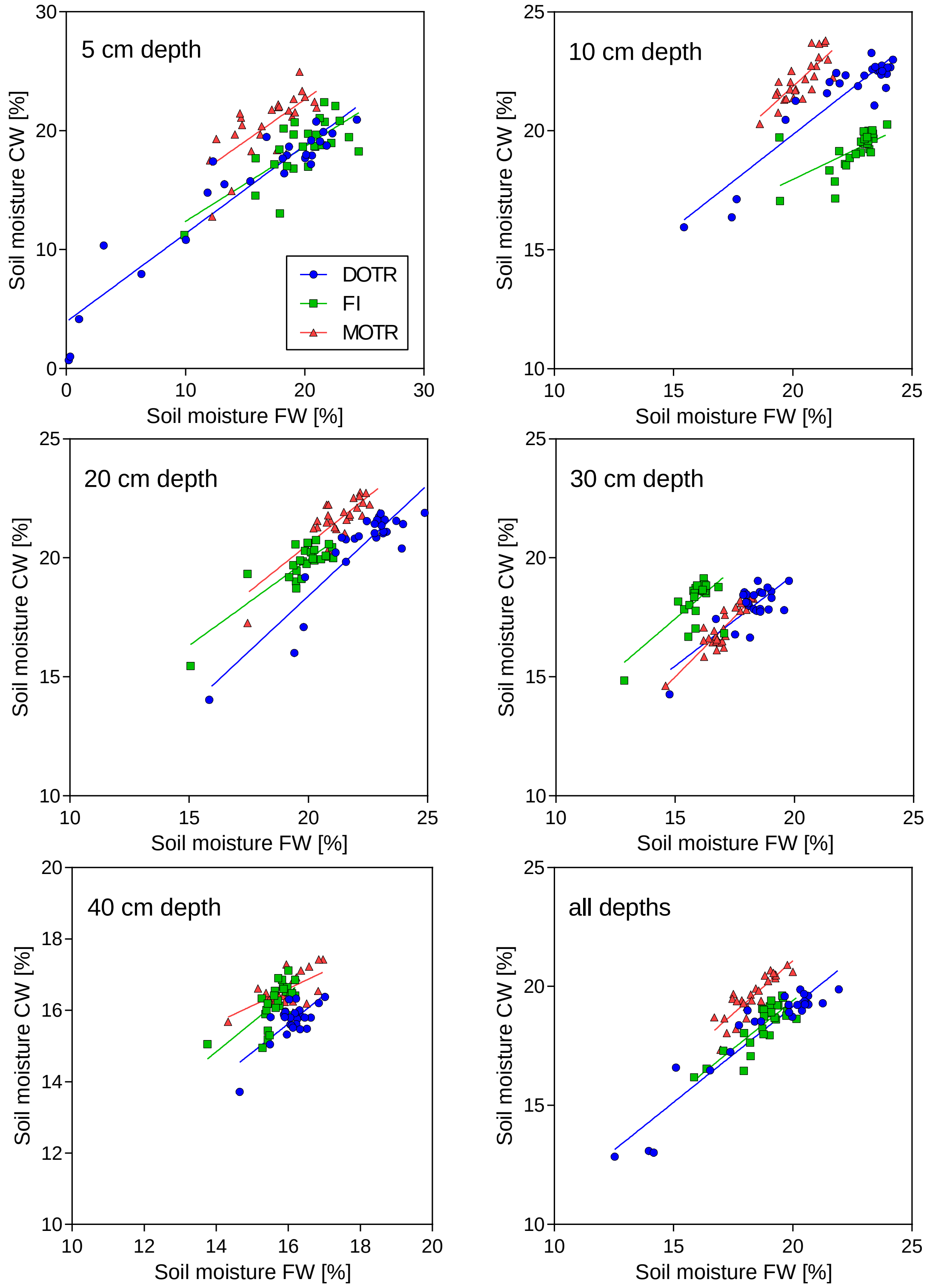


Figure 16. Soil moisture of plots with clean weeding measures (CW) related to farmer´s weeding measures (FW) for fully irrigated (FI) conditions and simulated Morogoro + tied-ridges (MOTR) and Dodoma + tied-ridges (DOTR) conditions for different soil depths.

3.1.2 Plant available water

In terms of plant maintenance not only soil moisture content is important but the ratio of water which is plant available. Therefore, PAW within the soil was determined by soil moisture content and the estimated PWP of soil layers. Negative values identify days of water absence for plants.

As expected, average PAW values showed same trends and patterns as soil moisture content (Figure 17). In soil layer average, MO and DO plots showed lower surface PAW values than FI during the whole season. Water shortage was only present in DO treatment beginning from DAS 93 to harvest. In MO and FI plots, soil water content was always higher than PWP. Figure 18 shows PAW for single soil layers and reveals water shortage phases during the season in more detail. PAW in soil layers of 10 cm depth and deeper did not correspond with water supply. FI plots had no water shortage for plants in 5, 10, 20 and 30 cm depth (Figure 18). Negative PAW values were reached in 40 cm depth that varied from -0.3 % to -2.7 %. Similar results were found for DO and MO plots in layers 10 to 40 cm: PAW did not show negative values for 10 and 20 cm depth in both rainfall scenarios but showed no negative to low negative values for 30 and 40 cm. In 30 cm depth, values for DO and MO plots varied from -2.35 to 0.72 % and -0.53 to 3.08 %, respectively. In 40 cm depth, PAW ranged from -2.48 to -0.32 in DO plots and from -2.18 to -0.17 % in MO plots. Surface PAW showed high variability during the season and was related to varying water supply. MO treatment had water shortage in the surface layer during the first weeks of experiment till DAS 83. Water shortage started at DAS 75 for DO treatment and went on till harvest. Although water supply for DO was higher or at similar level as FI (Figure 9), PAW was lower in DO plots than in FI plots. DO plots showed positive values until DAS 75 with peak at DAS 51. After DAS 51, PAW was decreasing to values of -13.27 %. MO treatment showed contrary surface PAW pattern during the experiment with negative values in the initial phase and positive values starting from DAS 89. Surface PAW was stronger affected by irrigation and evaporation compared to other layers.

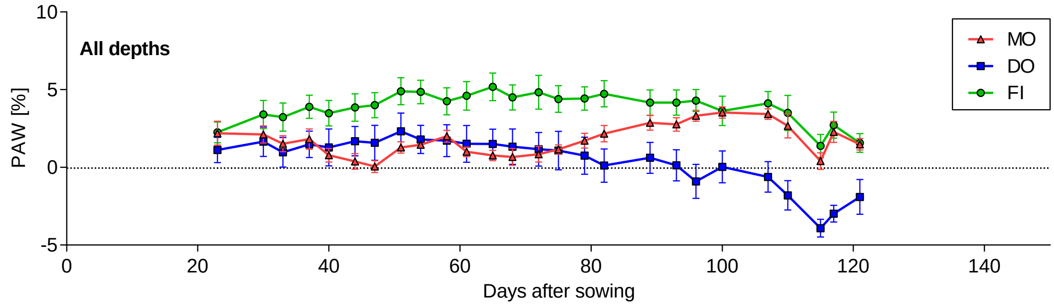


Figure 17. Plant available water (PAW) in different soil depths during experimental trial for Dodoma (DO) and Morogoro (MO) rainfall simulation and fully irrigated (FI) plots. Values are given as mean ±SE, n=5. Mean and SE were calculated with mean values per soil layer (5, 10, 20, 30, 40 cm depth). PAW was computed as current soil moisture in vol. % without permanent wilting point in vol. % of each soil layer.

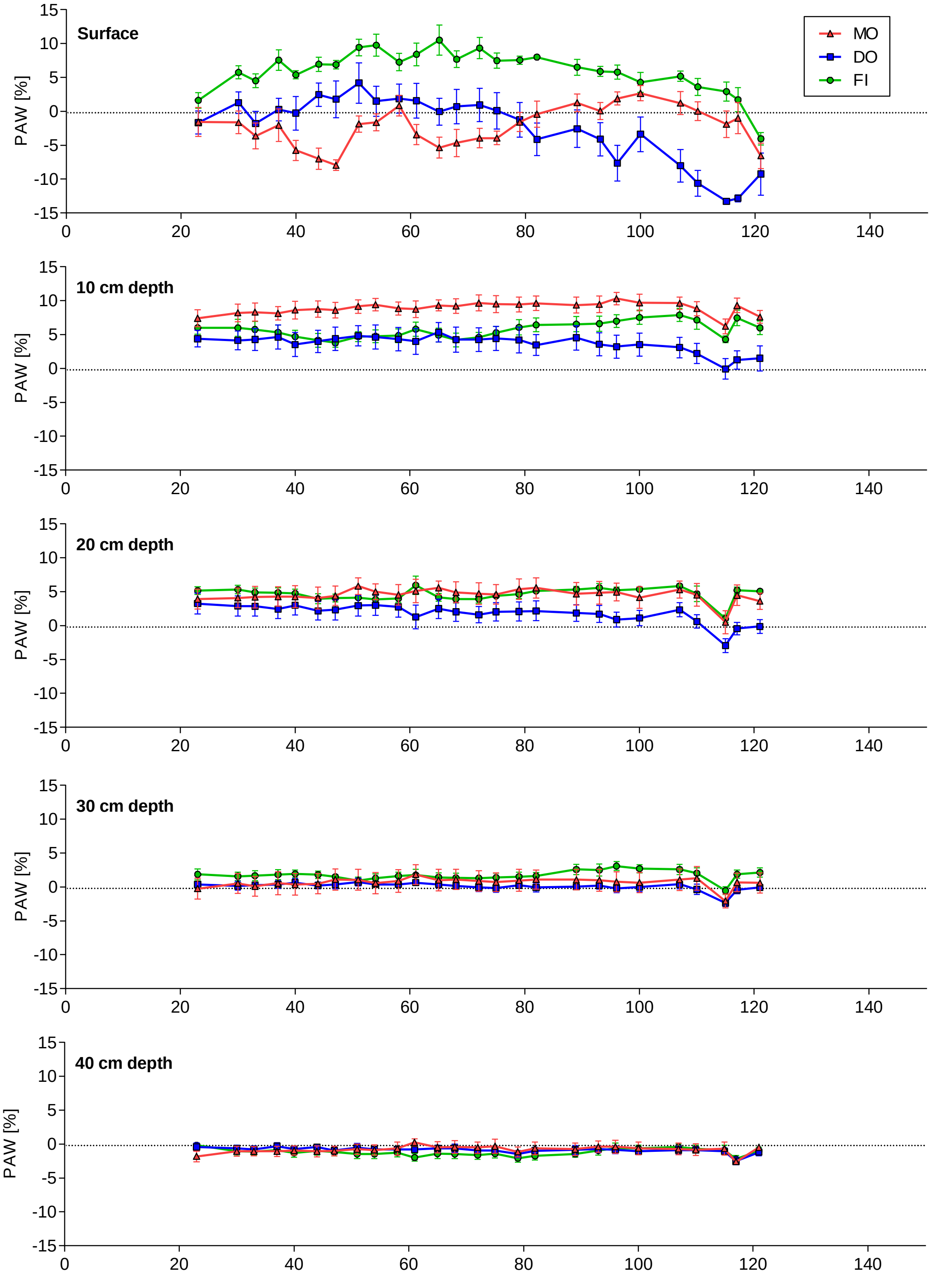


Figure 18. Plant available water (PAW) in different soil depths during experimental trial for Dodoma (DO) and Morogoro (MO) rainfall simulation and fully irrigated (FI) plots. Values are given as mean ±SE, n=6. PAW was computed as current soil moisture in vol. % without permanent wilting point in vol. % of each soil layer.

3.1.3 Leaf rolling index

In rice, LRI can be used as a subjective water stress indicator. To investigate the short-term physiological response of rice plant to water shortage, LRI was determined every week.

Highest LRI was found for CG14 for all treatments (Figure 19). CG14 reached values that were significantly higher than for other varieties with $p<0.05$. Lowest accumulation values were reached in IAC165, SupaIndia and WAB181-18.

Treatments had a significant effect on LRI ($p=0.002$). In treatment comparison FI plants had lowest accumulated LRI values for the whole period followed by plants in FI + CW. DO and DOTR had highest LRI values. On average, plants in DO were significantly more stressed than plants in FI and FI + CW. Plants in DOTR were more stressed than FI with $p<0.05$.

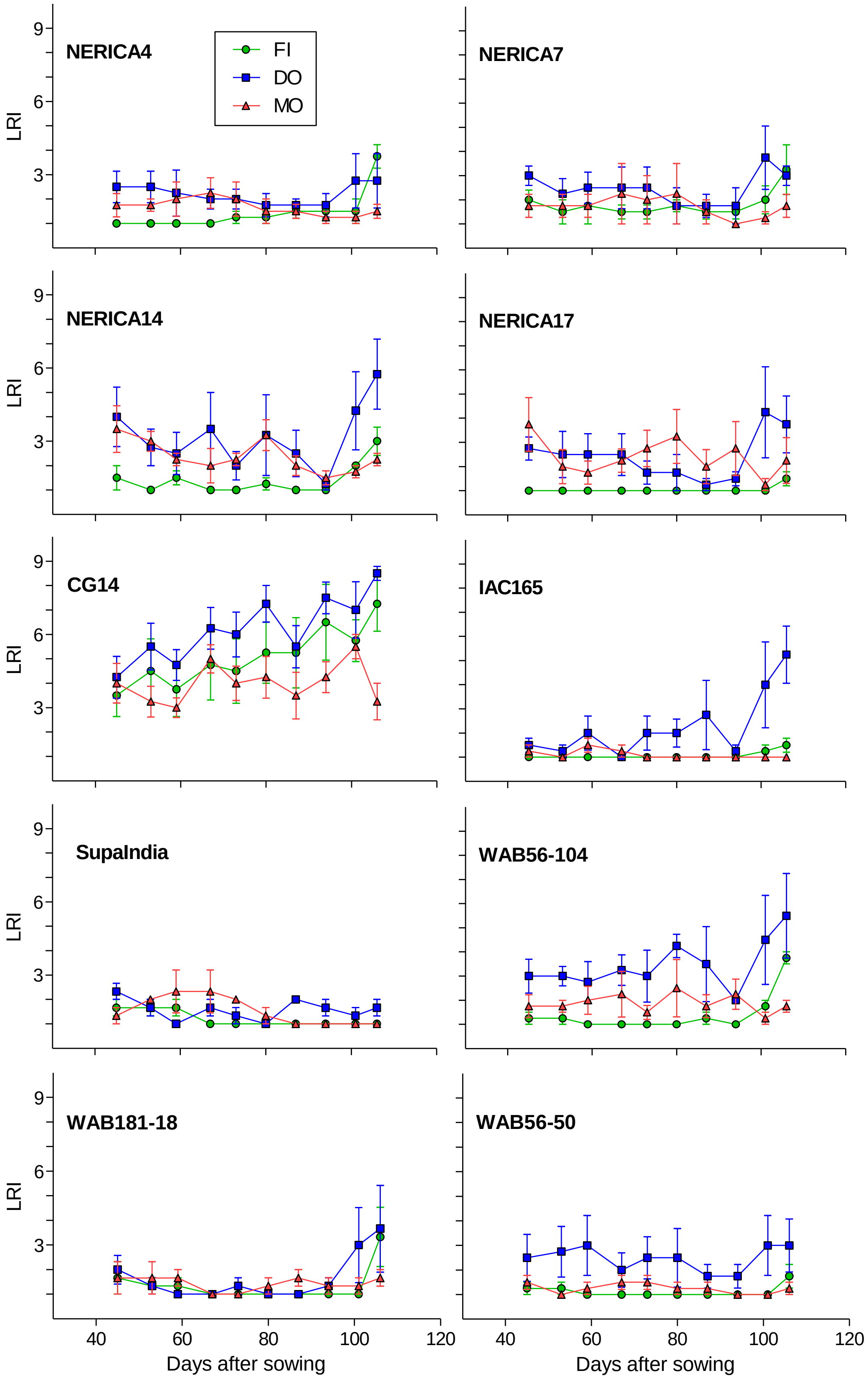


Figure 19. Leaf rolling index (LRI) development as subjective water stress indicator for different rice varieties under Dodoma (DO) and Morogoro (MO) rainfall simulation and fully irrigated (FI) plants. Evaluation scale ranged from 1 (no rolling) to 9 (totally rolled). Values are given as mean ±SE, n=4 and n=3 for SupaIndia and WAB181-18, respectively.

3.1.4 Correlation of PAW and LRI

The LRI is a subjective evaluation measure to identify stress reaction of rice plants according to water. LRI is expected to rise with lower PAW. To evaluate the validity of the LRI, the rolling stress index was related to PAW stress index to reveal existing correlations. Furthermore, the influence of PAW in different soil layers on plant stress reactions was evaluated since PAW in the effective root zone is most important.

Linear regression analysis showed that there was a significant correlation between PAW stress index in the soil surface and LRI stress index for IAC165, NERICA14, NERICA17, WAB56-104, WAB181-18 and WAB56-50 (Table 9). Other soil layers are provided in the appendix (Annex F, G, H and I). LRI increased significantly with increasing soil surface PAW stress index. For 10 cm depth PAW stress index, a correlation was found for IAC165, NERICA14 and WAB181-18. PAW stress was low in soil depths of 20 cm and deeper (considering Figure 18). Soil depth of 20 cm and 30 cm showed no correlation. A soil depth of 40 cm showed correlation for NERICA14, WAB56-104 and WAB56-50. Surface water content and surface plant available water had influence on plant stress reaction while deeper soil layers had lower effects or effects could not be revealed with this correlation as there was no or low PAW stress in deeper layers. For CG14, NERICA4, NERICA7 and SupaIndia, LRI did not show correlation to PAW in any soil layer.

Table 9. Results of linear regression analysis for rice leaf rolling index and PAW (plant available water) stress index in soil surface layer (5 cm depth) for different varieties.

Variety	Lin. Regression		Slope sig. non-zero	p-value
CG14	y=-0.053x+3.67	R^2=0.00	No	0.689
IAC165	y= -0.22x+0.16	R^2=0.20	Yes	0.004
NERICA14	y= -0.36x+0.45	R^2=0.37	Yes	< 0.0001
NERICA17	y=-0.17x+0.42	R^2=0.15	Yes	0.015
NERICA4	y=-0.14x+0.55	R^2=0.09	No	0.055
NERICA7	y=-0.15x+0.86	R^2=0.07	No	0.089
SupaIndia	y=-0.13x+0.31	R^2=0.09	No	0.108
WAB56-104	y=-0.10x+0.31	R^2=0.21	Yes	0.010
WAB181-18	y=-0.26x+0.70	R^2=0.21	Yes	0.003
WAB56-50	y=-0.22x+0.28	R^2=0.16	Yes	0.010

3.2 Phenological development

Based on the phenological development stages designed by LANCASHIRE et al. (1991) the phenological development of the 10 genotypes for the different treatments was analyzed. The most crucial development stages are panicle initiation (PI), flowering and ripening. Table 10 presents the average number of days to 50 % appearance of the principle development stages across the investigated water supply and weeding treatments aggregated over 10 upland rice varieties.

Length of vegetative plant growth was affected by water availability. Duration from sowing to PI was shorter in plots with sufficient water supply according to CWR while PI was delayed in plots under rainfall conditions (Table 10). On average, vegetative plant growth was shortest for plants in FI with 62.96 ± 0.22 days and longest for plants in DOTR with 68.18 ± 0.9 days. On average, water supply in FI was 419.45 mm until plants reached 50 % PI stage. Plants in DO were supplied with 281.31 mm until average PI date, plants in MO with 222.76 mm.

Table 10. Average duration from sowing to 50 % appearance of development stages across 9 irrigation treatments with farmer´s and clean weeding. Treatments include Dodoma (DO) and Morogoro (MO) rainfall plots and advanced rainfall treatments as simulated tied-rides (TR), life saving irrigation (LSI) and clean weeding (CW). Data represent mean in days after sowing (DAS) ± SE aggregated over 10 varieties, n=9. Values with different letters identify significant differences with $p<0.05$, tested with LSD-test.

Treatment	**Date of 50 % appearance (DAS)**			
	Panicle initiation	Flowering	Ripening	Senescence
DO	66.38 ± 0.85 ^{cd}	99.20 ± 1.6	109.63 ± 2.6	116.00 ± 2.32
DOLSI	65.88 ± 0.69 ^{bc}	99.80 ± 3.53	111.42 ± 4.41	119.93 ± 3.9
DOTR	68.18 ± 0.90 ^{d}	101.33 ± 3.46	112.81 ± 3.83	116.79 ± 3.99
DOTR + CW	64.30 ± 0.60 ^{ab}	98.60 ± 3.95	108.09 ± 3.64	117.02 ± 4.15
FI	62.96 ± 0.22 ^{ab}	95.78 ± 3.85	108.73 ± 4.86	116.95 ± 4.32
FI + CW	64.86 ± 0.74 ^{bc}	98.82 ± 5.15	109.26 ± 5.06	118.00 ± 4.25
MO	64.44 ± 0.64 ^{abc}	94.68 ± 5.17	105.46 ± 4.89	115.01 ± 4.45
MOTR	66.03 ± 0.58 ^{cd}	97.88 ± 4.48	109.69 ± 4.58	117.68 ± 4.1
MOTR + CW	65.52 ± 0.64 ^{bc}	98.70 ± 4.06	111.97 ± 4.47	118.03 ± 4.39
Mean	**65.52 ± 0.26**	**98.31 ± 1.3**	**109.56 ± 1.39**	**117.27 ± 1.29**

Table 11. Average rice crop duration from sowing to 50 % appearance of development stages across 10 varieties. Data represent mean in days after sowing ± SE aggregated over 9 irrigation and weeding treatments, n=10. Values with different letters identify significant differences with $p<0.05$, tested with LSD-test.

Treatment	**Date of 50 % appearance (DAS)**			
	Panicle initiation	Flowering	Ripening	Senescence
CG14	63.89 ± 0.54 [a]	89.39 ± 1.4 [ab]	102.28 ± 1.43 [bcd]	112.83 ± 1.3 [b]
IAC165	64.19 ± 0.44 [a]	96.69 ± 1.4 [c]	107.5 ± 1.15 [cdef]	113.67 ± 1.24 [b]
NERICA14	64.42 ± 0.55 [a]	87.69 ± 1.53 [a]	96.25 ± 1.23 [a]	105.83 ± 0.93 [a]
NERICA17	66.28 ± 0.87 [bcd]	108.68 ± 1.31 [d]	122.63 ± 1.77 [g]	125.94 ± 2 [c]
NERICA4	66.59 ± 0.91 [cd]	95.64 ± 1.36 [c]	106 ± 1.44 [cdef]	114.25 ± 0.72 [b]
NERICA7	64.72 ± 0.48 [ab]	96.72 ± 1.08 [c]	108.42 ± 1.24 [def]	115.08 ± 1.13 [b]
SupaIndia	66.81 ± 0.81 [cde]	128.52 ± 2.91 [e]	141.19 ± 1.87 [h]	148.78 ± 1.84 [d]
WAB56-104	68.70 ± 0.91 [e]	91.92 ± 1.57 [abc]	100.36 ± 1.49 [cdef]	109.69 ± 1.34 [b]
WAB181-18	65.36 ± 0.63 [acd]	95.37 ± 1.61 [bc]	108.33 ± 1.84 [ab]	114.93 ± 1.2 [c]
WAB56-50	64.19 ± 0.70 [a]	92.47 ± 0.79 [bc]	102.67 ± 0.55 [bcde]	111.67 ± 1.05 [b]
Mean	63.89 ± 0.54 [a]	**98.31 ± 1.3**	**109.56 ± 1.39**	**117.27 ± 1.29**

Although the beginning of the generative plant development was affected by water availability, crop duration from sowing to 50 % flowering, ripening and senescence on average did not differ significantly between all varying water supply and weeding measures. Total crop duration ranged from 115.01 ± 4.45 days for plants in MO to 119.93 ± 3.9 days for plants in DOLSI.

Table 11 shows the average 50 % appearance of development stages across the 10 rice varieties aggregated over all treatments. It is shown that development speed was dependent on variety.

On average, PI was later for WAB56-104 (68.70 ± 0.91 days) than for other genotypes with $p<0.05$ while PI was earliest in CG14 (63.89 ± 0.54 days) than for all other genotypes. Duration to 50 % flowering varied from 87.69 ± 1.53 DAS (NERICA14) to 128.52 ± 2.91 DAS (SupaIndia). NERICA17 and SupaIndia reached the 50 % flowering stages at significantly higher DAS values than all other varieties with $p<0.05$. While average for flowering was DAS 98.31 ± 1.3, this stage was reached 10.37 days later in NERICA17 and 30.21 days later in SupaIndia. Due to the late flowering appearance for these two varieties, the duration from sowing to ripening stage and senescence stage were significantly longer than for other genotypes. Senescence was reached at DAS 125.94 ± 2 for NERICA17 and 148.78 ± 1.84 for SupaIndia while duration for other varieties ranged from 105.83 ± 0.93 in NERICA14 and 115.08 ± 1.13 in NERICA7.

The mean delay of BBCH stage appearance for DO and MO rainfall treated plants related to FI plants aggregated over all tested varieties is presented in Figure 20 and Figure 21. Plant development was not only affected by total irrigation amount but also by water shortage timing in relation to plant development.

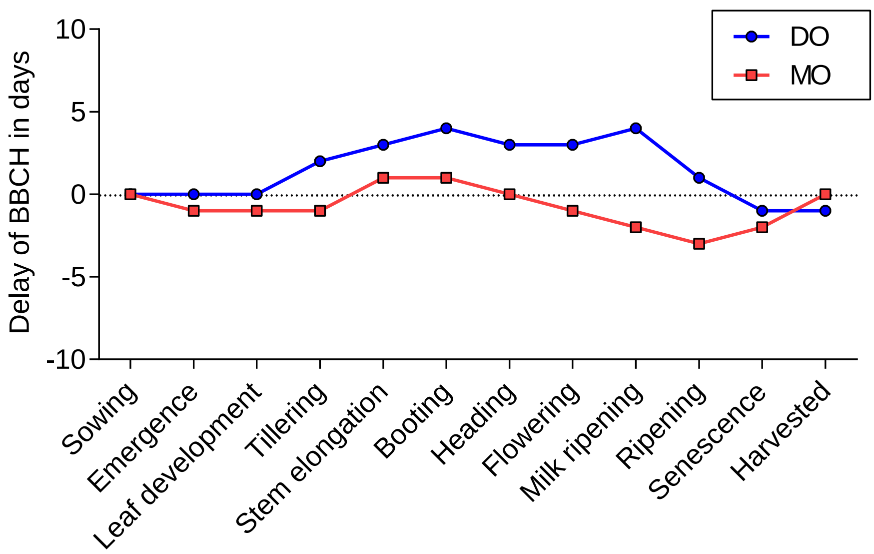


Figure 20. Delay of 50 % developing stage appearance in the field as mean for 10 different rice varieties for simulated Dodoma (DO) and Morogoro (MO) rainfall events related to fully irrigated plots (FI); n=36. The x-axis is a non-metric scale representing different development stages plus sowing and harvest. Positive values indicate delay, negative values indicate earlier appearance.

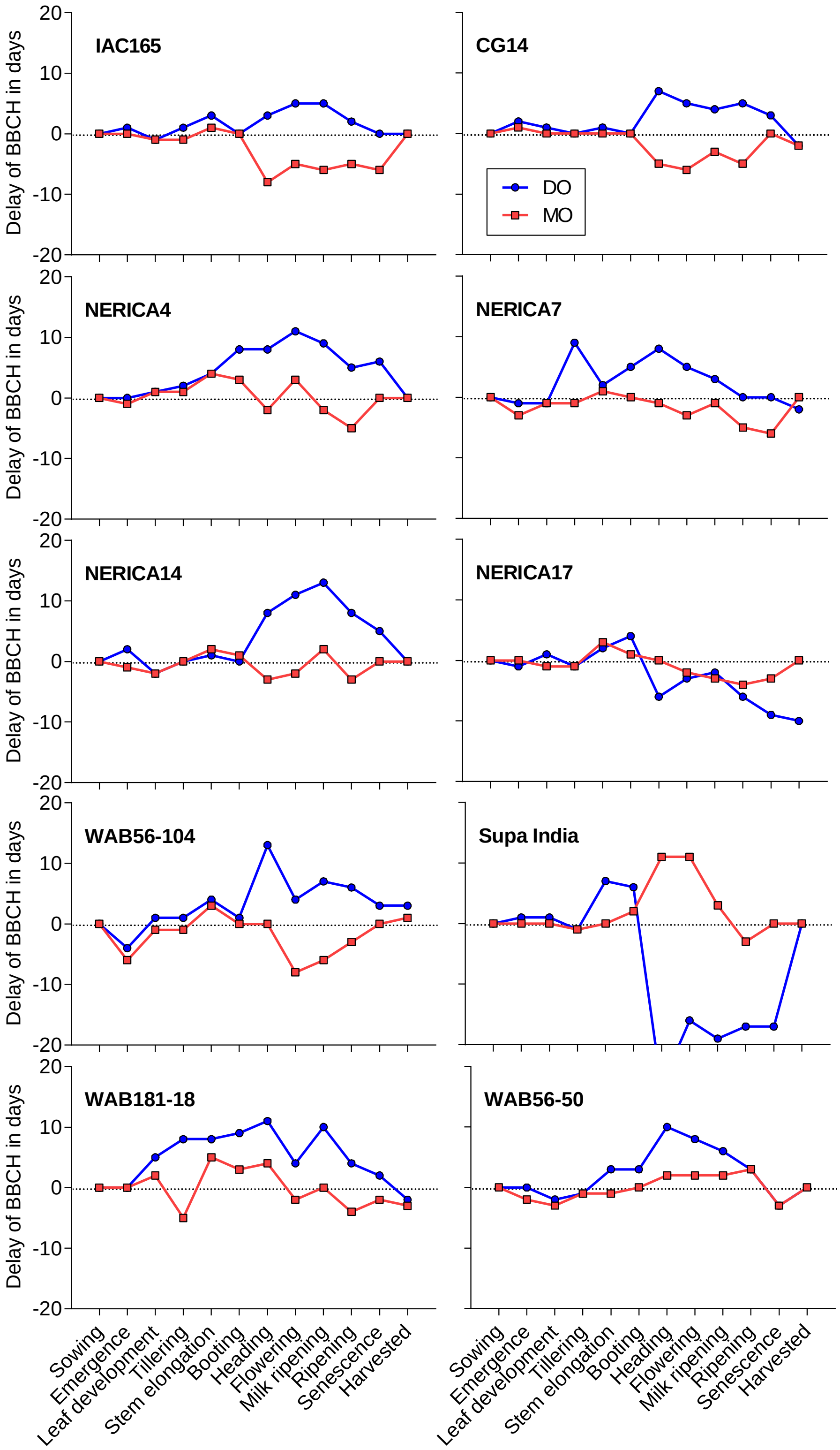


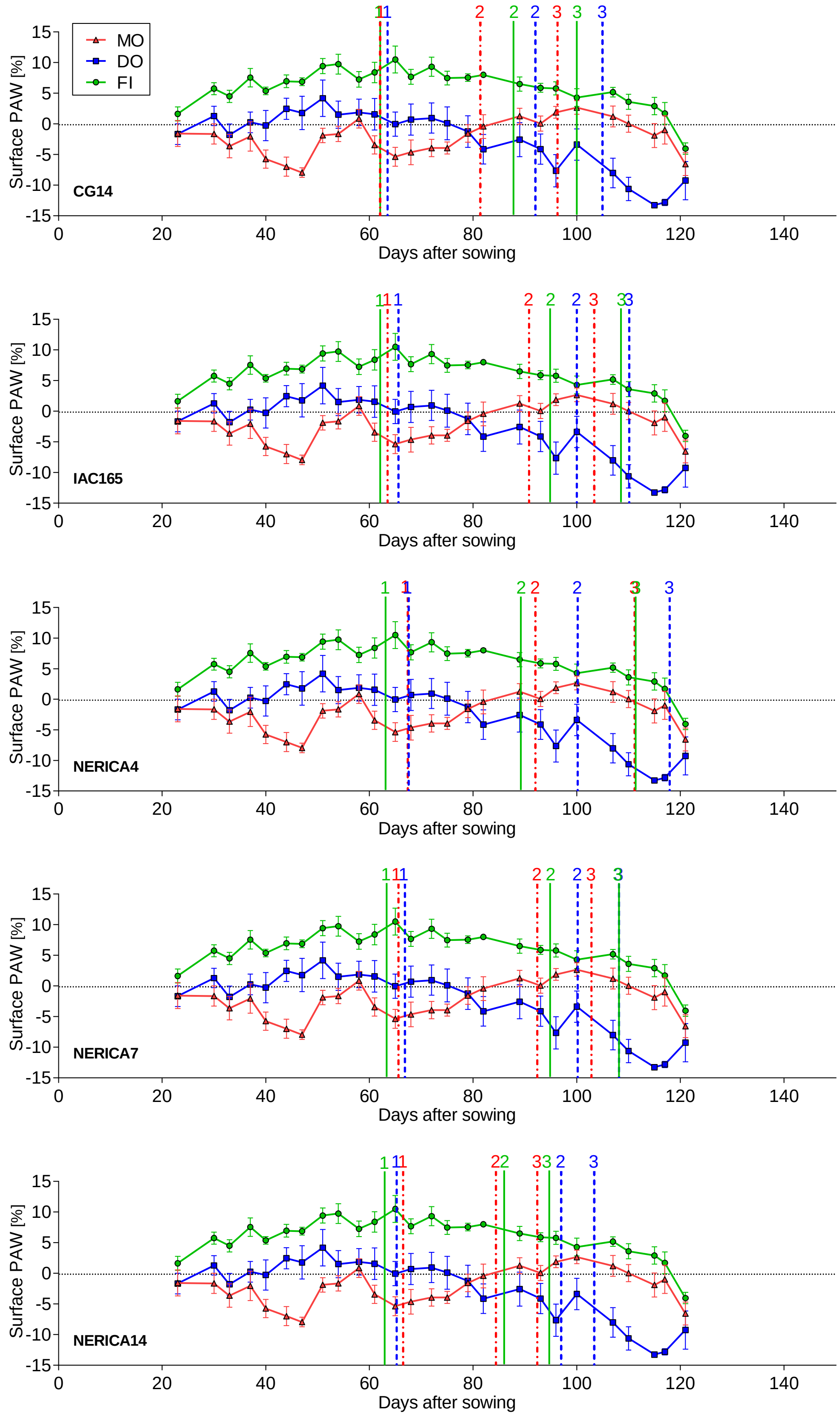
Figure 21. Delay of BBCH stages appearance in days of simulated Morogoro (MO) and Dodoma (DO) rainfall events related to fully irrigated water supply for different rice varieties. A BBCH stages counted as reached when 50 % of plants per plot entered the specific stage. Delay was computed as average duration from sowing to specific development stages for MO + FW and DO + FW to average stage under FI, n=4. DO heading delay for SupaIndia was -27. The x-axis is a non-metric scale representing different development stages plus sowing and harvest. Positive values indicate delay, negative values indicate earlier appearance.

DO rainfall simulation caused a mean delay of development of up to four days beginning from tillering stage. Average 50 % tillering stage was dated on DAS 30. Until DAS 34 DO rainfall simulation plots were supplied with more water than FI plots. In this initial growth phase rice plants were in stages of emergence, leaf development and tillering. Excess water supply during the first time of vegetative plant growth did not affect plant development in comparison to full irrigation. On average, MO rainfall treatments had lowest average water supply during the first weeks after sowing compared to DO and FI treatments and affected plants with a slight tendency of faster plant development beginning from emergence.

To analyze the effect of different treatments on development in different varieties, development delay per rice variety is presented in Figure 21. Varieties performed diverse. PI was treatment independent for CG14, IAC165, NERICA4 and WAB56-104. For CG14, IAC165, NERCIA14 and WAB56-140 plant development speed was increased in DO starting from panicle initiation. NERICA4, NERICA7, WAB181-18 and WAB56-50 showed similar trends. Accumulated water supply in DO treatment from sowing to PI stage was still 65.0 to 70.6 % of FI depending on variety. Mean PI date for plants in DO ranged for all varieties from DAS 71 to DAS 81. MO treated CG14 and IAC165 plants showed faster development speed from panicle initiation compared to plants in FI. Other varieties showed similar tendencies. At PI stage, varying from DAS 71 to DAS 76, accumulated water supply in MO treatment from sowing to PI stage was 56.3 to 58.0 % of full irrigation depending on the variety.

NERICA17 and SupaIndia showed different behaviour of BBCH delay on DO and MO irrigation pattern. MO treated SupaIndia plants had slower BBCH development compared to FI, while DO treated plants had faster development. Flowering stages were reached by SupaIndia 11 days later in MO treatment and 27 days earlier in DO treatment than in FI. NERICA17 showed similar MO results as presented with mean BBCH delay (Figure 20), but plants in DO revealed faster development than FI.

To detect a possible influence of water shortages and water surplus, phenological development has been compared according to PAW during the season. Section 3.1.2 identified that the soil surface layer was stronger dependent on water supply compared to deeper soil layers. Therefore, possible treatment effects in plant phenology and yield performance mostly can be ascribed to soil surface PAW (Figure 22). However, the development showed no clear relation to surface PAW.


MO
DO
FI
Surface PAW [%]
Days after sowing
CG14
IAC165
NERICA4
NERICA7
NERICA14

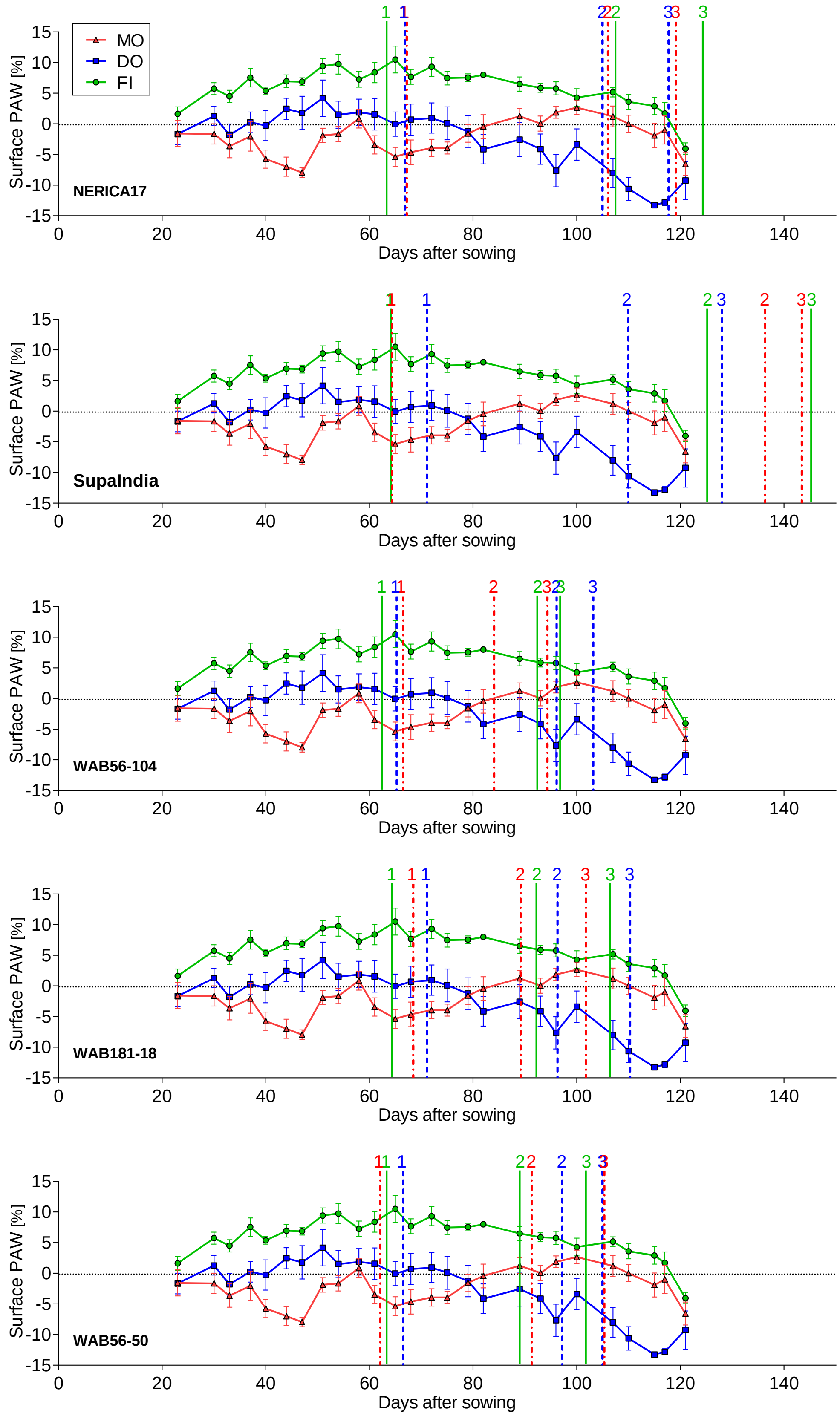


Figure 22. Plant available water (PAW) in vol. % in soil surface layer (0-5 cm) for Dodoma (DO) and Morogoro (MO) rainfall simulation and fully irrigated (FI) during cropping period with appearance of specific plant development stages. Vertical lines identify days after sowing when 50 % of the crops reached the respective BBCH stage under each treatment: 1-Panicle initiation, 2-Flowering, 3-Ripening.

3.3 Biomass and yield performance

3.3.1 Grain yield performance

As grain yield is the most important factor in terms of rice cultivation and production, the following section will analyze the effects of water and weeding treatments on rice yield and the different yield level realized by different genotypes.

Y_{act} was compared among all variety and treatment combinations. Under fully irrigated conditions without water shortage at any time, yield level was not significantly different between genotypes with $p<0.05$. Nevertheless, NERICA4 and WAB56-104 showed the highest average Y_{act} with 359.6 g m^{-2} in NERICA4 and 340.3 g m^{-2} in WAB56-104. Lowest average Y_{act} was obtained for CG14 with 76.1 g m^{-2}.

For all investigated genotypes and treatments, statistical analysis revealed no interaction with $p<0.05$. Thus, rice varieties did not respond differently to specific water supply and weeding treatments. Linear regression showed that all varieties tended to higher grain yield performance with higher total water supply (Figure 23, Table 12). Results of NERICA17 and SupaIndia showed significant increases with increasing total water supply with $p<0.05$.

Table 12. Results of linear regression analysis for actual grain yield over total water amount during cropping period.

Linear Regression		
IAC165:	$y = 0.16x + 61.85$	$R^2=0.076$
NERICA4:	$y = 0.38x - 74.11$	$R^2=0.16$
NERICA14:	$y = 0.054x + 106.40$	$R^2=0.00$
NERICA7:	$y = 0.18x - 16.31$	$R^2=0.13$
NERICA17:	$y = 0.36x - 139.20$ *	$R^2=0.41$
CG14:	$y= 0.031x + 33.03$	$R^2=0.01$
WAB56-104:	$y = 0.41x - 78.46$	$R^2=0.11$
WAB56-50:	$y = 0.11x + 83.62$	$R^2=0.03$
WAB181-18:	$y = 0.058x + 56.22$	$R^2=0.02$
SupaIndia:	$y = 0.21x - 89.12$ *	$R^2=0.43$

*: slope differed significant from 0 with $p<0.05$

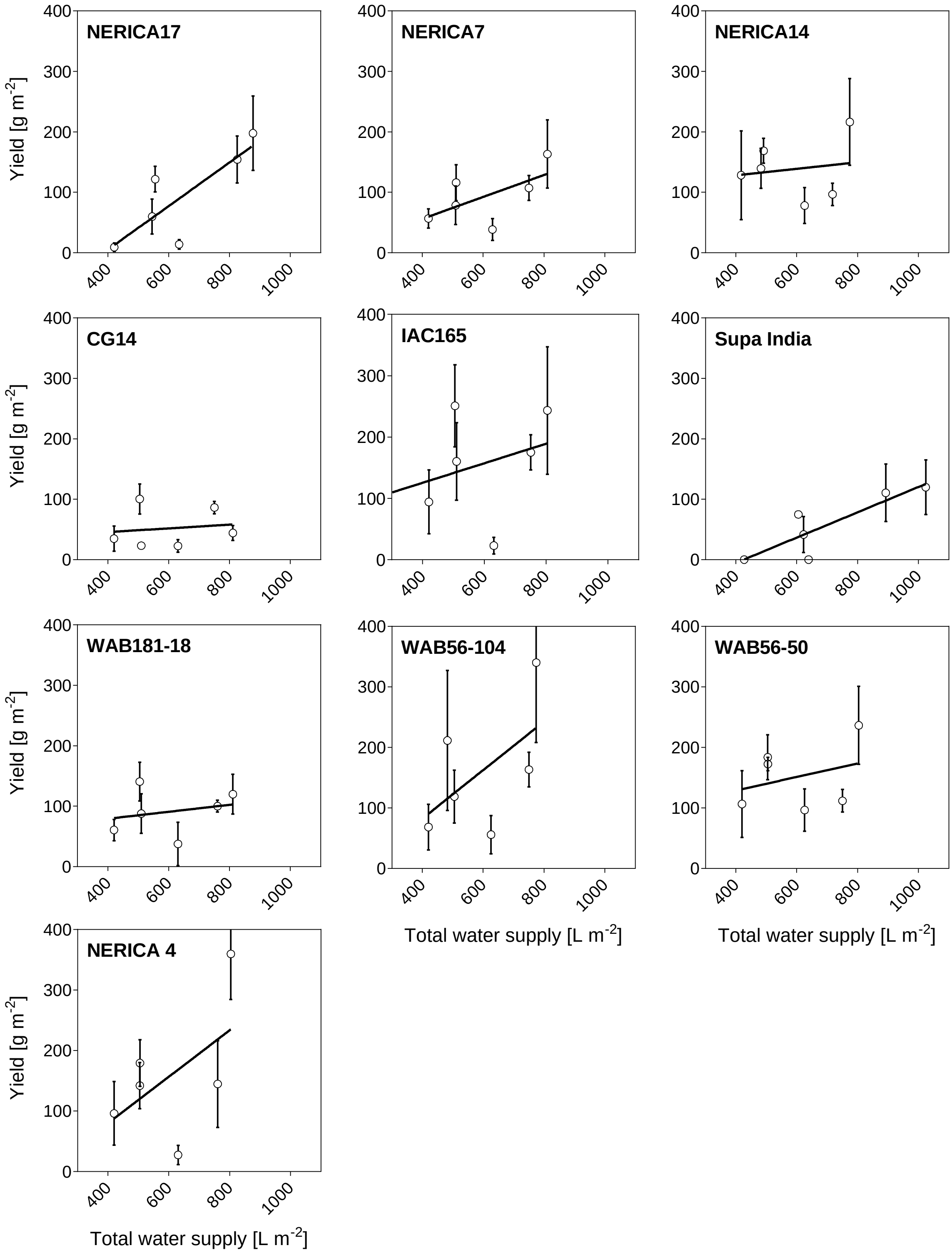


Figure 23. Mean yield performance (g m^{-2}) of upland rice varieties in different water supply scenarios for total water supply (L m^{-2}). Data represent mean values ± SE; n=4; n=3 for SupaIndia and WAB181-18, respectively.

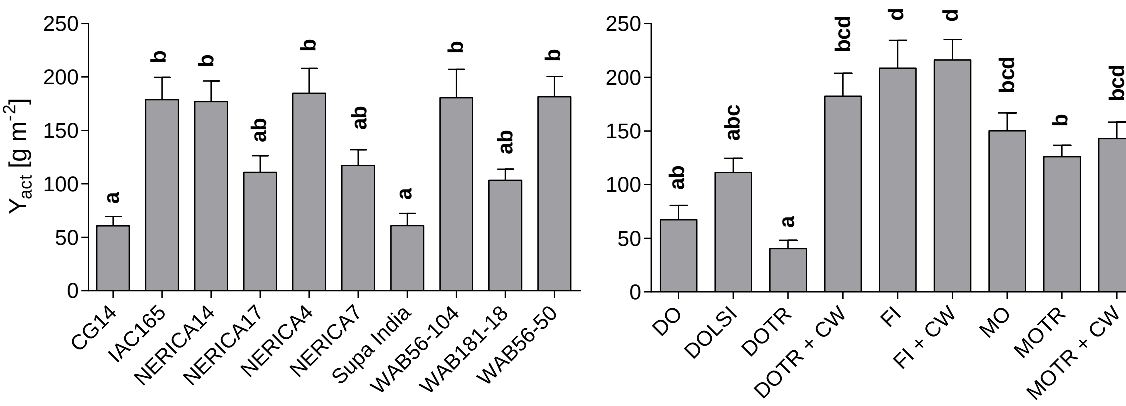


Figure 24. Average actual yield in g m^{-2} (Y_{act}) for varieties and irrigation treatments. Left: Mean biomass for all water supply treatments ± SE, n=36 and n=27 for SupaIndia and WAB181-18, respectively; right: mean biomass for all water supply treatments with ± SE, n=38. Treatments include Dodoma (DO) and Morogoro (MO) rainfall plots and advanced rainfall treatments as simulated tied-rides (TR), life saving irrigation (LSI) and clean weeding (CW). Different small letters identify significant differences with p<0.05 tested with Tukey-test.

Since statistical analysis revealed no interaction between treatment and variety, overall grain yield levels for varieties among all treatments and for treatments among all varieties were analyzed (Figure 24). On average, plants in FI and FI + CW had highest Y_{act} production and performed grain yield of 208.54 ± 26.08 g m^{-2} and 216.07 ± 19.11 g m^{-2}, respectively. Lowest average Y_{act} was found in plants in DOTR and DO with 40.41 ± 7.83 g m^{-2} and 67.30 ± 13.44 g m^{-2}, respectively. Supplementary irrigation and water management for DO caused yield increase of 182.35 ± 21.42 g m^{-2} for plants in DOTR + CW while plants in MOTR + CW showed no change compared to MO.

In genotype comparison, yield ranged from 60.61 ± 8.70 g m^{-2} to 184.78 ± 23.49 g m^{-2} (Figure 24). Highest average Y_{act} was performed for IAC165, NERICA14, NERICA4, WAB56-104 and WAB56-50. Significantly lowest yield was produced in CG14 and SupaIndia. SupaIndia and NERICA17 were late flowering rice varieties. In treatment comparison, highest average Y_{act} was reached for FI plots and for FI plots with CW.

In treatment comparison for single genotypes, NERICA17 Y_{act} was significantly (p<0.05) decreased under DO and DOTR water supply. Y_{act} decreased by 95.5 % in DO plots and by 93.0 % in DOTR plots in comparison to FI plots. For NERICA4, DOTR treatment resulted in significantly lower Y_{act} than in FI plots with p<0.05. Here, Y_{act} was decreased by 92.4 % compared to FI. Y_{act} showed a significant increase for plants in DOTR + CW in comparison to plants in DOTR for NERICA7 with p<0.05. Plants in DOTR had a decrease of Y_{act} by 76.5 % while plants in DOTR + CW gained a Y_{act} increase by 36.1 % compared to FI. CW did not affect the grain yield for plants in FI and MOTR while plants in DOTR + CW had significantly higher Y_{act} compared to plants in DOTR.

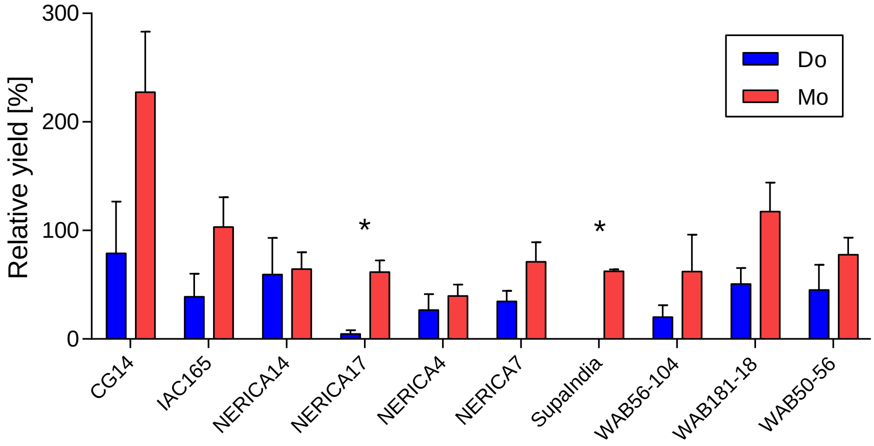


Figure 25. Relative grain yield of different rice varieties under simulated Dodoma (DO) and Morogoro (MO) rainfall conditions related to fully irrigated (FI) plants. Values are given in % of FI ±SE, n=4 and n=3 for SupaIndia and WAB181-18, respectively. Marked varieties (*) showed significant differences between treatments with $p<0.05$ tested with t-test.

Yield increased with increasing total water supply. Results showed significant chances of yield performance in DO and MO rainfall simulation (Figure 24). To highlight the effects of water supply to seasonal water distribution during plant development, Y_{act} of DO and MO treatments were compared to FI (Figure 25). Relative yield was significantly higher for plants in MO compared to plants in DO in NERICA17 and SupaIndia.

On average, DO treatment caused higher grain yield loss compared to FI and MO treatments. Supplementary irrigation and water management such as LSI and TR + CW resulted in a trend of increased grain yield. Y_{act} increased due to LSI supplement under DO simulation. Only in CG14 yield was reduced by 31.49 % in DOLSI plots in comparison to DO plots. The highest increase due to LSI was 572.24 % was found in NERICA17. The average increase was 122.45 %. In SupaIndia DOLSI gained a yield of 41.53 ± 31.88 g m^{-2} while SupaIndia did not perform any yield under DO rainfall. Unexpectedly, DOTR treatment caused yield reduction for all varieties except for NERICA17. In this treatment, yield reduction varied from 9.40 to 75.52 % compared to plants in DO; NERICA17 yield was increased by 54.69 % compared to plants in DO. DOTR + CW reached yield increase of 74.60 % in WAB181-18 to 1440 % in NERICA17 compared to same genotypes in DO plots. Average increase over all genotypes was 298.34 %. SupaIndia reached 13.31 ± 7.01 g m^{-2}.

The positive effect of irrigation supplements and water management was not detected for MO rainfall simulation. MO plots with TR irrigation supplements showed yield reduction in all varieties except for NERICA4 and NERICA17 compared to MO rainfall. MOTR treatment caused changes in Y_{act} from a reduction of 39.16 % in WAB56-50 to an increase of 26.67 % in NERICA17. MOTR + CW plots showed changes in Y_{act} from a reduction of 39.61 % in WAB56-104 to an increase of 64.21 % in NERICA14.

3.3.2 Biomass accumulation

In the following section, accumulated biomass at harvest was analyzed. Biomass, hereinafter mentioned, contained the whole above ground rice biomass without spikelets.

The tested rice genotypes did not differ in DM_B accumulation under FI. However, compared varieties showed some trends: lowest DM_B values were found for NERICA7 with 214.53 ± 71.30 g m^{-2} and highest for the late flowering variety SupaIndia with 376.38 ± 69.49 g m^{-2} (Figure 26). Total mean for all varieties under FI was 298.87 ± 19.06 g m^{-2}. Interaction of varieties and water supply for DM_B accumulation was not significant with $p<0.05$. Thus, analysis was performed on average values. In total, average DM_B accumulation for varieties aggregated over all treatments ranged from 135.89 ± 15.52 g m^{-2} for WAB181-18 to 231.48 ± 27.89 g m^{-2} for SupaIndia. The DM_B accumulation of SupaIndia was significantly higher in comparison to WAB181-18 (Figure 26).

Water availability affected the total DM_B accumulation. The average DM_B of different treatments ranged from 73.58 ± 9.64 g m^{-2} in DOTR to 298.87 ± 19.06 g m^{-2} in FI plots and increased with water availability. DM_B accumulation increased significantly with water supply for SupaIndia, WAB56-104 and WAB181-18. The other tested varieties also showed a tendency of increasing with increasing water supply. Simulated rainfall irrigation treatments reduced DM_B accumulation in comparison to FI plots. Plants in MO treatment gained a mean DM_B accumulation of 183.09 ± 13.81 g m^{-2} and DO of 127.193 ± 13.93 g m^{-2}. The average DM_B accumulation of plants in FI and FI + CW treated plots were significantly higher than for all other investigated treatments with $p<0.05$. Lowest DM_B accumulations occurred in plants in DO and DOTR treatments and were significantly lower than in all other treatments.

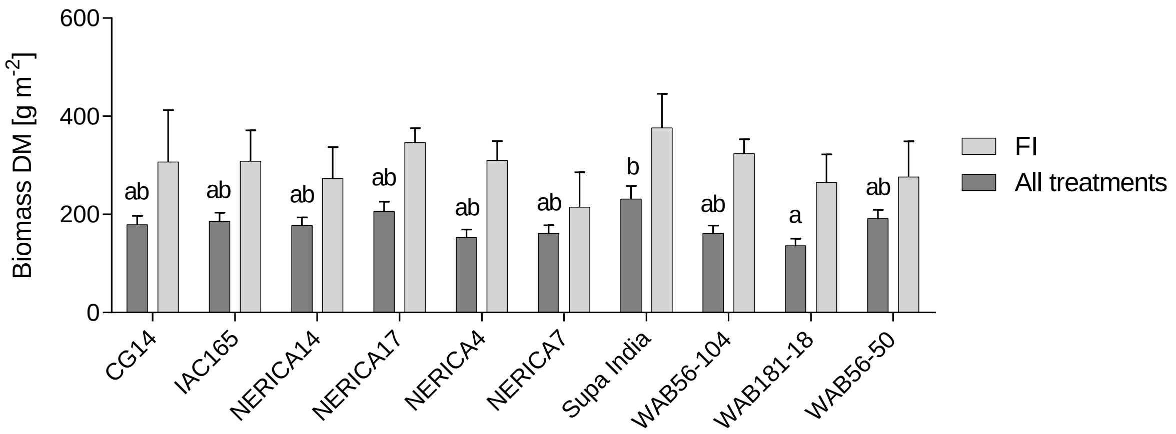


Figure 26. Accumulated biomass at harvest for all varieties under fully irrigated conditions (FI) and average biomass aggregated over all treatments. Values are given as mean biomass with ±SE, n=38 and n=27 for SupaIndia and WAB181-18 in all treatment columns; n=4 and n=3 for SupaIndia and WAB181-18 in FI columns. Lowercase letters indicate significant differences between varieties with p<0.05 tested with Tukey-test.

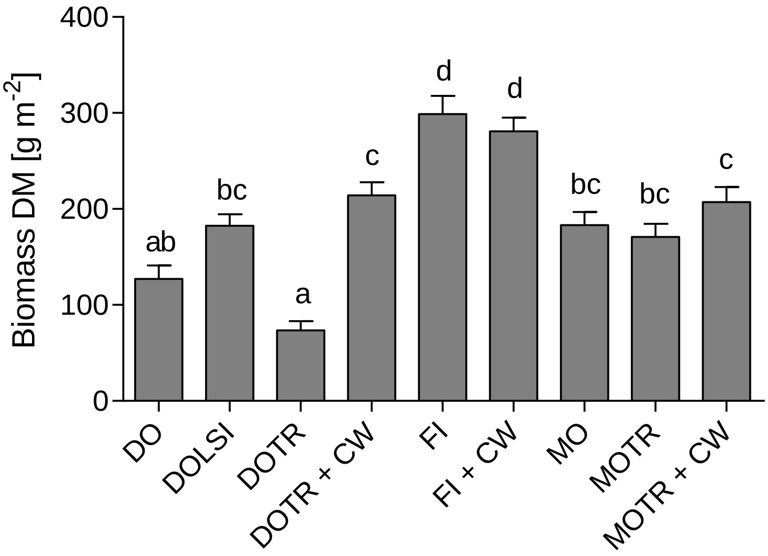


Figure 27. Accumulated biomass at harvest for different water and weeding treatments aggregated over 10 upland rice varieties. Values are given as mean ± SE, n=38. Treatments include Dodoma (DO) and Morogoro (MO) rainfall plots and advanced rainfall treatments as simulated tied-rides (TR), life saving irrigation (LSI) and clean weeding (CW). Different lowercase letters identify significant differences with $p<0.05$ tested with Tukey-test.

3.3.3 Harvest Index

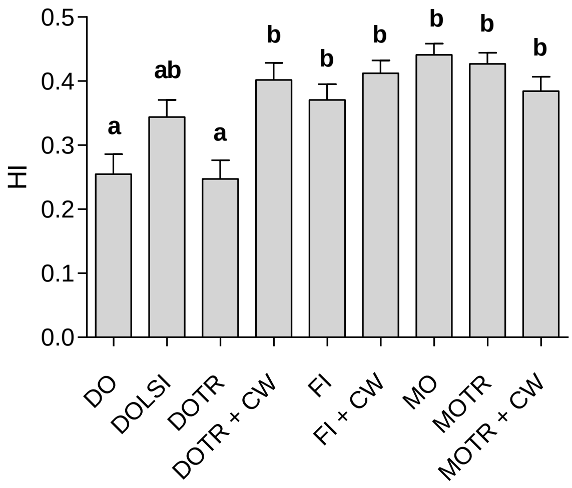


Figure 28. Mean harvest index (HI) aggregated over 10 tested varieties, n=38. Treatments include Dodoma (DO) and Morogoro (MO) rainfall plots and advanced rainfall treatments as simulated tied-ridges (TR), life saving irrigation (LSI) and clean weeding (CW). Columns with different letters show significant differences with p<0.05 tested with Tukey-test.

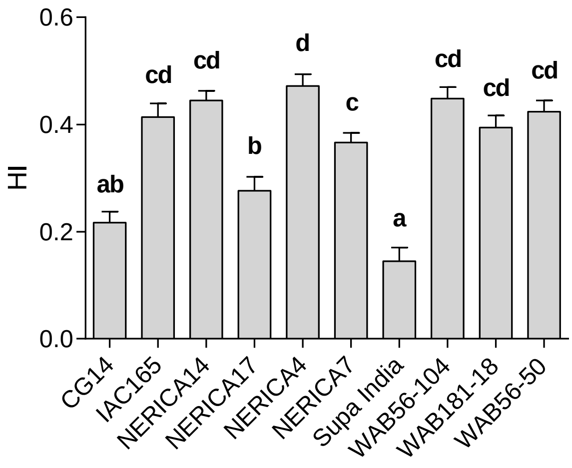


Figure 29. Mean harvest index (HI) aggregated over 9 irrigation and weeding treatments, n=36 and n=27 for SupaIndia and WAB181-18, respectively. Columns with different letters show significant differences with p<0.05 tested with Tukey-test.

Figure 27 reveals that HI was variety dependent. Lowest HI was found for late flowering SupaIndia with 0.14 ± 0.13, followed by CG14 with 0.22 ± 0.12. CG14 was a high tillering rice variety and characterized by strong leaf development. Highest HI was performed by NERICA4 with 0.47 ± 0.13. Overall average HI was 0.36 ± 0.16.

Water availability had an influence on HI. Mean HI was calculated for all treatments aggregated over all investigated varieties (Figure 29). HI was lowest for plants in DO with 0.25 ± 0.20 and DOTR with 0.25 ± 0.18, followed by plants in DOLSI with 0.34 ± 0.27. Plants in all MO including treatments had similar HI as plants in FI and FI + CW and HI values were significantly higher than HI in plants in DO and DOTR with p<0.05. DOTR + CW plants had a HI at the same level as FI plots. Thus, DO simulated rainfall decreased mean HI compared to FI. Higher water availability due to LSI and weeding plus tied-ridging simulation reduced the effect.

Genotype specific effects of water availability on HI were investigated. CG14 and WAB181-18 showed a tendency of decreasing HI with higher total water supply. Other varieties had tendency of higher HI with increasing water supply. Increase by higher water supply was significant for NERICA17 with p=0.01 and for SupaIndia with p=0.02.

3.3.4 Yield components

Total grain yield is influenced by yield creating components. Yield creating components contain plants per m², productive tillers per plant, filled and unfilled spikelets per panicle and seed weight. This study should contribute to a better understanding how water availability influences yield components and yield and to point out the role of different rice genotypes. Some of the most important yield components were presented and analyzed here. Parameter “per plant” presented in the following section were investigated per whole “plant hill” (compare section 2).

Most of the yield component parameters were significantly influenced by genotype and treatment (Table 13). Number of plants per m² was fixed during sowing according to irrigation system. Plants nursery and transplanting periods should ensure the same number of plants in each subplot. Number of plants per m² did not differ between genotypes. Reduction of plants during the experiments was dependent on treatment (Table 13). Water stress due to water shortage led to plant dying and caused a limited number of plants at harvest time. This treatment effect was independent on varieties.

Number of tillers per plant hill was dependent on genotype and treatments. Effects of treatments on this parameter showed no interaction with genotype (Table 13). Results for plants in FI, DO and MO treatments are presented in Table 14. Number of panicles per plant hill and panicle DM were dependent on treatments and genotypes. Effect of water supply and weeding measures was not affected by genotypes.

Table 13. Results of statistical analysis for different yield component parameters. A parameter is identified as significant (Sig.) influenced by a factor if p<0.05. Parameters tested with Tukey-test.

Parameter	Genotype		Treatment		Genotype*Treatment	
	Sig?	p-value	Sig?	p-value	Sig?	p-value
Plants m^{-2}	No	0.245	Yes	<0.001	No	0.857
Tiller $plant^{-1}$	Yes	0.037	Yes	<0.001	No	0.072
Panicles $plant^{-1}$	Yes	0.003	Yes	<0.001	No	0.133
Grain weight $plant^{-1}$	Yes	0.001	No	0.129	No	0.384
DM $panicle^{-1}$	Yes	0.002	Yes	0.003	No	0.886
Filled seeds $panicle^{-1}$	Yes	<0.001	Yes	<0.001	No	0.862
Unfilled seeds $panicle^{-1}$	Yes	<0.001	Yes	<0.001	Yes	<0.001
Filled seed unfilled $seeds^{-1}$	Yes	<0.001	No	0.111	No	0.407
Total seeds $panicle^{-1}$	Yes	<0.001	Yes	<0.001	Yes	0.067

Table 14. Number of tillers per plant hill, number of panicles per plant hill and panicle dry matter (DM) after harvest for 10 different rice varieties under fully irrigated conditions, simulated Dodoma rainfall and Morogoro rainfall conditions. Values are given as mean ± SD; n=4; n=3 for SupaIndia and WAB181-18, respectively. Values with different lowercase letters identify significant genotype differences with p<0.05 tested with Tukey-test, capital letters identify significant treatment differences with p<0.05tested with Tukey-test.

	Full irrigation			**Dodoma**			**Morogoro**		
Variety	**Tiller hill^{-1}**	**Panicles hill^{-1}**	**Panicle DM (g)**	**Tiller hill^{-1}**	**Panicles hill^{-1}**	**Panicle DM (g)**	**Tiller hill^{-1}**	**Panicles hill^{-1}**	**Panicle DM (g)**
CG14	23 ± 14	22 ± 22 ^{B}	0.25 ± 0.11	13 ± 5	5 ± 3 $^{a\,A}$	0.2 ± 0.24	35 ± 11 ^{b}	19 ± 7 $^{b\,AB}$	0.55 ± 0.36
IAC165	11 ± 4	7 ± 2	1.37 ± 1.07	9 ± 4	6 ± 6 ^{b}	0.83 ± 0.54	6 ± 2 ^{a}	4 ± 1 ^{a}	1.13 ± 0.28
NERICA14	15 ± 5	10 ± 3	1.13 ± 0.47	10 ± 4	7 ± 3 ^{ab}	0.92 ± 0.51	11 ± 3 ^{a}	7 ± 2 ^{ab}	0.8 ± 0.49
NERICA17	11 ± 7	7 ± 3	0.92 ± 0.49	12 ± 6	2 ± 1 ^{b}	0.32 ± 0.22	16 ± 7 ^{ab}	6 ± 4 ^{ab}	1.01 ± 0.51
NERICA4	12 ± 4	7 ± 2	1.19 ± 0.57	6 ± 1	4 ± 4 ^{b}	0.84 ± 0.6	7 ± 2 ^{a}	5 ± 2 ^{ab}	1.24 ± 0.81
NERICA7	5 ± 1	3 ± 2	0.72 ± 0.55	5 ± 3	3 ± 2 ^{b}	0.49 ± 0.3	9 ± 5 ^{a}	5 ± 2 ^{ab}	1.26 ± 0.62
SupaIndia	19 ± 8	9 ± 4	0.87 ± 0.41	14 ± 8	0 ± 1 ^{ab}	0 ± 0	25 ± 16 ^{ab}	5 ± 1 ^{ab}	0.59 ± 0.21
WAB56-104	19 ± 19	9 ± 4	1.33 ± 0.2	12 ± 6	5 ± 3 ^{ab}	0.79 ± 0.56	9 ± 3 ^{a}	6 ± 3 ^{ab}	1.01 ± 0.38
WAB181-18	20 ± 8	11 ± 7	1.01 ± 0.17	8 ± 3	4 ± 5 ^{ab}	0.72 ± 0.45	5 ± 3 ^{a}	2 ± 1 ^{a}	0.47 ± 0.46
WAB56-50	6 ± 2	4 ± 2	1.26 ± 0.74	10 ± 5	8 ± 5 ^{b}	0.79 ± 0.87	19 ± 22 ^{ab}	6 ± 3 ^{ab}	1.28 ± 0.53
Mean	**14 ± 10**	**9 ± 9**	**1.01 ± 0.59**	**10 ± 5**	**4 ± 4**	**0.6 ± 0.53**	**14 ± 12**	**6 ± 5**	**0.96 ± 0.53**

The total number of harvested seeds, filled and unfilled, per panicle were influenced by genotype and treatment. DO and DOTR treatments resulted in a lower seed number compared to FI and FI + CW treatments. Additionally, plants in DOTR had lower seed numbers per panicle than plants in DOTR + CW and MOTR + CW. Highest numbers were reached in plants under FI (54.42 ± 3.67 seeds) and FI + CW (57.66 ± 3.43 seeds) followed by plants in DOTR + CW (52.84 ± 3.85 seeds) and MOTR + CW (51.76 ± 1.22 seeds). In genotype comparison, the total number of seeds varied from 0 to 135 seeds per panicle. On average, the lowest total seed number was found in CG14 with a significantly ($p<0.05$) lower numbers than in all other genotypes except for NERICA7. NERICA7 had also significantly lower seed numbers compared to WAB56-104 and WAB181-18. The highest average seed number was found in WAB181-18 with 60.37 ± 5.76 seeds per panicle. As the analysis could not reveal any interaction of genotype and treatment, all genotypes were affected in the same way that seed number was reduced by decreasing water amounts. Thereby, the timing of water shortage had no influence as tested with DO and MO treatments.

Filled and unfilled seeds per panicle were counted for each panicle of one plant hill. Numbers of filled seeds per panicle were significant for varieties and treatments. Statistical analysis revealed no interaction of varieties and treatments (Table 13). The highest filled seed number was reached in CW treated plots as FI + CW (36.89 ± 3.09 seeds), DOTR + CW (36.33 ± 3.67 seeds) and MOTR + CW (33.99 ± 2.95 seeds). Plants in DO and DOTR had lowest seed numbers while plants in MO including treatments were not negatively affected. Number of unfilled seeds per panicle was significantly different for varieties and treatments. Analysis showed interaction for both factors (Table 13). Unexpectedly, plants in FI and FI + CW reached highest mean values for unfilled seeds.

The ratio of filled and unfilled seeds was further investigated to reveal differences in seed filling process under water shortage. The ratio of the two parameters was not affected by treatments but varieties. There was no significance for interaction of treatment and genotypes. Thus, water shortage induced by DO and MO rainfall simulation did not affect the filling process.

Furthermore, the influence of supplementary irrigation and water management on yield components was investigated for NERICA varieties, IAC165 and SupaIndia. NERICA4 had significantly higher numbers of tillers per hill under LSI than under rainfall. Supplementary irrigation and water management increased the amount of tillers resulting in higher grain yield. While Y_{act} of NERICA4 was 96.1 g m^{-2} in DO plots, plants in DOLSI gained 179.3 g m^{-2} which represents an increase of 86.5 % by LSI. Although LSI and TR + CW treatmentshowed equal increases compared to the rainfall simulation treatments for most other components and varieties, statistical tests showed no significant changes in yield parameters with $p<0.05$.

Table 15. Number of filled and unfilled seeds per panicle after harvest for 10 different rice varieties under fully irrigated, simulated Dodoma rainfall and Morogoro rainfall conditions. Values are given as mean ± SD, n=4 and n=3 for SupaIndia and WAB181-18, respectively. Values show no significant difference for genotypes and treatments with $p<0.05$ tested with Tukey-test.

	Full irrigation		Dodoma		Morogoro	
Variety	**Filled seeds per panicle**	**Unfilled seeds per panicle**	**Filled seeds per panicle**	**Unfilled seeds per panicle**	**Filled seeds per panicle**	**Unfilled seeds per panicle**
CG14	7 ± 7	26 ± 6	6 ± 11	22 ± 12	18 ± 13	17 ± 26
IAC165	44 ± 28	9 ± 4	27 ± 20	17 ± 9	32 ± 6	2 ± 9
NERICA14	36 ± 11	19 ± 12	32 ± 16	15 ± 7	26 ± 15	12 ± 19
NERICA17	23 ± 10	27 ± 7	12 ± 10	17 ± 5	29 ± 13	13 ± 27
NERICA4	41 ± 19	26 ± 17	35 ± 25	9 ± 7	48 ± 32	11 ± 26
NERICA7	19 ± 15	14 ± 17	18 ± 12	11 ± 3	32 ± 15	18 ± 14
SupaIndia	33 ± 20	26 ± 12	6 ± 10	13 ± 22	24 ± 13	36 ± 26
WAB56-104	46 ± 5	14 ± 5	29 ± 21	19 ± 11	35 ± 12	17 ± 14
WAB181-18	28 ± 12	63 ± 27	26 ± 16	25 ± 7	22 ± 26	11 ± 63
WAB56-50	43 ± 24	11 ± 9	26 ± 30	15 ± 13	42 ± 16	13 ± 11
Total	**32 ± 19**	**22 ± 18**	**22 ± 19**	**16 ± 10**	**31 ± 18**	**14 ± 22**

3.3.5 Water use efficiency

Water use efficiency (WUE) is used to identify the most productive rice variety per water unit and to identify the most effective irrigation amount per variety. In the following, WUE was separated into WUE of grain yield (WUEG) and WUE of plant biomass (WUEB).

WUEG was treatment dependent. Average WUEG over all varieties ranged from 0.06 ± 0.0 g L^{-1} for plants in DOTR to 0.30 ± 0.03 g L^{-1} for plants in MO. Higher water availability in FI, FI + CW, DOTR + CW AND MOTR + CW increased WUEG compared to DO, DOLSI, DOTR, and MOTR ($p<0.05$). TR treatments providing higher soil water conservation by clean weeding had slightly higher WUEG compared to FI and FI + CW treatments. Water availability was increased by weed elimination but total water supply was lower than CWR. Since presented grain yield was similar, WUEG was increased for plants in DOTR + CW and MOTR + CW.

Under fully irrigated conditions average WUEG differed for different genotypes. Lowest WUEG was found in CG14 with 0.05 ± 0.02 g L^{-1}, followed by SupaIndia (WUEG = 0.12 ± 0.08 g L^{-1}) and WAB181-18 (WUEG = 0.15 ± 0.03 g L^{-1}). Highest values were obtained with NERICA4 with 0.45 ± 0.09 and WAB56-104 with 0.43 ± 0.17. Changes were not significant with $p<0.05$. Mean WUEG for the investigated varieties over all treatments were calculated and presented in Figure 30. WUEG was significantly higher for IAC165, NERICA14, NERICA4, WAB56-104 and WAB56-50 in comparison to CG14 and SupaIndia. CG14 and SupaIndia had lowest HI and lowest WUEG. Highest WUEG was found for IAC with 0.27 ± 0.23 g L^{-1} followed by WAB56-104 with 0.26 ± 0.27 g L^{-1}. Lowest WUEG was performed in SupaIndia with 0.07 ± 0.07 g L^{-1}.

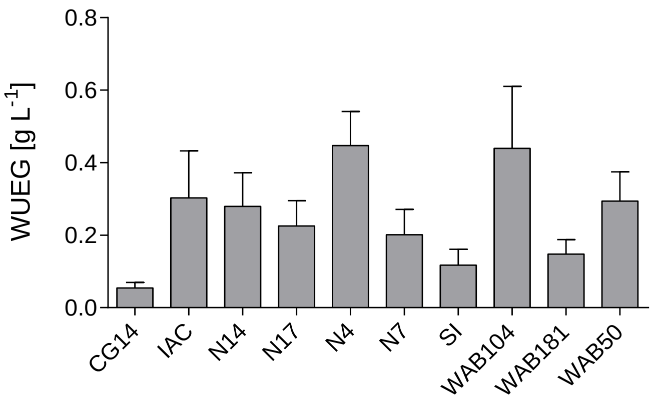


Figure 30. Mean water use efficiency for grain yield (WUEG) ± SE of different rice varieties aggregated over six different irrigation treatments with farmer´s weeding measures (n=24; n=18 for SupaIndia and WAB181-18, respectively). Columns with different letters show significant differences with p<0.05 tested with Tukey-test.

In addition, WUEG and WUEB were determined for all subplots and plotted for different vegetation period lengths independent from varieties. Results and linear regressions are presented in Figure 31. To distinguish between WUE differences and weeding effects, WUEG and WUEB for farmer´s weeding measures (FW) and clean weeding measures (CW) were plotted separately. WUEG + FW fluctuated from 0 g L^{-1} to 1.16 g L^{-1} while WUEG + CW ranged from 0 g L^{-1} to 0.71 g L^{-1}. Highest WUEG and WUEB values were reached in DO and MO rainfall simulated plots. Average WUEG was higher for CW than for FW treated plots.

Linear regression analysis revealed that FW and CW plots with a shorter vegetation period showed a higher WUEG than with longer vegetation period. Slopes for both linear regressions were significant non-zero (p=0.002 for FW and p<0.001 for CW). In contrast, WUEB plots showed no significant difference between CW and FW treatments and no significant changes with longer vegetation period for CW and FW.

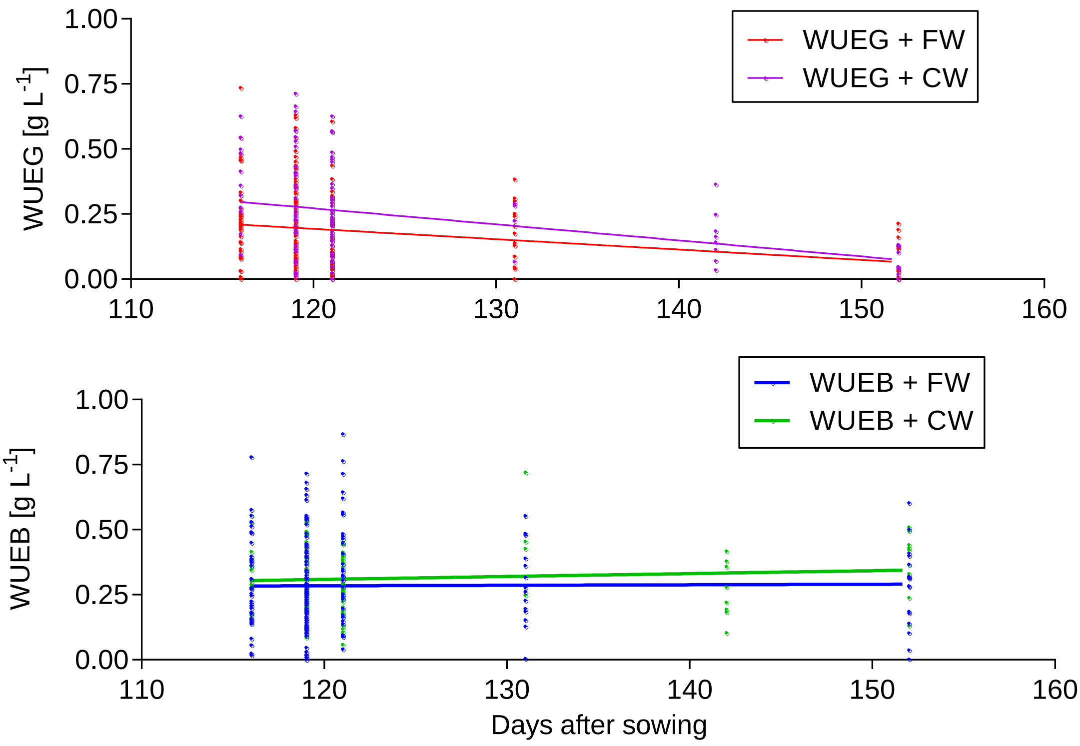


Figure 31. Water use efficiency for grain yield (WUEG) and biomass (WUEB) plotted for days after sowing until harvest (n=340). Plots are divided into two treatments: farmer´s weeding measures (FW) and clean weeding measures (CW). Linear regressions: WUEG + FW: y=-0.005x+0.76 R^2=0.06; WUEG + CW: y=-0.006x+1.01 R^2=0.14; WUEB + FW: y=0.0452 R^2=0.00; WUEB + CW: y=0.03 R^2=0.02.

Furthermore, WUEG and WUEB for FW plots were related to total irrigation amount during vegetation period (Figure 32). Higher water supply did not produce a significant variation of WUEG for FW treated plots. For CW treated plots, WUEG decreased with higher total water supply. Slope of linear regression was non-zero with p=0.01. Linear regression analysis showed that with a total water supply of 925 mm and more, CW measures did not increase WUEG in comparison to FW. With lower amounts, CW trended to result in higher WUEG compared to FW.

Linear regression analysis showed no significant differences between WUEB in CW and FW treatments and no significant changes in WUEB with changing water quantity.

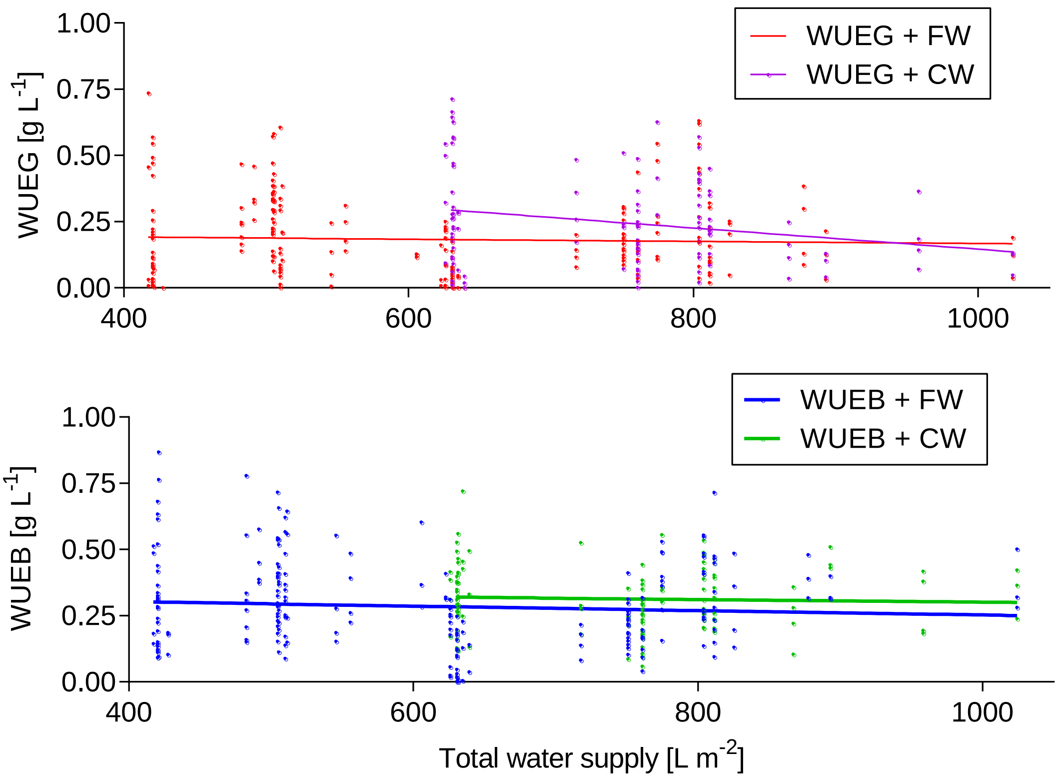


Figure 32. Water use efficiency for grain yield (WUEG) and biomass (WUEB) plotted for total water supply until harvest (n=340). Plots are divided into two treatments: farmer´s weeding measures (FW) and clean weeding measures (CW). Linear regressions: WUEG + FW: y= 0.23 R^2= 0.00; WUEG + CW: y= -0.0004x + 0.55 R^2= 0.06; WUEB + FW: y= -0.02x + 0.08 R^2= 0.01; WUEB + CW: y= -0.06x+ 0.07787 R^2= 0.00.

For further analyses, WUEG was related to total water supply for individual varieties. Results showed that WUEG increases significantly with increasing total irrigation amounts for NERICA17 and SupaIndia (Figure 33). Both varieties showed slower development speed and had a significantly longer vegetative and generative development phase with $p<0.05$. However, SupaIndia and NERICA17 had low average WUEG in comparison to other tested varieties (Figure 30). WUEG did not vary significantly with higher water supply for all other tested treatments with $p<0.05$. Nevertheless, all other varieties tended to lower WUEG with higher water supply (compare also Figure 32).

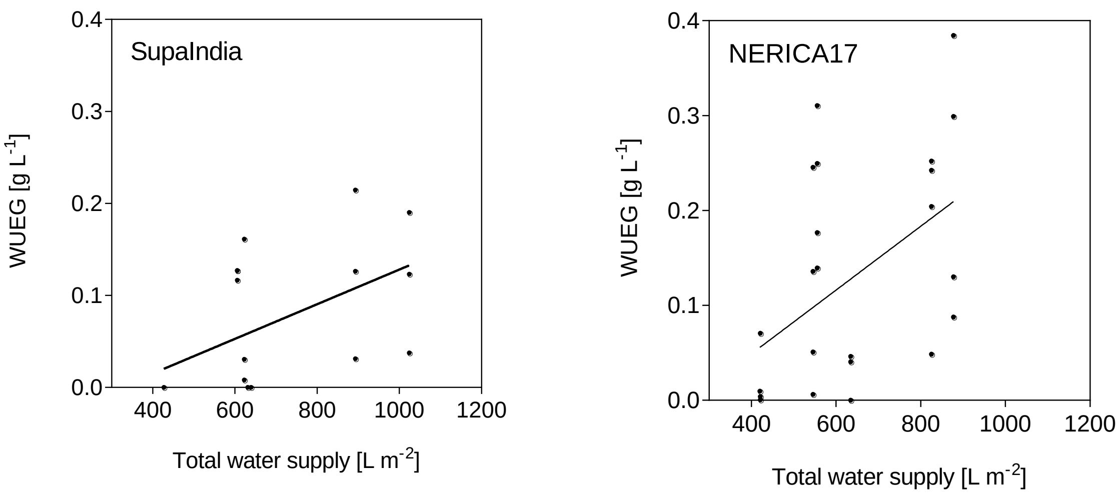


Figure 33. Water use efficiency of rice grain yield in g L^{-1} per total water amount irrigated during whole vegetation period for SupaIndia and NERICA17. Linear regression: SupaIndia: y=0.0002x – 0.0602 R^2=0.26; NERICA17: y=0.0003x – 0.0855 R^2=0.22.

3.3.6 Leaf area index

Figure 34 shows the indirect measured LAI development during the cropping period measured with LAI2000 device. Before DAS 60, data collection was not possible due to high radiation sensitivity of the LAI device and scanty plant density. LAI was highest in FI plots for all three varieties, followed by MO plots. For IAC165, LAI in DO plots was significantly lower than in MO and FI plots, but MO and FI did not differ significantly with p=0.24.

For NERICA4 and NERICA14 LAI did not differ between DO and MO plots. Both treatments affected LAI negatively in comparison to FI with $p<0.05$. Total water supply levels affected LAI in all genotypes. Similar results were found for DOLSI plots. Changes in water distribution during the season had no effect on LAI in NERICA4 and NERICA14.

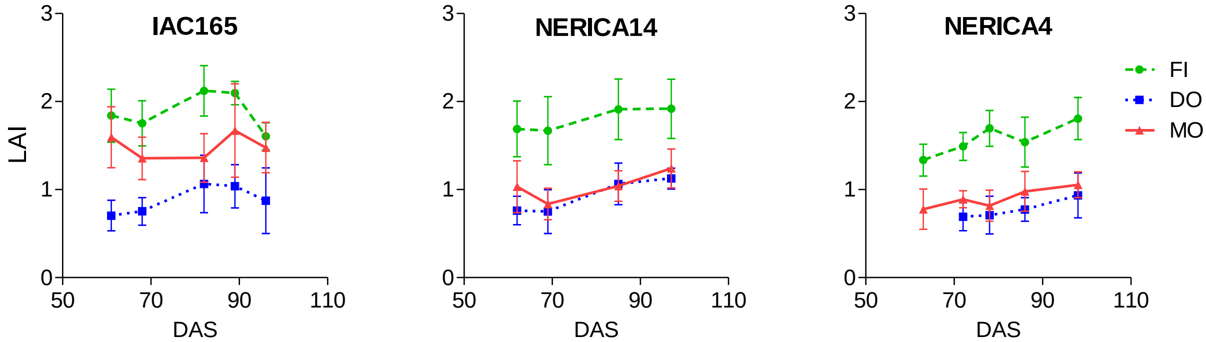


Figure 34. Leaf area index (LAI) development for rice varieties across days after sowing (DAS) for fully irrigated, simulated Dodoma rainfall and simulated Morogoro rainfall conditions. Presented LAI values are given as mean values ± SE, n=4 and n=3 for SupaIndia and WAB181-18, respectively. Data based on non-destructive measurement with LAI2000.

3.4 Weed growth

Weed dry matter accumulation was measured after general weeding to analyze interspecific competition and weed tolerance and effects on grain yield and biomass. Considered weeding dates were independent from clean weeding treatment (CW treatments) and were dated for row closure and postharvest. The analysis revealed no genotype related difference in weed suppression for the three varieties under adequate water conditions. DM_W in fully irrigated plots did not differ significantly between rice varieties for both weeding dates. Postharvest DM_W values were lower for all varieties compared to DM_W on first weeding date.

Weed growth increased with increasing total water supply (Figure 36). This effect was significant in NERICA14 plots with p=0.0097. NERICA14 also showed tendency of DM_W reduction for the highest water supply level representing FI plots. Plants with sufficient water supply were able to suppress weeds more effective than for plants with lower water supply.

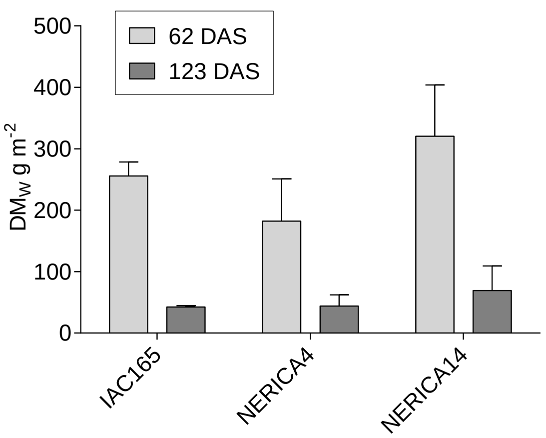


Figure 35. Mean weed dry matter (DM_W) in g m^{-2} ± SE (n=4) within rice field of three different genotypes for two different days after sowing (DAS). Fully irrigated plot with farmer´s weeding treatment (FW), right: fully irrigated plot with clean weeding (CW) treatment during vegetation period. First weeding during row closure, second weeding after harvest.

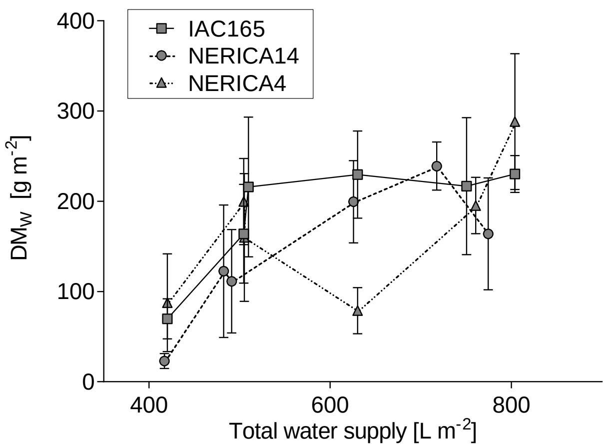


Figure 36. Weed dry matter (DM_W) collected during day after sowing 62 and 123 for related to different total water supply amount during cropping period. Values represent mean ± SE, n=4.

4 DISCUSSION

The aim of this study was the analysis of yield performance and phenological development of 10 different upland rice varieties under varying water supply. The Main focus was put on simulated unimodal and bimodal water distribution and the effects of supplementary irrigation, simulated water harvesting and weeding treatments. The Effects of water supply on previously presented parameters across tested genotypes are discussed in the following section.

4.1 Water supply and water availability

Nyamangara and Nyagumbo (2010) mentioned soil infertility caused by soil water as a crucial factor limiting crop production in SSA. The soil water balance is affected by soil evaporation, infiltration, internal drainage and plant transpiration (Reddy, 1983; Ritchie, 1998).

Dodoma is characterized by semi-arid conditions. In this study, DO rainfall treatments received 417.1 to 427.3 mm; treatments with tied-ridging simulation gained around 200 mm more water during one growing season, an increase of 50 % of total water. LSI treatments received 491.2 to 622.6 mm, depending on variety. As Dodoma climate is characterized by drought spells especially at the end of the growing season, harvest time is determining the necessary water amount needed for LSI. The highest supplementary irrigation inputs needed for LSI were not higher than additional water provided by tied-ridging compared to rainfall. Morogoro rainfall treatments were supplied with 482.4 to 605.4 mm, while MOTR received 717.6 to 892.8 mm. As expected, higher water supply resulted in higher soil moisture contents and PAW during the experiment. Soil water content of simulated treatments was corresponding with irrigation pattern of the two regions. Rainfall shortage at the end of Dodoma growing season and the beginning of simulated Morogoro rainfall ended up in deficit of PAW (Figure 18). Vogel (1993) identified tied ridging as an effective method to reduce soil and water loss from fields. Tillage management as tied-ridging can improve soil conditions favourable for soil moisture conservation and improve crop performance (Biamah et al., 1993). The effect of tied-ridges on soil fertility should be kept in mind. A study by Nyakatawa et al. (1996) investigated possible interaction of tied ridges and soil fertility. They mentioned high rainfall which causes leaching especially in semi-arid area as reason for poor soil fertility. Heavy rainfall events commonly occurring in Dodoma during rainy season can increase leaching and enhance nutrient depletion. The aim of this M.Sc. study was the investigation of impact of varying water supply on plant development and yield performance. The experiment was designed for fundamental research on minimal water management. Irrigation was done daily to minimize water amounts per irrigation and to avoid leaching. This thesis tested tied-ridge effects by higher water supply simulating a run off reduction. Effects on leaching and soil conservation could not be pointed out. Wiyo et al. (2000) already mentioned that tied-ridges as water harvesting method will not be accepted by local farmers unless waterlogging and excessive nutrient loss by leaching in wet years can be avoided. Further soil focused research is needed to evaluate the positive effects on soil water content considering possible changes in infiltration pattern and soil fertility.

Water supply according to CWR was 774.5 mm to 1024.1 mm, depending on variety dependent harvest time. These water amounts are double of the rainfall in semi-arid regions like Dodoma. Rainfall of 600 to 1000 mm per growing season naturally can be found in Africa's sub-humid areas which are suitable growing areas for water intensive crops as maize, soybeans and cashews (Brouwer and Heibloem, 1986).

Varying soil layers displayed different wetting patterns during the season. Upper soil layers as 5 cm and 10 cm depth were most susceptible to irrigation treatments. Deeper soil layers were mostly not affected by water supply. High radiation, low relative humidity and high wind speed are factors increasing evapotranspiration (Brouwer and Heibloem, 1986). As the experiment was conducted during dry season, relative humidity was lower than during normal growing season in Dodoma and Morogoro. Average wind speed at ARI Makutupora found as 2 to 3 m s^{-1} possibly increased evaporation and transpiration. It can be assumed that evapotranspiration during the field trial was higher compared to Morogoro and also higher compared to Dodoma rainy season. Transpiration losses were tried to be avoided by dripper irrigation and water supply in the morning. Water was supplied daily to minimize irrigation amounts and to avoid leaching and nutrient loss. Due to local water conditions, water supply was not possible for three days during the experimental trial. Although these three irrigation gaps were considered as marginal affecting crop performance due to water supply on previous and following days, sufficient water logistics should be ensured for future field trials at ARI Makutupora. Especially in plots with low daily irrigation amounts like rainfall, one day of total deficiency can cause high damage.

The effective root zone varies during plant and root growth (Beyrouty et al., 1988). Thus, the decisive PAW of the specific soil layer varied during the investigation. Literature showed that rooting in rice is genotype dependent and is strongly influenced by environmental conditions (Gowda et al., 2011). Root growth and development takes place during vegetative plant development (Beyrouty et al., 1988). Root morphology and rooting diameter and depth are affected by drought during root growth. Gowda et al. characterized upland rice as deep rooting plant in order to counteract dry spells and enable water sourcing from deeper soil layers. Morogoro rainfall induced drought spells during the first weeks of plant growth. Soil water deficit occurred in MO soil surface layers. In this initial phase, root systems were shallow. It can be assumed that plants in MO plots developed a wider root system during vegetative plant growth. When water supply increased during generative plant development, water supply was sufficient due to high PAW values and an established root system. Dodoma rainfall was characterized by soil water deficit in the generative phase. During initial plant growth PAW was higher and may have caused weaker root growth compared to MO. It can be assumed that the weaker root system led to water stress during following drought spells which especially occurred in DO soil surface layer. Further research on root development related to unimodal and bimodal rainfall with variable drought spells is suggested.

It has to be considered that this thesis presents a rainfall simulation study. Recorded rainfall of 30 years led to an average rainfall amount on daily basis for Dodoma and Morogoro that was applied daily. Drought spells and erratic rainfall naturally occurring in the mentioned regions and therefore limiting crop production are weakened by computing an average. Thus, results of this investigation can hardly represent rice performance in the two regions but rather explain performance at specific water supply levels with different distribution patterns. However, as mentioned before the experimental field trial was designed for research on minimal water management and to identify different effects of varying water supply on rice growth.

4.2 Effects on water stress

To investigate the effects of water supply on plant performance the knowledge of beginning water stress is important for the further understanding of the relation between phenology and yield performance. Below-zero values of PAW did not necessarily end up in plant water stress. Unfortunately, water stress could not be assessed consistently within this study. The inconsistent LRI data raises the question whether a) soil water deficit was not severe enough to cause visible stress symptoms in rice or b) chosen rice varieties generally do not show leaf rolling under water stress or c) the visual assessment at the field was inappropriate.

Parker (1968) stated that leaf rolling is a plant protection measure reducing water losses by transpiration during drought. Turner et al. (1986) mentioned dryland rice cultivars as leaf rolling during drought conditions. The leaf rolling increased with decreasing leaf water potentials (Turner et al., 1986). The leaf water potentials and turgor pressures showing first sights of leaf rolling were cultivar dependent. Parker stated that some species do not show any signs of leaf rolling until water potential has been decreased to lethal levels (Parker, 1968).

NERICA varieties are known as drought resistant. Therefore it was expected that NERICA plants were well adapted to water deficit conditions and could manage low water supply by transpiration reduction in form of leaf rolling. However, NERICA varieties did not show leaf rolling for transpiration reduction in this study. “Supa” landraces are also known as locally adapted and are commonly grown in East Africa. SupaIndia was expected to show leaf rolling during soil water deficit phases as protection mechanism. Since NERICA varieties SupaIndia showed low LRI values in comparison to other varieties (Figure 19), it can be assumed that LRI is not a qualitative measure for stress index for all rice varieties. Other varieties also showed no correlation of LRI and PAW. Although leaf rolling was observed as transpiration reducing mechanism, it might be influenced by leaf morphology, specific leaf area (SLA) and stress severity.

Previous research on LRI and related leaf water potential were conducted during drought for several weeks (Turner et al., 1986; Parker, 1968). Water was withheld during the complete drought period. Dodoma and Morogoro rainfall led to soil water deficit and negative PAW values during drought spells but did not completely withhold water for such a long period. Especially average rainfall calculation (consider 0) minimized the number of days with 0.0 mm irrigation. The soil water deficit may not have been severe enough to end up in visible stress symptoms.

4.3 Effects on plant development

Plant growth, development and biomass were affected by water supply. The higher rate of plant dying during the growing period under lower water supply was noticeable. It can be assumed that the high number of plant gaps was not just caused by water stress itself but by water conditions during transplanting. During the transplantation weeks, plants did not emerge or died in early plant growth phases in all water supply treatments. Transplantation was done with most possible care and as long as reasonable to ensure an equal initial point for treatments. Despite ample water supply to transplanted plants directly after transplantation and during the next days, transplantation-mortality rate was higher in DO and MO plots.

Crop duration is mentioned as an essential factor in crop development and yield composition and was affected by genotype and environment interactively (Dingkuhn and Asch, 1999). Whole crop duration is influenced by a lower development rate. Decisive for flowering induction are photoperiod and temperature (Dingkuhn et al., 1995; Asch, 2005). Rice was observed as short-day plant (Dingkuhn and Miezan, 1995; Asch, 2005) and showed sensitivity to photoperiod and to temperature (Ritchie, 1993; Asch, 2005). Also water appeared to play a major role in phenological development. Asch (2005) investigated the influence of water availability on plant development. On average, vegetative plant growth was shortest in FI plots and longest in advanced rainfall conditions (TR, TR +CW). Water supply in FI plots was 419.45 mm until average PI stage. Plants in DO were supplied with 281.31 mm until average PI date; plants in MO were supplied with 222.76 mm water. Although water distribution was different for DO and MO treatments during the initial growth phase, PI dates did not differ. Shortest duration from sowing to flowering was found in rice plant exposed to low water stress and changing water conditions. Delay in flowering occurred if environmental conditions were not well suitable for specific genotypes (Asch, 2005). Those results can be confirmed with results in this thesis. Soil water deficit, starting at tillering or booting stage in DO and DOTR plots, caused longer duration from sowing to flowering compared to FI plots (Figure 22). Single varieties except for NERICA17 and SupaIndia showed similar results. Stages during generative phase were delayed for most varieties in DO compared to FI. DO conditions seemed to be marginal suitable for tested varieties on average, evidenced by development delay. On average, MO plants showed similar duration as FI plants. Soil water deficit in MO plots was strongest during the initial development stages. According to Asch´s findings, time from sowing to flowering for plants in MO was expected to be shorter than for plants in FI due to bimodal rainfall and short water stress in the initial phases. By taking a look at BBCH delay in individual genotypes (Figure 21), time to flowering and following stages had tendency to appear earlier than in FI. This is in agreement with findings in literature (Asch, 2005). Total cropping duration till harvest was not treatment dependent in this study.

Dingkuhn and Asch pointed out that phenological response on environmental conditions is genotype dependent (Dingkuhn and Asch, 1999). In the present investigation, phenological development was also dependent on genotype. Flowering in NERICA17 and SupaIndia had occurred later (DAS 109 and 129, respectively) compared to other varieties (mean of all other varieties 94 DAS). The later flowering induced later ripening and senescence stages in comparison to early flowering varieties. The duration of the generative phase revealed no difference for these two varieties compared to others. Water supply was equal for all varieties within one treatment. It can be assumed that temperature and photoperiod played a major role in development delay for these two species. SupaIndia is a commonly grown variety in Tanzania (Gangopadhyay and Padmanabhan, 1987). Usual cropping period takes place during rainy season. This investigation was conducted during dry season from May to October. Temperature and day length did not match conditions during commonly used growing season. Colder temperatures during booting stage and different day length conditions during vegetative stages may have caused flowering delay.

Africa Rice promotes some NERICA varieties as rice with short vegetation period which makes it more suitable for regions with short growing period. NERICA4 and 7 are described having maturity on DAS 95 to 100; NERICA 8 even reaches maturity on DAS 75 to 85

(Somado et al., 2008). In this study it was found that NERICA14 showed a short-cycle of around 97 days on average over all treatments. NERICA4 and 7 were harvested at around 107 and 109 days on average over all tested treatments. Despite this, NERICA and NERICA parents had shorter growth cycles than local grown landrace SupaIndia. Seck et al. (2013) said that locally common landraces are long-duration rice cultivars. This further undermines the fragile system of rainfed production. Thus, NERICA varieties seem to be suitable varieties for semi-arid regions where local farmers are reliant on short growing seasons. Nevertheless, SupaIndia probably shows different development patterns during rainy season. Further research and a cropping calendar are suggested to enable new perspectives for landraces and new varieties in terms of an effective rainfall usage.

The presented results showed that biomass accumulation is strongly influenced by water supply while the genotype showed lower influence. Johnson et al. (1998) said that the number of tillers is related to growth rate and consequently influences biomass accumulation. Boonjung and Fukai (1996) revealed decreased tiller numbers caused by soil water deficit during vegetative growth stages. Results in this thesis showed a slightly lower number of tillers for plants in DO compared to plants in FI but DO treatments had soil water deficit during generative growth stages. Results for MO were inconsistent.

Findings of Boonjung and Fukai (1996) indicated lower biomass increase in rice plants after severe water stress periods. In their investigation, reduction in biomass accumulation was higher when water stress occurred when plants were younger. Older plants showed stronger drought tolerance in terms of biomass accumulation (Boonjung and Fukai, 1996). During the first development phases, young plants use water and assimilates for vegetative growth such as tiller production and leaf development (Yang and Zhang, 2010). In older plants, energy is used for grain yield development and starch storage. Thus, water stress affects biomass accumulation stronger during vegetative plant growth than during generative phase as shown by Boonjung and Fukai. In this study, DO and MO treatments resulted in lower biomass accumulation. DO treatment with soil water deficit during the later growing phase caused higher biomass reduction than MO treatment with soil water deficit during the initial growing phase. For the 10 genotypes, PI started before water deficit had begun in surface layers in DO plots. So, water availability was sufficient during the vegetative plant growth which should have resulted in strong tiller and leaf development. Nevertheless, average biomass accumulation was decreased by 57.44 % for plants in DO compared to plants in FI. A possible explanation is that water deficit during the vegetative plant growth might have caused stronger leaf senescence. Early leaf senescence in rice can be induced by water stress during grain filling (Yang and Zhang, 2010). MO treatment with soil water deficit during the initial phases was expected to cause lower biomass accumulation. Biomass in all MO including treatments showed lower values compared to FI. However, bimodal surface PAW seemed to have lower effect on biomass than a long water deficit period shown in DO. The different water supplies with unimodal and bimodal rainfall were supposed to affect the plant morphology and development during different phases. Thus, intermediate harvests and sampling occasions would have been advantageous for analysis of biomass partitioning during the growing season. Due to small plot size and low number of plants per plot, intermediate harvests were not possible.

LAI in rice plants was decreased by severe water stress (Boonjung and Fukai, 1996). After stress periods, LAI increased up to 1.0 until leaves senescence. Puteh and Mondal (2014) showed reduced plant height, leaf area and growth rate under water stress for three rice mutants. Kumar et al. (2014) investigated rice responses of 75 different genotypes to drought stress during reproductive stages in India. They found out that reproductive stage drought stress decreased leaf area of plants by 34.87 %. In the present study, plants with sufficient water supply due to CWR developed the highest LAI. Soil water deficit in surface layer caused by Dodoma rainfall reduced LAI compared to FI plots in all tested cultivars. Morogoro rainfall caused similar reduction in NERICA4 and NERICA14. Lack of water caused lower leaf development and consequently ended up in lower leaf area per unit ground. Seasonal changes of PAW had no influence on LAI development during the growing period. DO water supply was characterized by high irrigation amounts during the initial growing period enhancing tiller and leaf development. MO plots had water shortage phases during the initial period. LAI was expected to be higher for DO plots than for MO plots in the beginning of measurements. This could not be proven in this investigation. However, values for LAI in FI plots were about 1.0 matching the results of rice under temporary drought found in literature (Boonjung and Fukai, 1996).

In general, plant phenology and growth was highly heterogeneous. Reasoned by poor emergence in some varieties transplantation was done for two months after sowing. During the experiment, the transplantation period was evaluated as too long resulting in high heterogeneity within subplots. Furthermore, small plot size and high measurement frequency caused soil compaction and frequent interference with plants. This might have influenced plant development. Larger plots and higher number of central plants could result in more representative data.

4.4 Effects on grain yield performance and HI

In the conducted experiment, all environmental parameters were constant for all varieties and treatments except for water supply and weeding treatments. Water supply in FI and FI + CW treatments was done to achieve optimal water supply during different growth stages according to FAO guidelines. In this study, upland rice showed grain yield varying from 44.16 g m^{-2} (0.44 t ha^{-1}) to 359.61 g m^{-2} (3.59 t ha^{-1}) under fully irrigated conditions depending on variety. Average yield under FI without CG14 was 2.22 t ha^{-1}, average NERICA yield under FI was 2.34 t ha^{-1}. Matsumoto et al. (2014) described a NERICA yield of 3 t ha^{-1} with a total water supply of 500 mm. In this study, FI plots received 774.53 mm to 1024.13 mm of water accumulated during the whole experimental period, depending on variety dependent harvest date. Although water supply was much higher, most of the varieties did not reach yield levels shown by Matsumoto. AfricaRice promotes NERICA seeds with a potential yield of 5 t ha^{-1} for NERICA4 to NERICA8. This experiment reached 3.39 t ha^{-1} and 1.63 t ha^{-1} under FI for NERICA4 and NERICA7, respectively, and 2.72 t ha^{-1} and 1.85 t ha^{-1} under FI + CW, respectively. However, the maximum yield was lower than AfricaRice references. Possible yield reduction can be explained by poor soil conditions and plant nutrition, high soil compaction during measurements in small plots and different environmental conditions during dry season compared to wet season (temperature, radiation, air humidity). East African soil is known as poor soil with low nutrient availability (Murange et al., 2000; Kaihura et al., 1999).

Presented results showed that upland rice yield increased with increasing water supply. Different slopes of linear regressions analysis showed different genotype specific reaction of rice plants to higher water supply. By comparing slopes of different varieties the variety that showed highest yield improvement with lowest additional water should be identified. Linear regression showed significant increase with $p<0.05$ for NERICA17 and SupaIndia. Other tested varieties showed too low R^2 values in linear regression analysis. High R^2 values can be explained by high heterogeneity between replications. Nevertheless, NERICA17 had higher increase in grain yield per water unit than SupaIndia and seemed to be more susceptible to supplementary irrigation treatments. However, this analysis did not reveal differences due to water distribution.

Under common farmer´s practice and rainfed upland rice systems in West Africa, AfricaRice referenced an average upland rice yield of 1 t ha^{-1} in 2003 (Somado et al., 2008). Cultivating upland rice in Dodoma and Morogoro region is not common (Figure 1). Rainfed systems in both regions are prone to drought spells: in Morogoro during the initial phase of plant development and in Dodoma during the final phase of development. These drought spells showed influence on grain yield. Dodoma rainfall caused lower grain yield compared to FI and Morogoro rainfall. PAW in Dodoma showed no water deficit in lower soil layers but in soil surface during drought spells at the end of the growing season. LRI showed a tendency to higher values in Dodoma compared to other treatments but showed no significant drought stress reactions due to these drought spells identifying starting plant water stress. However, a total water supply of 417.1 to 427.3 mm per growing season with unimodal irrigation pattern and a long soil water deficit period after panicle initiation (here portrayed as Dodoma rainfall) caused grain yield reduction. Performed yields under DO were below average upland rice yield of 1 t ha^{-1} presented by AfricaRice and could not be considered as sufficient in terms of rice production. Mahoo et al. (1999) mentioned Morogoro as high-potential growing area of Tanzania. Nevertheless, Morogoro is not known for rice cultivation (Figure 1) and also Mahoo recommended crops as maize and sorghum for this cultivation area instead of rice. This study revealed that rice yield under Morogoro rainfall was lower than in FI plots for most of the tested cultivars. However, all varieties except for CG14 reached yield levels of 1 t ha^{-1} and higher under Morogoro rainfall. A total water supply of 482.4 to 605.4 mm within one growing period under bimodal supply schedule was able to result in sufficient grain yield aiming at average upland rice yield of 1 t ha^{-1} presented by AfricaRice. Reduced yield and reduced biomass accumulation are results of water stress but even occure without soil water deficit (Stürz, 2014). Supplementary irrigation (LSI) and water management treatments (TR + CW) showed increase of grain yield in DO. This effect was weaker to not visible for Morogoro. As yield reduction was higher under DO water supply, the potential of additional water supply was higher compared to MO water supply, where yield reduction was lower. Upland rice yield is not only reliant on water availability. AfricaRice mentioned weed competition as one of the most important yield-reducing factor in upland rice systems (Somado et al., 2008). However, in this study reduced weed competition by clean weeding did not result in higher yield under good water condition (FI). Plants under water supply that does not fulfill CWR as DOTR and MOTR treatments could benefit from clean weeding. Nevertheless, CW had no impact on grain yield under FI and MOTR. Y_{act} was significantly increased for plants in DOTR + CW compared to plants in DOTR which can rather be explained by low yield performance in DOTR than by weeding measures. Shown results of plots with frequently executed weed reduction by clean weeding could not show evidence of improved yield performance.

In general, minimal water management and supplementary irrigation can be a useful tool to improve rice production. LSI is always dependent on external water input. Drought spells can be compensated and as shown in this study grain yield performance and biomass performance can be improved. Tied-ridges and weeding measures are methods in minimal water management without external water input in practice and therefore more suitable for local farmers. Taking into account that both treatments had similar positive effect on grain and biomass yield while tied-ridging and clean weeding did not require external water supply, this technique could be recommended for rice production in semi-arid areas. Nevertheless, the investigated techniques might show different results under real rainfall conditions. As mentioned before, the applied rainfall simulation might alleviate drought spells and distorted effects of tied-ridges. It is possible that LSI is a more useful technique to ensure plant growth and yield performance when drought spells are too long to be compensated by water harvesting techniques such as tied-ridges. Further research is needed to proof the positive impact of water harvesting and clean weeding on upland rice performance under real rainfall conditions.

Presented reductions in biomass accumulation and grain yield under Dodoma and Morogoro rainfall consequently had effects on HI. Morogoro rainfall resulted in slightly decreased grain yield and biomass while Dodoma showed significantly lower yield and biomass compared to FI plots. Results showed that HI for plants in FI, MO including treatments, DOLSI and DOTR + CW reached same levels. Plants in DO and DOTR had significantly lower HI of 0.25 ± 0.20 and 0.25 ± 0.18, respectively. A possible reason could be the different daily water supply of treatments, especially during different growth and development stages. DO including treatments received high water amounts during the initial growth stages and had low water supply during middle and final growth stages. High water availability during the vegetative growth stages may have enhanced biomass accumulation. Low water availability in later stages may have caused leaf dying, explaining the low DM_B for plants in DO compared to plants in FI, but also inhibition of seed filling processes resulting in low grain yield. Overall average HI was 0.36 ± 0.16. These results prove findings in literature. Bouman et al. (2006) found a HI of 0.38 to 0.40 under flowed conditions and 0.27 to 0.35 under dry conditions for aerobic rice varieties.

4.5 Effects on yield components

The actual grain yield of each rice variety is influenced by yield components developed at different phenophases (Shrestha et al., 2012). Environmental conditions during the respective phenological stages have an impact on the current plant development and therefore on yield components (Shrestha et al., 2012). Thus, interactions between genotype and environmental conditions affect the final grain yield of a specific genotype. As shown in Table 13, most of the yield components were affected by genotype, treatment or interaction of these parameters. Nevertheless, neither differences in water distribution (MO and DO) nor in water quantity due to advanced irrigation (TR, LSI, TR + CW) showed any influence on most yield determining components in this study. Rice plants under fully irrigated conditions which were irrigated matching the crop water requirements performed best in grain yield while tested yield determining components did not differ compared to MO and DO. Boonjung and Fukai (1996) found that soil water deficit during vegetative stages reduced grain weight in rice by 30 % due to reduced panicle number per unit area and reduced number of filled spikelets per panicle. Soil water deficit during panicle development influenced grain yields severely and caused yield loss of up to 60 % due to total reduction of filled spikelets down to zero. This could not be proven true with results of this investigation. One of the frequently mentioned yield determining components in literature is thousand grain weight (TGW). Due to time shortage, determination of TGW was not possible in framework of this investigation. With TGW data the source of total grain yield (whether grain weight or grain number) could have been evaluated and compared to previous investigations. Nevertheless, also panicle DM revealed no changes with varying water supply.

4.6 Effects on WUE

It was shown that average WUE was increased by higher water availability. Similar results were presented for NERICA17 and SupaIndia (Figure 33). Treatments including TR + CW or FI water amounts had significantly higher WUEG compared to DO, DOTR and MOTR. FI and FI + CW used slightly more water per unit grain yield compared to TR + CW treatments. In TR + CW treatments, total water input was lower but water availability was increased by total weed removal. Since grain yield was similar to fully irrigated plot, WUEG was more advantageous for TR + CW where highest use efficiency for irrigation water for these environmental conditions was reached. Higher water input, as done in FI and FI + CW, still could increase yield (3.3.1) but marginal in consideration of water input.

WUEG was also influenced by genotype. IAC165, NERICA4 and 14, WAB56-104 and WAB56-50 showed the highest WUEG over all treatments. CG14 showed a low WUEG which can be explained by a poor grain yield performance in this variety. Even in FI plots CG14 showed low yield compared to all other varieties and compared to yield reported in literature (Dingkuhn et al., 1998). CWR was computed with K_c values according to FAO guidelines (Allen et al., 1998). Due to experimental design, all varieties within one treatment had to be supplied with the same amount of water. The K_c value is dependent on crop characteristics. Thus it is possible that the used K_c value did not match CG14 properties and the computed CWR did not match the CG14 CWR.

WUEG and WUEB were not influenced by weeding treatments and did not change with total water supply or with longer growing period. Results shown in Figure 31 and 32 were based on results of single subplots. Due to main harvest dates and uncontinuous harvesting, value distribution seemed to be not accurate for linear regression.

4.7 Effects on weed growth

Results have shown that DM_W was higher during the first weeding compared to postharvest weeding. It can be assumed that the ability to suppress weeds in the plant population was higher at DAS 123 after row closure when rice plants were fully developed.

NERICA varieties are considered as weed tolerant varieties (Somado et al., 2008). NERICA rice varieties did not reveal differences in weeding competition compared to IAC165. As expected, higher water supply resulted in higher weed growth. Different rice varieties did not reveal differences in weeding competition in this investigation.

4.8 Problems and suggestions

In this study, rainfall scenarios were simulated. This seems to be marginal suitable to investigate the actual crop performance under Dodoma and Morogoro rainfall as average rainfall on a daily basis undermine drought and erratic rainfall events that are the most crucial factors in cultivation limitations in semi-arid regions. Therefore this study should be seen as an investigation for different water supply levels with varying climax of supply.

Due to field environment plant performance was strongly plot dependent. Blocks were created to minimize possible slope effects. Border plants were used to minimize different environmental influences. However, the first and last plot row performed poorly. Unfortunately, DOTR and MOLSI plots were allocated to these positions by randomization. Although MOLSI treatment should receive as much water as necessary to enhance plant life and performance, plants died even under high water supply rates. As results were considered as not representative according to high water supply, MOLSI treatments had to be excluded from further analyses. Also DOTR performed poor in biomass accumulation and grain yield compared to DO, while water supply was higher than DO.

5 CONCLUSION

In this study, yield performance and phenology in upland rice was investigated under simulated Dodoma and Morogoro rainfall scenarios. Morogoro rainfall simulation seemed to be suitable for rice cultivation. Dodoma rainfall simulation revealed that Dodoma region without efficient water management is marginal suitable for rice cultivation. It was shown that higher water availability during drought spells due to supplementary irrigation and minimal water management affected rice performance. Life saving irrigation and a combination of tied-ridges and weeding measured had similar effect and increased biomass and grain yield up to adequate level even for Dodoma rainfall scenario. The required amount of water needed for life saving irrigation is dependent on harvest date. Simulation of tied-ridges plus clean weeding achieved similar or better results compared to LSI without external water input in practice. Thus, minimal water management can be considered as a useful tool to enhance rice cultivation in semi-arid areas in SSA. External water sources did not seem to be indispensable to enable sufficient production as water harvesting in combination with weeding measures could also lead to higher yield performance. Water harvesting techniques in rice production need to be tested under real rainfall conditions. More knowledge about infiltration patterns changed by soil modification and possible risks as nutrient leaching is necessary to evaluate the most suitable minimal water management for drought prone areas.

In this study, most NERICA cultivars and most NERICA parent cultivars performed better than the tested locally used landrace. The NERICA yield levels promoted by AfricaRice could not be realized under tested experimental conditions. However, most NERICA varieties and NERICA parents can be considered to lead to higher rice production and higher food security in seasonal dry areas. NERICA17 and SupaIndia revealed a long-growth cycle, performed poorer in comparison to other genotypes and showed higher potential for supplementary irrigation or minimal water management in terms of grain yield.

Further research is needed to define the minimal water amount for life saving irrigation considering actual soil water content. Daily monitoring of plant available water and rainfall can reveal new opportunities do define a more accurate water amount. Moreover LSI is suggested as opportunity to start the Dodoma growing season earlier and to enhance the water use efficiency of unimodal rainfall. Further investigations on cropping calendars and exact LSI water requirements are suggested.

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