Smallholder irrigation productivity for sustainable intensification: Water balances for high value crops in northern Ghana

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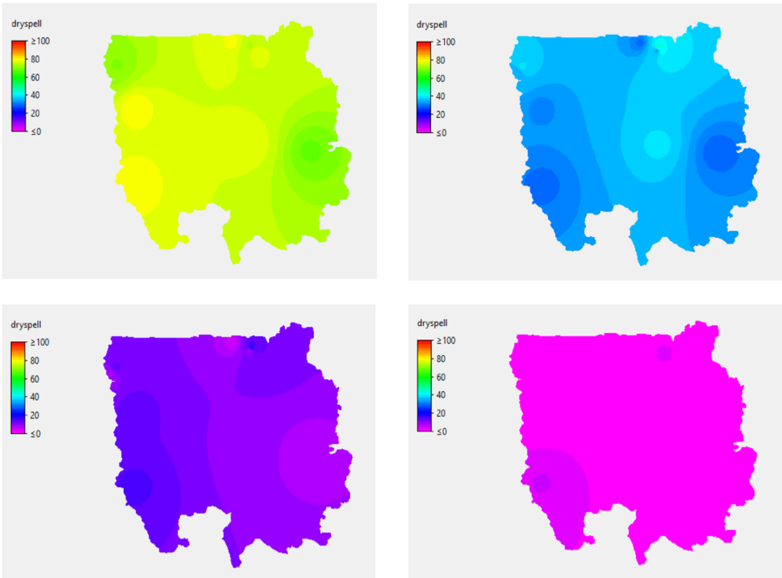

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Contents

Executive summary

Sustainable intensification for smallholder farming systems in sub-humid and semi-arid zones of West Africa critically hinges not only on agronomy and crop varieties but also the management of on-farm water in rain-fed and dry seasons to enhance crop and livestock productivities. Long-term dry spell analysis was carried out using INSTAT+ v3.37 while CROPWAT v8.0 model was used to estimate supplementary irrigation for wet season crops and irrigation requirement for dry season irrigated high value crops.

The results showed that although average annual rainfall amounts across the northern regions exceeds 1,000 mm/year, there is a 60-80% chance of a dry spell exceeding seven days and 30-40% chance of a dry spell exceeding 10 days. On the other hand, longer dry spells of 14 and 21 days do occur but are much less frequent. Dry spells ultimately result in yield decrease unless water management strategies are practiced to increase infiltration. Shorter dry spells (7 -10 days) can be overcome by infield water harvesting and increasing water holding capacity of the soils; however, supplementary irrigation is to be considered for longer dry spells (14-21 days).

In addition, dry season irrigation – of between 50-75% required by crops - results in best productivity (kg yield m^{-3} water applied), attaining 70-90% of potential yield if well-scheduled, especially for high value crops such as tomato, onion, and pepper. To maximize incomes per unit water in dry season irrigation, farmers needs good scheduling advice and devices. This also benefits sustainable intensification. Hence, we recommend assisting farmers to improve water management to fully meet objectives of sustainable intensification.

Introduction

Sustainable intensification is critical for attaining smallholder production and productivity targets. Water management in rain-fed systems and irrigation in dry season or supplemental systems is one fundamental enabling component of sustainable intensification. There is emerging evidence that water management can improve production and productivity in smallholder farming systems (ICSU, ISSC, 2015), and improve household nutritious and food secure diets (Domenech, 2015), all part of national and global targets of the Sustainable Development Goals (SDG) agenda. More importantly, irrigation improves incomes (Xie et al., 2014; Giordano et al., 2012), providing farmers and families with choice to pursue livelihood benefits.

Fundamentally, water management reduces risk in crop and livestock systems, builds resilience in production towards shocks and change, and enhances value of additional farm systems investments (i.e., improved seeds, labor, fertilizers/ nutrients) and integrated pest and weed management in crop-livestock production systems. Globally, there is scope to sustainably intensify through better water management in rain-fed systems alone close to 61% of water related yield gap and increase 41% of current yields at global level (FAO and DWFI 2015; Global Yield Gap and Water Productivity Atlas, 2016). Irrigation systems also show potential for improved water utilization and intensification with possible efficiency gains of 30 to 48%, resulting in additional 26% yield increase (Jagermeyr et al., 2016).

In northern Ghana, the current yields could increase 4-6 t/ha through reduced crop water deficit during rainy season in the dominant smallholder systems, which is around 50 to 70% of potential achievable yields (see Global Yield Gap and Water Productivity Atlas). In addition, only small proportion of cropland is under more than one crop cycle per year. Water resources are typically abundant on annual level; this means that there is an opportunity for sustainable intensification realized through improved water management. However, this can only be realized through: (i) changes in practices of current water management both within rain-fed systems and in dry season fully irrigation systems; and (ii) achieving better productivity and efficiency of water use at plot, farm and landscape level for sustainable intensification, and contribution to Sustainable Development Goals, especially SDG 6.3 for water productivity improvements.

Because the efficiency of water in agricultural production is generally low at field /farm level, it will be critical to develop agricultural water management strategies with smallholder farmers to attain production and productivity gains. A first step is to ensure intra-seasonal dry spells can be managed during rain-fed seasons as these potentially reduce yields within typical savanna agroecological systems of northern Ghana (Mul et al., 2016; Barron et al., 2003). Only 40 to 60% of the water is effectively used by the crop; the rest of the water is lost for productive use in the system or in the farm, either through various processes such as evaporation, runoff or percolation into the groundwater. Irrigation scheduling, if properly managed can offer a good solution to improve water efficiency in the farm. Irrigation scheduling ensures that water is optimally available to the plant if applied according to crop requirements. However, irrigation also incurs a cost for labor and energy so the optimal water allocation from the biophysical and crop production perspective rarely coincides with the economic optimal water productivity (Oweis et al. 2007).

This study is presented to show agricultural water management in sustainable intensification of northern Ghana in smallholder rain-fed and dry season crop production systems. It aims to explore (1) incidence of dry spell occurrence and the impacts on major commodities, such as maize, in rain-fed systems; (2) opportunity in dry season irrigation systems; and (3) implications on water balances and water productivity of different water management strategies.

Methodology

Site description, technology trials, and soils

Historical rainfall data from meteorological stations in northern Ghana, with daily rainfall data covering at least twenty years, were analyzed for dry spells analysis in this study (Table 2-1). Missing data at the stations were filled using the average rainfall recorded at nearby meteorological stations or where unavailable, using the average reading taken on that day over the years. Additionally, further detailed analyses of historical rainfall data from Navrongo in the Anyari catchment in the Upper East Region was carried out in this study. The locations of the stations and length of data at each station are shown in Figure 2-1. For this study, the entire dataset for each station was used in the analysis.

Table 2-1. Rainfall gauging stations used in study

Station	Altitude	Latitude	Longitude	Time period	Extent of gaps (%)
Babile	304.7	10.5167	–2.8333	Nov 1948 to Jul 2004	10.6
Bole	299.5	9.0333	–2.4833	Jan 1960 to Dec 2007	2.7
Bolgatanga	213.0	10.8000	–0.8667	Jun 1975 to Oct 2006	1.3
Lawra		10.5900	–2.7670	Jan 1940 to Dec 2002	22.4
Navrongo	201.3	10.9000	–1.1000	Jan 1960 to May 2008	0.5
Tamale	183.3	9.5500	–0.8500	Jan 1960 to Feb 2008	3.0
Vea		10.8500	–0.8500	Jan 1972 to Dec 1993	2.7
Wa	322.7	10.0500	–2.5000	Jan 1960 to Dec 2004	1.5
Yendi	195.2	9.4500	–0.0167	Jan 1960 to Dec 2008	1.4
Zuarungu	213.0	10.7833	–0.8000	Jan 1939 to Oct 2004	2.1

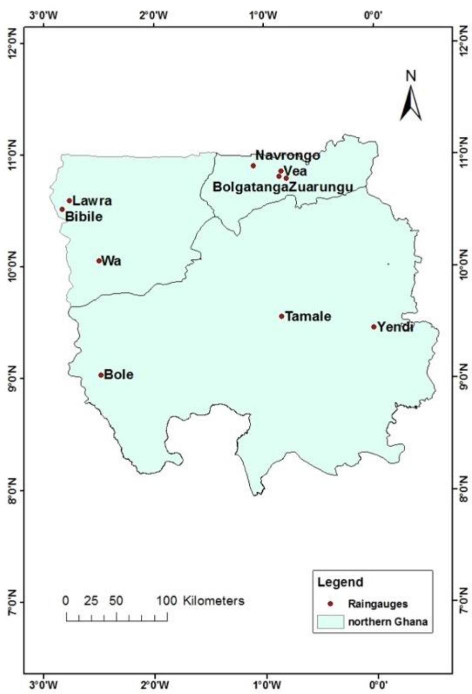


Figure 2-1. Rainfall stations in northern Ghana.

Rainfall and dry spell analysis methodology

Dry spell analyses

Long-term dry spell analysis was carried out using INSTAT+ v3.37 developed by the Statistical Service Centre of University of Reading (Stern and Knock 1998). For this study, a *dry day* is defined as a day with less than 0.85 mm of rainfall while a *dry spell* is defined as a period with consecutive dry days once the cropping season begins (Barron et al. 2003). The threshold of 0.85mm is in line with the focus of this study, which is agricultural dry spell analysis, where higher rainfall thresholds (approximately 1mm) are appropriate as compared to meteorological dry spell analysis (Barron et. al. 2003; Fisher et al. 2013). The start of the cropping season (sowing date) is assumed to coincide with the onset of rains in northern Ghana. It is defined as the first day after mid-April each year when total rainfall for three consecutive days is greater than 20 mm with no dry spell lasting seven days or more in the following ten days (Enfors 2009; Sivakumar 1992).

The dry spell analysis of northern Ghana was carried out for a 90-day cropping season, the typical length of the cropping season for maize. The probabilities of dry spell lengths exceeding 7, 10, 14, and 21 days were calculated for each of the 10 stations depicted in Figure 2-1. The output from this was then extrapolated over northern Ghana to create maps of dry spell probabilities of the area using ArcGIS and PCRaster.

For the detailed analysis using Navrongo rainfall data (located close to the Dimbasinia catchment), the probabilities were calculated for different crop types with different lengths of growing season. In addition to the seasonal probability, probabilities were calculated during each growing stage for six crops grown in the catchment. The crops selected were maize (90 and 120 days), millet, sorghum, groundnut, and cowpea.

Water balance estimation with CROPWAT 8.0

CROPWAT 8.0 (FAO, 2005) was used to determine crop water requirement (CWR) and for scheduling irrigation. The following general procedures were employed to calculate CWR and irrigation scheduling. The most important input data in CROPWAT 8.0 used to determine CWR and irrigation scheduling include climate [to estimate evapotranspiration (ET_o)], rainfall, crop, and soil data.

Determination of Reference Crop Evapotranspiration

Daily Reference Crop ET_o was computed using the FAO Penman Monteith equation:

$$\lambda ET = \frac{\Delta(R_n - G) + \rho_a c_p \frac{(e_s - e_a)}{r_a}}{\Delta + \gamma\left(1 + \frac{r_s}{r_a}\right)}$$

Where:

ET	the same as ET;
λ	heat of vaporization;
R_n	net radiation;
G	soil heat flux;
$(e_s - e_a)$	represents the vapor pressure deficit of the air;
ρ_a	mean air density at constant pressure;
c_p	specific heat of the air;
Δ	represents the slope of the saturation vapor pressure temperature relationship;
γ	psychrometric constant; and
r_s and r_a	(bulk) surface and aerodynamic resistances.

Although, Penman Monteith equation requires several climatic parameters, Penman Monteith in CROPWAT 8.0 can estimate using minimum and maximum temperature using the Hargreaves method given by Hargreaves and Samni (1985):

$$\boldsymbol{ET_o = 0.0023 \times (T_{mean} + 17.8) \times (T_{max} - T_{min})^{0.5} \times R_a \qquad eq.(1)}$$

Where:

ET_o	potential evapotranspiration (mmd^{-1});
R_a	extra-terrestrial radiation ($MJm^{-2}d^{-1}$);
T_{max}	maximum temperatures;
T_{min}	minimum temperatures; and
T_{mean}	mean temperatures for a given day (^oC).

Accordingly, ET_o was computed from minimum and maximum temperatures in CROPWAT 8.0 with parameter settings shown in Annex 1 (Figure 1).

Determination of effective rainfall

For agricultural production, effective rainfall refers to that portion of rainfall that can effectively be used by plants. This is to say that not all rain is available to the crops as some is lost through Runoff (RO) and Deep Percolation (DP).

How much water actually infiltrates the soil depends on soil type, slope, crop canopy, storm intensity, and the initial soil water content. The most accurate method to determine effective rainfall is through field observation. Rainfall is highly effective when little or no RO takes place. Small rainfall amounts are not very effective as these small quantities of water are quickly lost to evaporation. As input of monthly rainfall, the average, dependable or actual rain-fall data can be given. Care should be taken in selecting appropriate values for the dependable rainfall based on separately carried out statistical analyses of long-term rainfall records. CROPWAT 8.0 offers the possibility to use several methods to calculate the effective rainfall; and in this application, we used the USDA Soil Conservation Service Method. See Annex 1 for specific parameters and equations used.

Daily, decadal, and monthly effective rainfall was determined from observed data at Navrongo Weather Station (Table 2.1).

Determine crop parameters

Crop coefficient values for growth stages

The crop coefficient (Kc) integrates the effect of characteristics that distinguish a specific crop from the reference crop, typically selected as a dense well-watered short cut grass. According to the Kc approach, crop evapotranspiration under standard conditions (ETc) is calculated by multiplying the reference ET_o by the suitable Kc. Kc is influenced mostly by crop type and to a minor extent by climate and soil evaporation. Moreover, the Kc for a given crop varies over the crop growing stages since ground cover, crop height, and leaf area change as the crop develops. CROPWAT 8.0 requires Kc values for the initial stage, mid-season stage and at harvest. Kc values during the development and late season stages are interpolated.

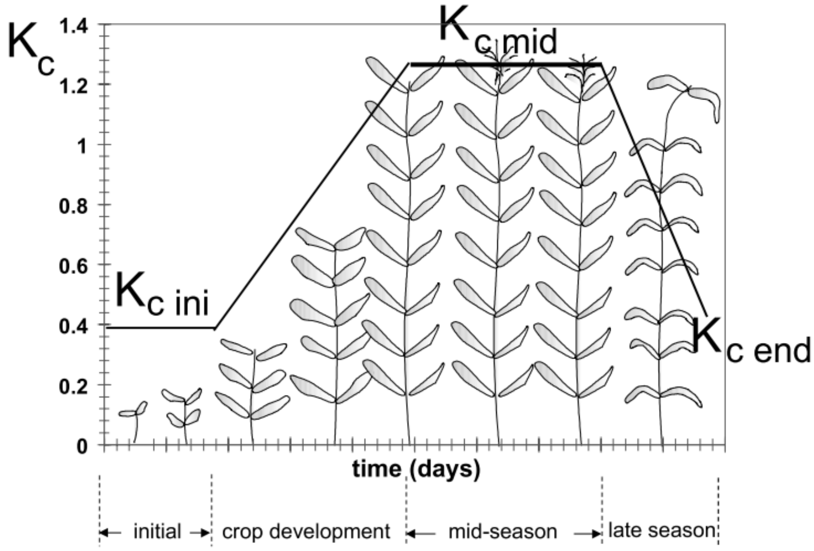


Figure 3. Generalized Kc curve for the single crop coefficient approach (Allen et al., 1998)

Rooting depth
The rooting depth defines the capacity of the crop to take advantage from the soil water reservoir. In CROPWAT 8.0 two values are required for the estimation of the rooting depth over the growing season: rooting depth of initial stage, normally taken as 0.25 - 0.30 m, representing the effective soil depth from which the small seedling abstracts its water; and rooting depth at full development at start of mid-season. For most irrigated field crops and vegetable crops, values vary between 1.0 and 1.40 m and 0.5 - 1.0 m, respectively.

Critical depletion
The critical depletion fraction (p) represents the critical soil moisture level where first water stress occurs affecting crop evapotranspiration and crop production. Values are expressed as a fraction of total available water (TAW) in the rooting depth and normally vary between 0.4 and 0.6. Lower values are taken for sensitive crops with limited rooting systems under high evaporative conditions, higher values for deep and densely rooting crops, and low evaporation rates. In addition, the fraction p is a function of the ET_o power of the atmosphere.

Yield response
The response of yield to water supply is quantified through the yield response factor (Ky), which relates relative yield decrease to relative ET_o deficit. Water deficit of a given magnitude, expressed in the ratio crop evapotranspiration under non-standard conditions (ETc adj) and ETc, may either occur continuously over the total growing period of the crop or it may occur during any one of the individual growth stages.

Crop height
This parameter has been introduced in CROPWAT 8.0 to allow the adjustment of Kc values under nonstandard conditions, particularly values of relative humidity that differ considerably from 45% or where wind speed is larger or smaller than 2.0 m/s. This parameter is optional and in case it is not provided, no adjustments will be made.

Soil parameters

Total available soil moisture (FC-WP)

The TAW represents the total amount of water available to the crop. It is defined as the difference in soil moisture content between field capacity (FC) and wilting point (WP). There is no water available for the plants above the FC level as water cannot be held against the force of gravity and it naturally drains as deep percolation. Likewise, water below WP level cannot be extracted by plant roots as it is retained at high pressures within the soil matrix. TAW depends on texture, structure and organic matter content of the soil. It is also expressed in mm per meter of soil depth.

Maximum rain infiltration rate

The maximum infiltration rate (mm day^{-1}) represents the water depth that can infiltrate the soil over a 24-hour period as a function of soil type, slope class, and rain or irrigation intensity. The maximum infiltration rate has the same value as the soil hydraulic conductivity under saturation. The maximum infiltration rate allows an estimate of the run-off (RO) occurring whenever rain intensity exceeds the infiltration capacity of the soil.

Maximum rooting depth

Although the genetic characteristics of the crop will determine the rooting depth in most cases, the soil and certain disturbing soil layers may restrict the maximum rooting depth. This is the case when hardpans exist in fields where mechanized practices have not been managed adequately. The maximum rooting depth is expressed in centimeters. Default value is set arbitrarily at 900 cm, which indicates that soil has no significant characteristics that can restrict root growth. Any value lower than crop rooting depth would indicate a limitation to root growth.

Initial soil moisture depletion (as %TAW)

The initial soil moisture depletion indicates the dryness of the soil at the start of the growing season (i.e., seeding in case of non-rice crops, or at the beginning of land preparation in case of rice). The initial soil moisture depletion is expressed as a percentage of TAW, in terms of depletion from FC. Default value of 0 % represents a fully wetted soil profile at FC and 100 % is a soil at WP. In this study, we assumed that the initial soil moisture depletion is 0%, indicating that the soil is at FC.

Initial available soil moisture

Initial available soil moisture is defined as the soil moisture content at the start of the growing season. It is calculated as the product of TAW by initial soil moisture depletion and expressed in mm per m of soil depth.

Determination of crop evapotranspiration under standard conditions

The ETc represents the evapotranspiration from disease-free and well-fertilized crops grown in large fields, under optimum soil water conditions, and achieving full production under the given climatic conditions. According to the Kc approach, ETc is calculated by multiplying the reference ET_o by the Kc. The Et_o is determined by the FAO Penman-Monteith method.

Determine irrigation requirement

The irrigation requirement, expressed in mm and computed over a certain period of time, expresses the difference between the ETc and the effective rainfall contributions over the same time. Irrigation requirement indicatively represents the fraction of the crop water requirements that needs to be satisfied through irrigation contributions to guarantee the crop optimal growing conditions. However, it should be noted that this parameter does not take into consideration soil water contribution to the crop.

Total net irrigation requirement
Total Net Irrigation (TNI) requirement can be determined at different levels of soil moisture depletion at the root zone. In this study, optimum irrigation, 20% depletion, 40% depletion, 50% depletion, and 75% depletion were used to estimate TNI of tomato, onion, and pepper in three soil textural classes.

Determination of water productivity
Water productivity of irrigated crops at different depletion levels were calculated based on the productivity of crops and TNI. This is the ratio of productivity of crops (kg) to the TNI m^3.

Soil parameters for water balances

The soil profiles used as input for parameters (Table 2-2) in CROPWAT applications were determined based on data collected at field site (section 2.1) during the 2014-2015 field season.

Table 2-2. Soil profile parameters based on site descriptions for Navrongo northern Ghana

Texture composition	FC-WP (mm/m)	Infiltration (mm/day)	Initial soil moisture depletion (%)
Clay loam	200	40	0
Loam	290	30	0
Sandy loam	140	60	0

Crop and soil parameters for rain-fed systems with water management

During the rainy season, farmers in the Dimbasinia catchment grow primarily staple crops such as maize, millet, and sorghum. Furthermore, groundnut and cowpeas are often intercropped with the staple crops. The lengths of growth stages for these crops are given in Table 2-3a while maize specific crop parameters with various impacts on dry spells are presented in Table 2-3b.

Table 2.3a. Growth stages of crops grown in Anyari catchment (Allen et al.1998)

Crop	Initial stage	Crop development stage	Mid-season stage	Late-season stage	Total season length
Maize (*Zea mays*)	20	30	30	10	90
Maize (*Zea mays*)	20	40	50	10	120
Millet (*Eleusine coracana*)	15	25	40	20	100
Sorghum (*Sorghum bicolor*)	20	35	45	30	130
Groundnut (*Arachis hypogaea*)	25	35	45	25	130
Cowpea (*Vigna unguiculata*)	20	30	30	20	100

Table 2-3b. Crop parameters for maize cultivated in rain-fed system with various impacts on dry spells in the north-eastern Region of Ghana (Adapted from Allen et al. 1998)

Crop –dry spell distribution	Parameters	Growth stages Initial stage	Crop development stage	Mid-stage	Late stage
Maize (long season)	Kc Value	0.3		1.2	0.35
	Stage (days)	20	40	50	10
	Crop height (m)			2	
	Root depth (m)	0.3		1	
Maize (short season)	Kc Value	0.3		1.2	0.35
	Stage (days)	20	30	30	10
	Crop height (m)			1.5	
	Root depth (m)	0.3			1

Crop and soil parameters for dry season irrigation systems

The various dry season irrigation systems undertaken in the Africa RISING sites includes various combinations of lift and distribution over three major high value crops (tomatoes, onion, and peppers). These crops were selected in consultation with farmers. The key crop characteristics needed for CROPWAT are presented in Table 2-4.

Table 2-4. Crop parameters for tomatoes, onion, and pepper cultivated in dry season irrigation in the north-Eastern Region of Ghana (Adapted from Allen et al., 1998)

Crop type	Parameters	Growth stages Initial stage	Crop development stage	Mid-stage	Late stage
Tomato	Kc Value	0.6	1.2	1.15	0.8
	Stage (days)	23	20	40	25
	Crop height	0.25			1
	Root depth			0.6	
Onion	Kc Value	0.7		1.0	1.0
	Stage (days)	20	45	20	10
	Crop height			0.3	
	Root depth	0.25			0.6
Pepper	Kc Value	0.6		1.05	0.9
	Stage (days)	25	35	40	20
	Crop height	0.25			0.6
	Root depth			0.70	

Results and discussion

Rainfall and dry spell distribution in northern Ghana

Descriptive statistics for the ten rainfall stations are shown in Table 2-2. The average daily rainfall in northern Ghana ranges from 2.5 to 3.4 mm. However, the median and maximum rainfall values show that for more than half the year, there is no rain; and rainfall in one day can be as high as 178.1mm. On the average, the start of the rains occurs between mid-April and mid-May with a maximum dispersion of 33 days.

Table 2-2. Descriptive statistics of rainfall at ten stations

Station	Annual rainfall (mm)	Start of Rains	
	Mean	Ave. start of rains	SD (days)
Babile	1065.8	27-Apr	16.7
Bole	1113.3	17-Apr	23.3
Bolga	945.4	26-Apr	15.7
Lawra	923.5	16-May	32.7
Navrongo	981.9	4-May	17.4
Tamale	1102.3	19-Apr	16.1
Vea	912.5	11-May	25.6
Wa	1047.6	22-Apr	15.1
Yendi	1233.7	22-Apr	14.4
Zuarungu	1022.0	6-May	19.8
Average	1034		

The results of dry spell analysis carried out at ten stations over a 90-day season in northern Ghana are given in Figure 2-2. The figure shows the probability of a dry spell exceeding 7, 10, 14, and 21 days for the ten stations. Across the region, the probability of a dry spell exceeding seven days is approximately 75% (3 out of 4 years). The highest probability of dry spells exceeding seven days is found in Wa in the Upper West region. On the other hand, at Vea station, the probability of dry spells exceeding 10 and 14 days is also relatively high compared to the other stations while the highest probability of a 21-day dry spell is at Zuarungu.

There is more than a 40% chance (2 out of 5 years) of a season with dry spell exceeding 10 days in two stations. Dry spells exceeding 14 days occurs 1 out of 10 years for five stations. Dry spells exceeding 21 days are observed in only three stations. The probabilities of dry spells at these stations were extrapolated over the entire area of northern Ghana to show the spatial variation (Fig. 2-3). This shows that generally, the eastern part of the northern region has lower probability of dry spells while higher probabilities are found in the central and south-west parts.

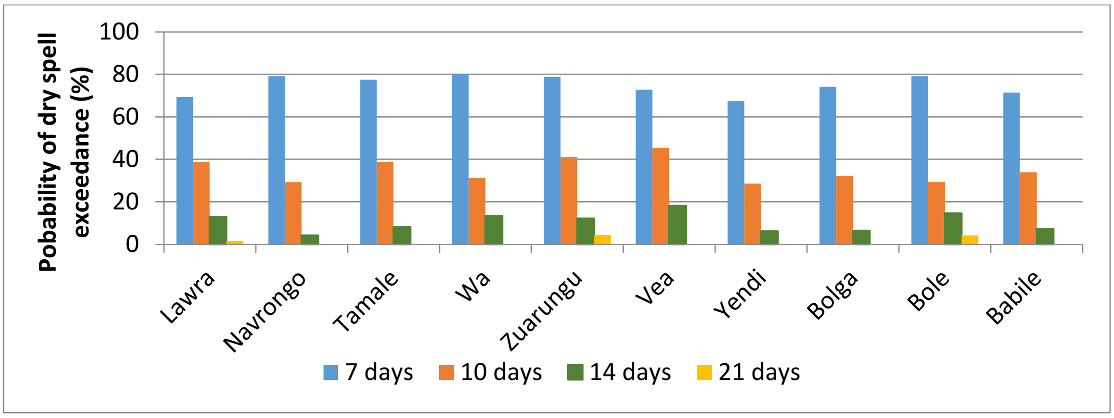
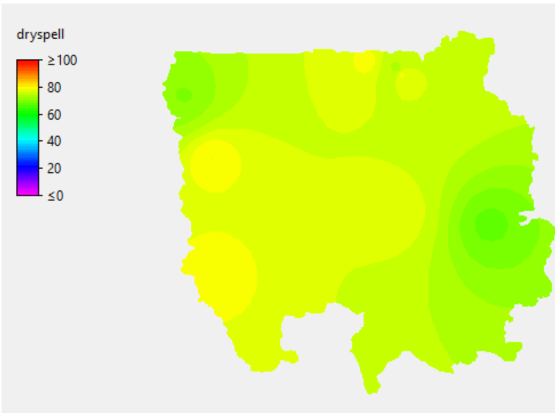
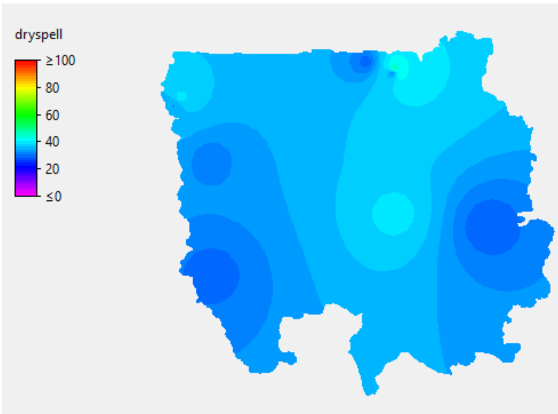


Figure 2-2. Probability that maximum dry spell will exceed 7, 10, 14, and 21 days over a 90-day growing season

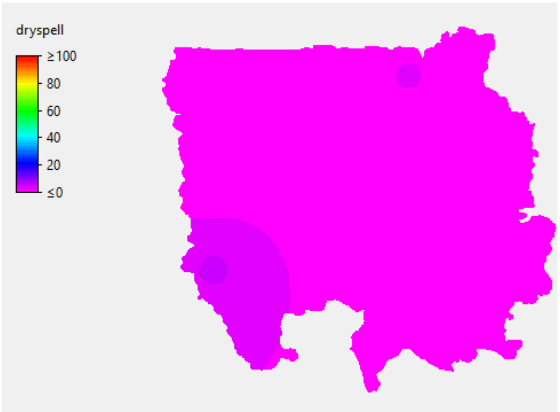


7 days



10 days

14 days



21 days

Figure 2-3. Probability of maximum dry spells exceeding 7, 10, 14, and 21 days over northern Ghana for a 90-day season

At Lawra, which had 22% of daily rainfall readings missing, 18.5% of this occurred in the growing season (Appendix, A3). In total, 13 years out of 63 (20%) of the years are affected [953 days of missing data out of a total of 5670 days (i.e., 90 days growing season over 63 years)]. The period 1983 to 1992 is noteworthy; on the average, there were 72 out of 90 days with missing data during the growing seasons. This may have influenced the results, reducing the probability of dry spells for Tamale.

Dry spell analysis at Navrongo

Figure 2-3 shows the onset of the cropping season at Navrongo while Figure 2-4 shows the maximum length of dry spells for each year over the various cropping seasons. For all the graphs, the average value over the years is also indicated. The start date of rains, and by extension the start of the cropping season, is very variable. The earliest onset of rains was observed on 1 April and the latest was on 11 June with an average start date on 4 May (Fig.2-4). The trend in the starting data is not significant at 95% confidence level.

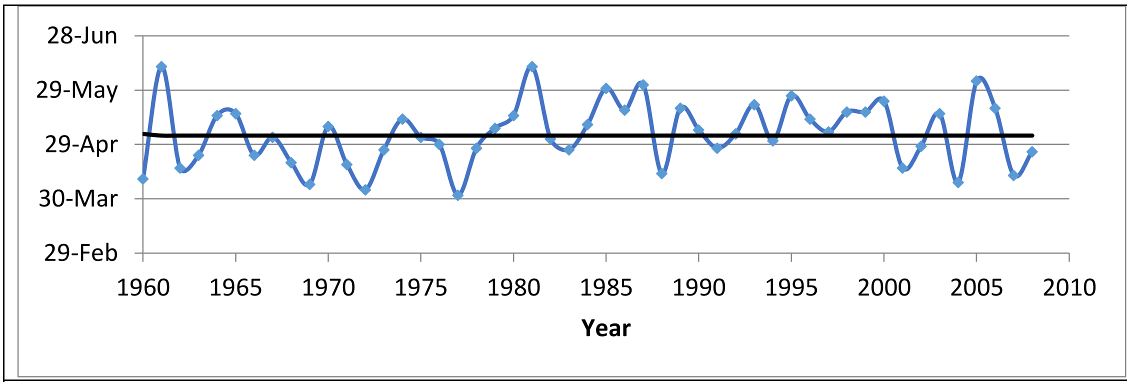
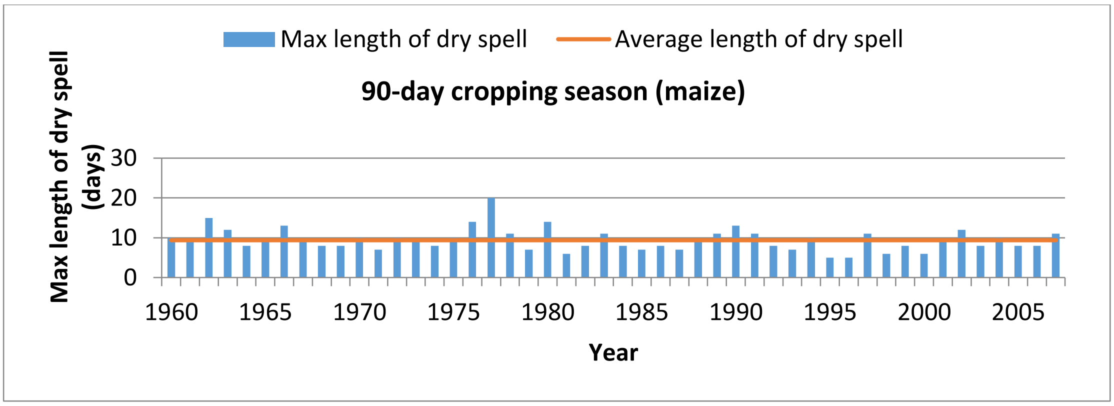


Figure 2-3. The start date of rains/cropping season at Navrongo

The average maximum length of dry spells is seen to increase with the length of the cropping season, from 9.42 days for the 90-day season to 10.10 days for the 130-day season (Fig. 2-4). Across all cropping seasons, it was in 1962 and 1977, which had the longest dry spells. While the maximum dry spell for 1977 held steady at 20 days irrespective of the total length of the season, the length increased from 15 to 31 days in 1963 suggesting that the maximum dry spell for that year occurred towards the end of the cropping season. The shortest dry spell length is five days occurring consecutively in 1995 and 1996. Since 2000, the maximum dry spell length has generally been less than 10 days except for 2002 and 2007 where it was 12 days and 11 days long, respectively. This implies that farming systems in Navrongo need to be buffered against relatively short dry spells, which last approximately one week as these are more frequent occurrences. These are confirmed in the analysis of dry spells in the growth stages of selected crops (Figure 8).



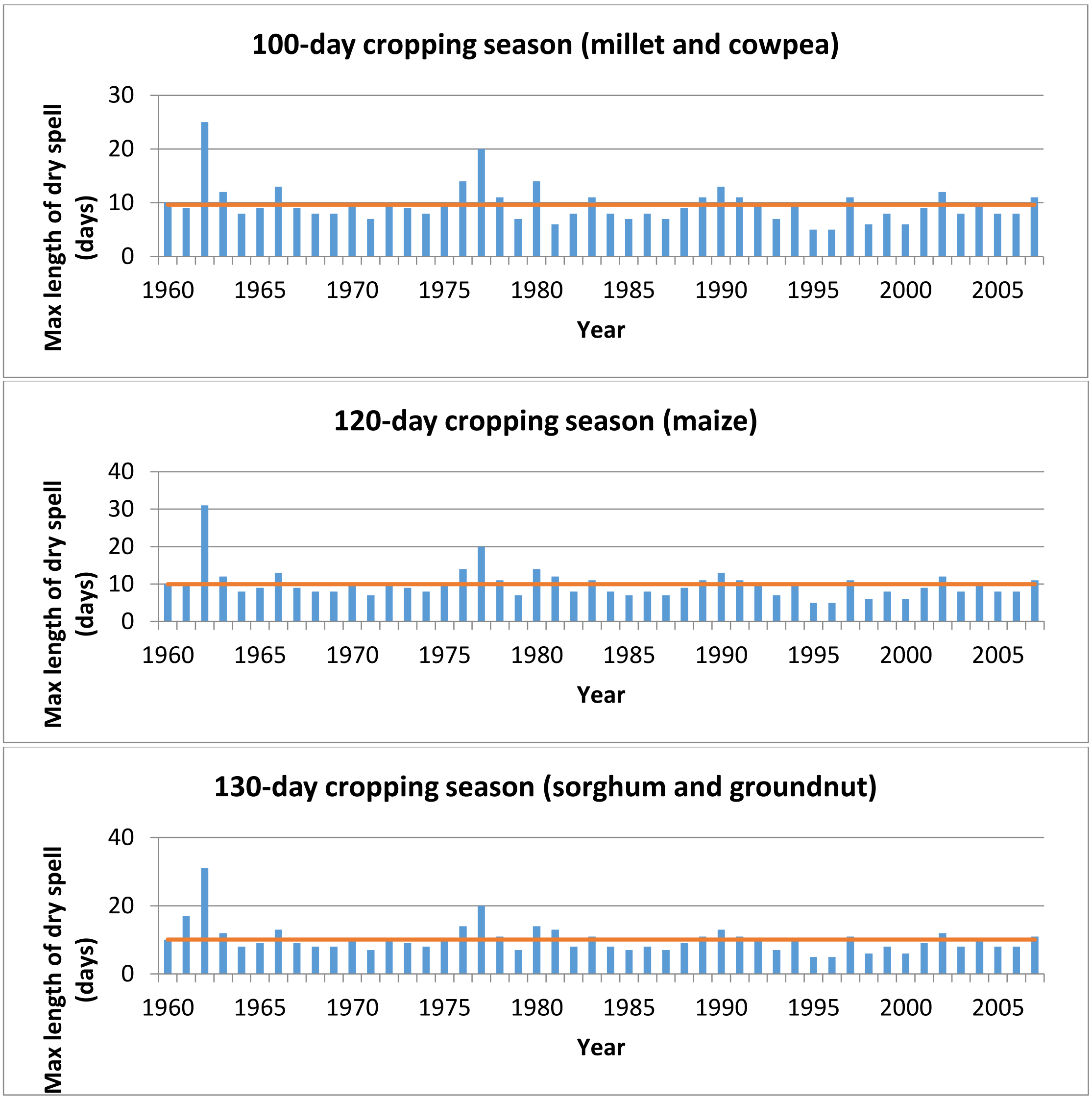
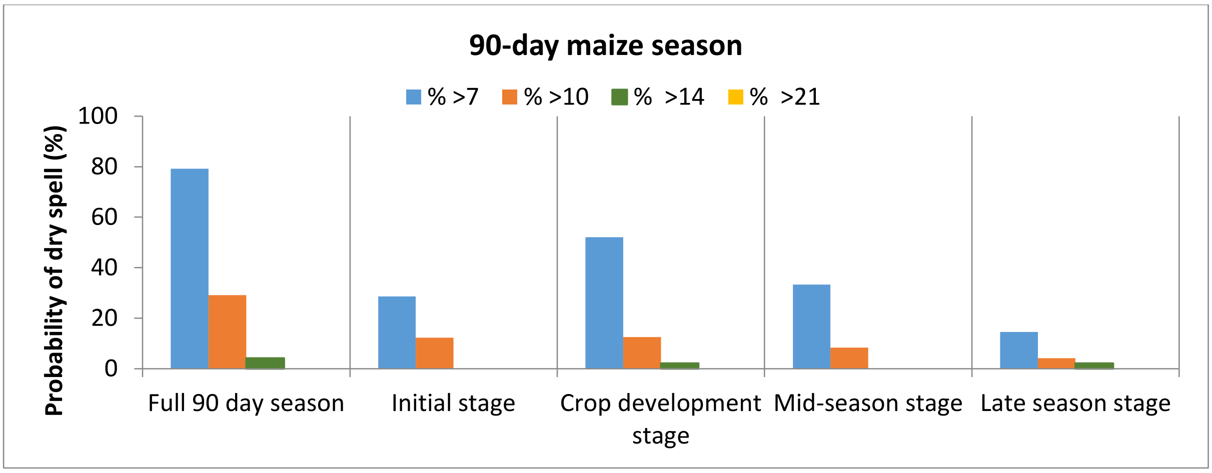
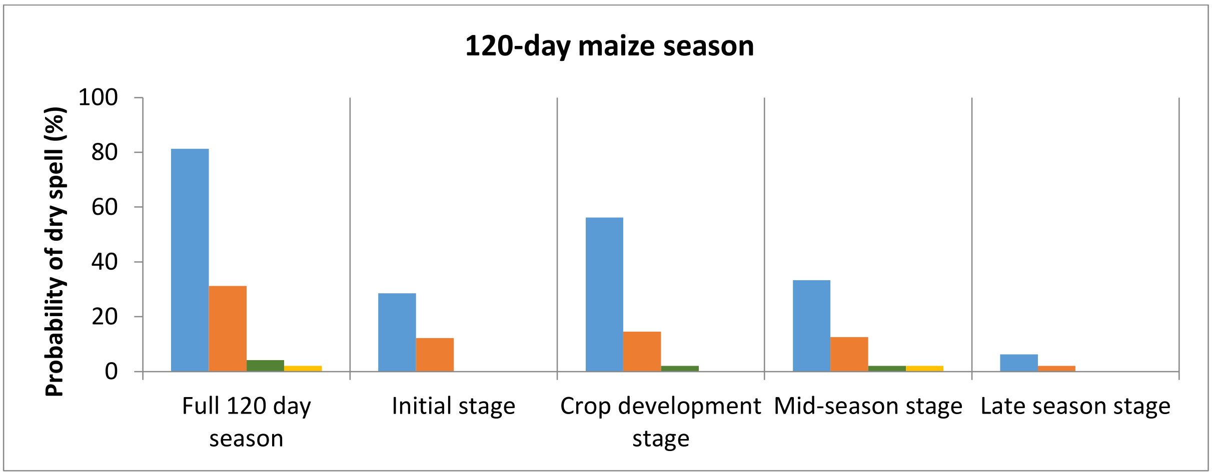


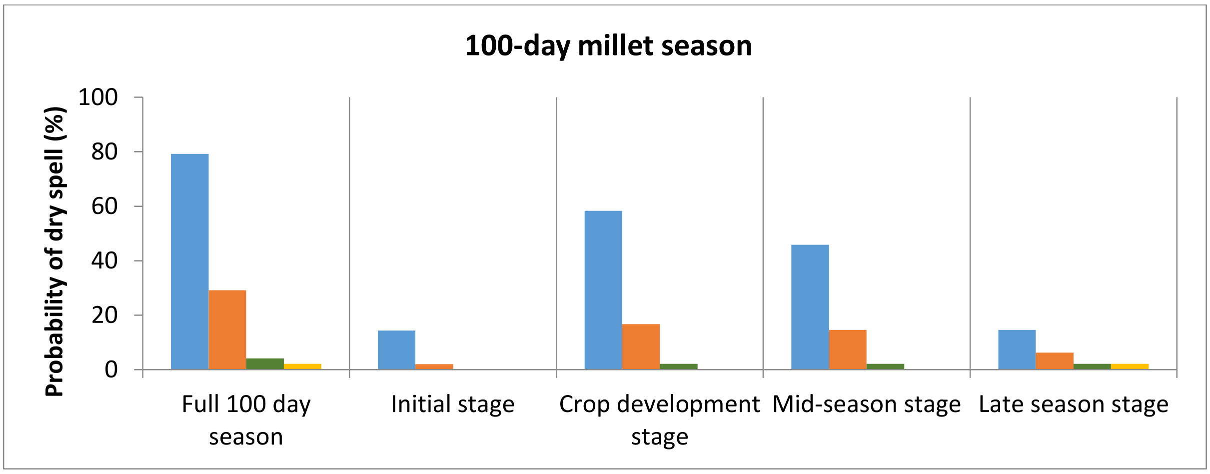
Figure 2-4. Maximum lengths of dry spells for various cropping season lengths

There is a high probability, approximately 80%, that dry spells exceed seven days during the cropping season, irrespective of crop season length (Fig. 2-5). For dry spells exceeding 10, the probability of occurrence reduces to 30% and then further reduces to 4-6% for dry spells exceeding 14. The probability of dry spells longer than three weeks is approximately 2% for all the cropping season lengths except for the 90-day season where no such dry spells have occurred over the years. These patterns confirm the spatial dry spell analysis carried out over a 90-day season in northern Ghana.

The probabilities that dry spells last longer than 7, 10, 14, and 21 days over the full cropping season and over each crop growth stage for the five crops are shown in Figure 2-5. Across the crop growth stages for all crops, the probability of a seven-day spell occurring is highest in the crop development stage, followed by the mid-season stage, the initial stage, and then the late season stage. Twenty-one-day spells do not occur in the initial and crop development stages but there is a low probability that (<3%) that they occur towards the end of the cropping season, in the mid-season stage, and late season stage.


90-day maize season
% >7
% >10
% >14
% >21
Probability of dry spell (%)
100
80
60
40
20
0
Full 90 day season
Initial stage
Crop development stage
Mid-season stage
Late season stage


120-day maize season
Probability of dry spell (%)
100
80
60
40
20
0
Full 120 day season
Initial stage
Crop development stage
Mid-season stage
Late season stage


100-day millet season
Probability of dry spell (%)
100
80
60
40
20
0
Full 100 day season
Initial stage
Crop development stage
Mid-season stage
Late season stage

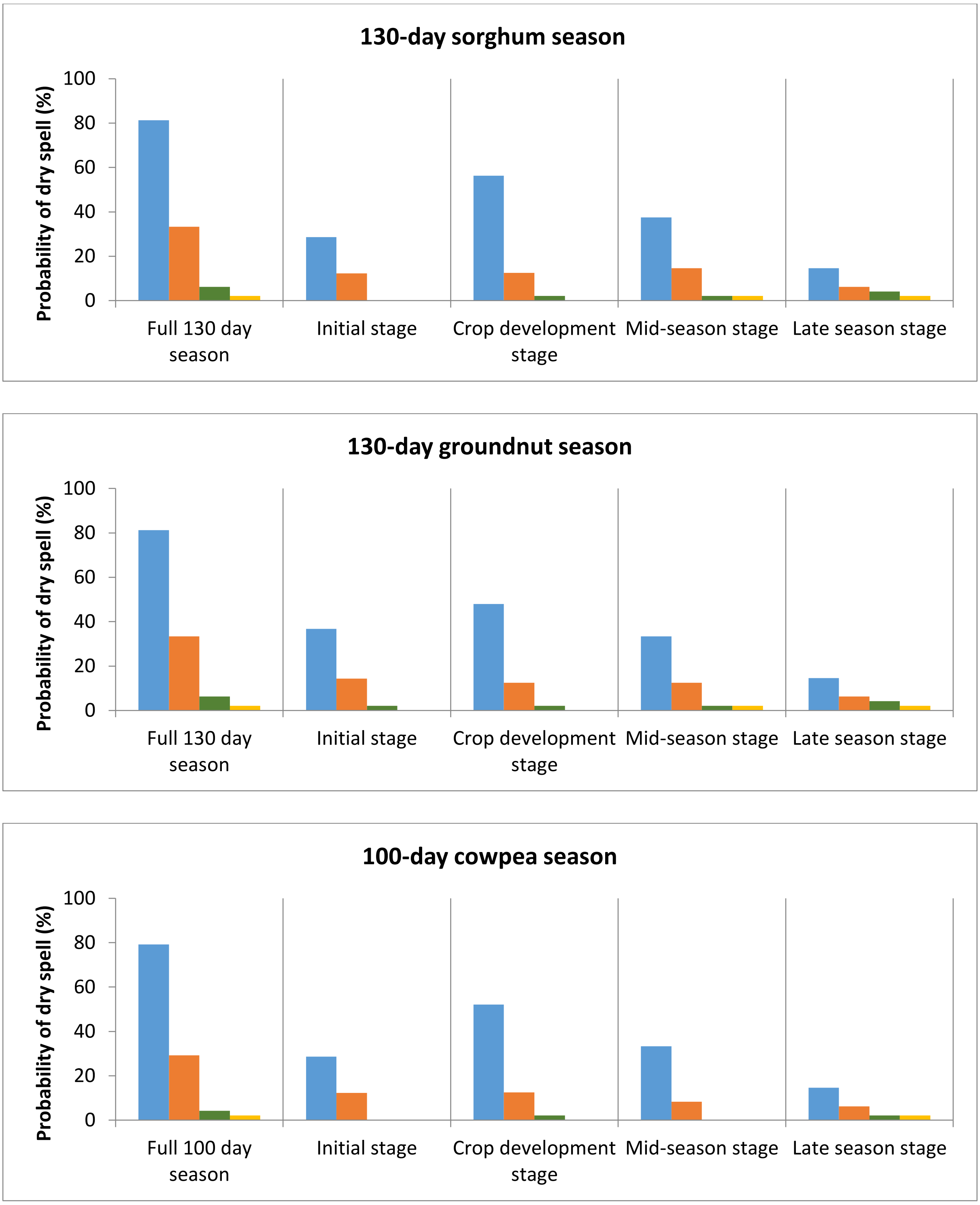


Figure 2-5. Probability that maximum dry spell will exceed 7, 10, 14, and 21 days over various seasons

Rain-fed systems water balance and yield response of maize with different rainfall scenarios and soil types

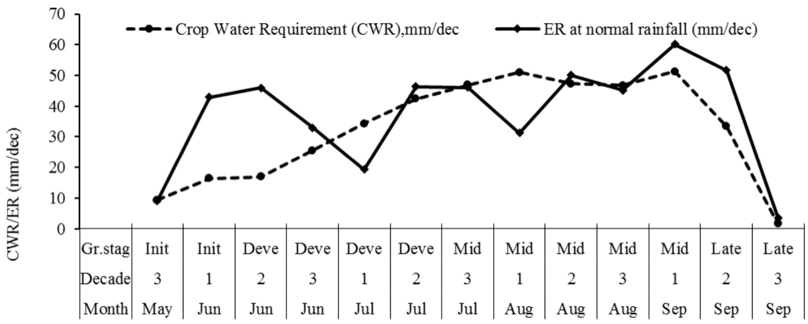
Water balance of maize at different growth stages

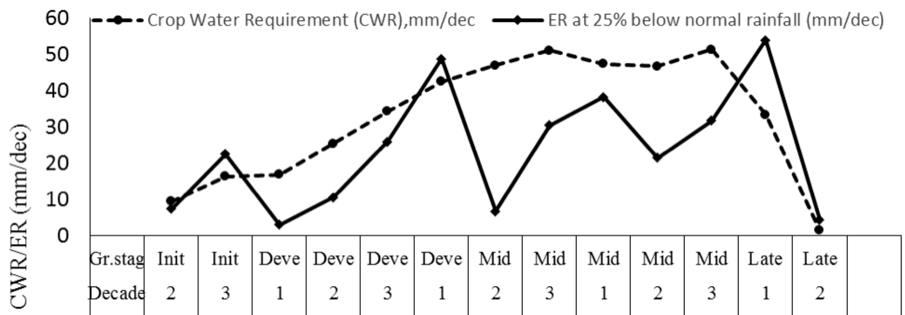
Three rainfall regimes were considered for assessing the water balance of maize (with growing length of 120 days). The first rainfall regime was a normal rainfall (long-term average, 1966-2008). The second regime was 25% above the normal rainfall and the third regime was 25% below the normal rainfall. The rainfall data shows that 25% below the normal rainfall occurs two years out of three years. However, 25% above the normal rainfall occurs only once every 17 years.

Generally, in all rainfall regimes, effective rainfall (ER)is sufficient for the initial and late growth stages of maize. In the normal rainfall regime, the ER was lower than the crop water requirement (CWR) of maize during the first decades of July (development stage) and August (mid-season stage) (Fig. 2-5). This corresponds to the highest probabilities of dry spell occurrence in these growth stages (Fig.2-4).

When the rainfall is 25% below the normal rainfall, the ER is much lower than the CWR of maize at all development and mid-season stages of maize (Figure 2-5). As shown in the figure, ER was lower than CWR of maize from June to August except during the first part of July. This shows that there is critical water deficit during these development and mid-season growth stages of maize.

The ER was higher than the CWR of maize during the growing period when 25% above the normal rainfall was considered. The ER was slightly below the CWR only in July. As shown in Figure 2-5, there is water surplus during the initial and the late growth stages of maize. This implies that moisture conservation strategies are crucial to utilize excess rainfall during initial stage for the development stage of crops.





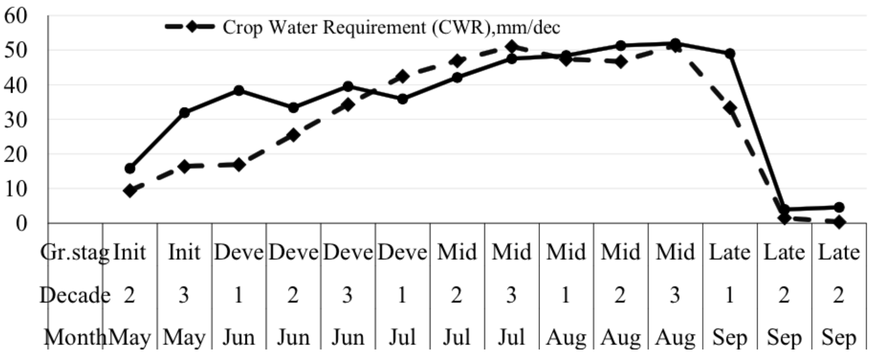


Figure 2-5. CWR and ER for maize during wet season (rain-fed system) at three rainfall scenarios (normal rainfall, 25% below the normal rainfall, and 25% above the normal rainfall)

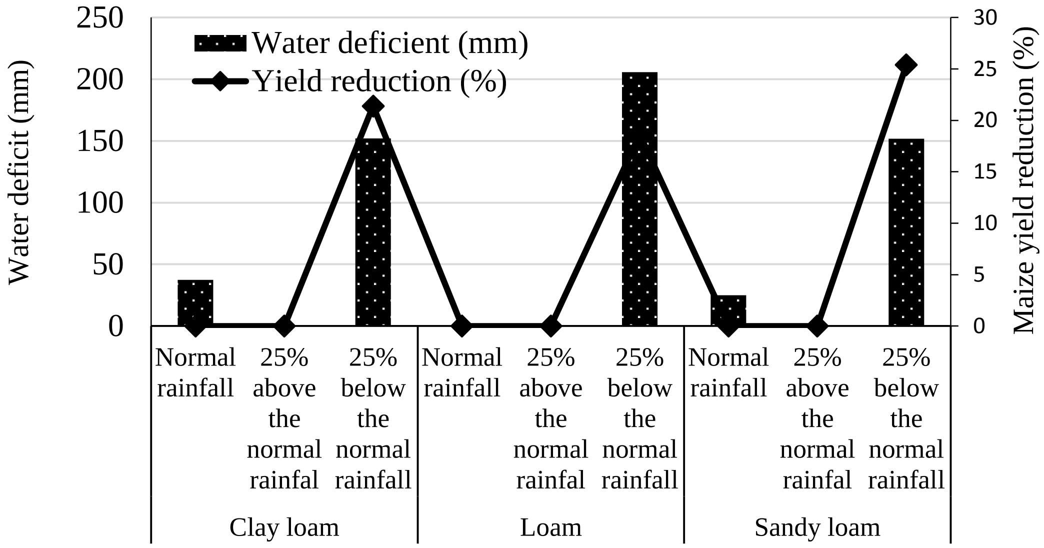


Figure 2-6. The response of maize for different rainfall regimes and under different soil types

Dry season irrigation production and productivity for high value vegetables

Total irrigation requirement and yield response for dry season high value crops

Overall, there is a marginal loss in yield with minor reductions in irrigation. However, the tipping points for substantial losses in yield due to water stress varies typically between the high value crops tested here due to different crop growth response curves. The TNI of tomato in clay loam soils ranged from 300 mm (75% depletion) and 577 mm (at 25% depletion). Similarly, TNI of tomato in sandy loam soils ranged from 426 mm (75% of deletion) to 572 mm (25% of depletion). The highest yield losses of tomato at all levels of soil moisture depletion were observed in sandy loam soils due to the low total available soil moisture holding capacity while the lowest yield losses were observed in clay loam soils (Fig. 3-5). Generally, the yield loss due to application of water at 25% of soil moisture was only about 1%. As shown in Figure 3-5, significant yield reductions were observed when water was applied at 50% soil moisture depletion in clay loam (23%), loam (27%), and sandy soils (28%).

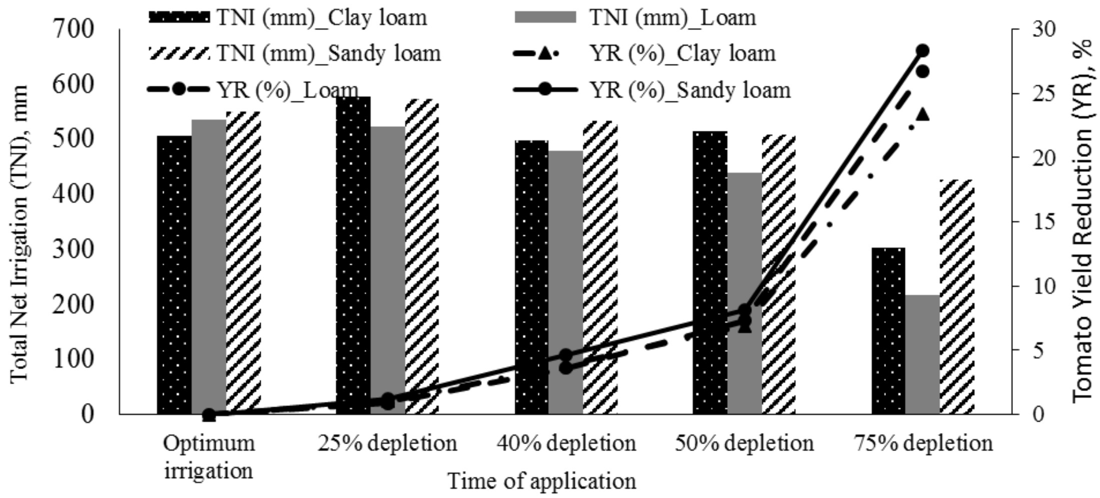


Figure 3-5. TNI and yield reduction at different levels of soil moisture depletion of tomato

The TNI of onion in clay loam soils were lower than (200 mm) at 50% depletion and (423 mm) at optimum level of irrigation than onion. Similarly, TNI of onion in sandy loam soils (ranged from 210 mm at optimum irrigation to 391 mm at 50% of depletion) were lower than tomato. Similar to tomato, the highest yield losses of onion at all levels of soil moisture depletion were observed in sandy loam soils and the lowest yield losses were observed in clay loam soils (Fig.3-6). Generally, the yield loss due to application of water at 25% of soil moisture depletion was 5% (Fig. 3-6). As compared to tomato, yield reductions of onion were the highest at 40% and 50% soil moisture depletion in all soil types.

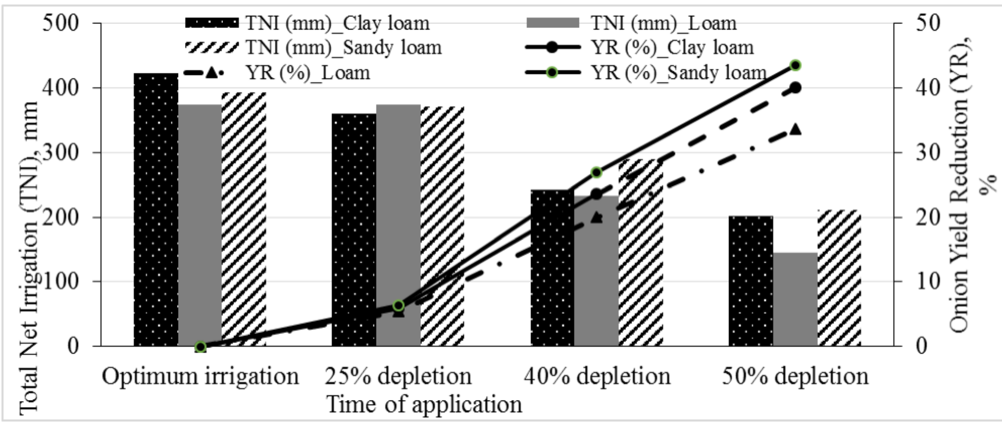


Figure 3-6. TNI and yield reduction at different levels of soil moisture depletion of onion

The TNI for pepper in clay loam soils ranged from 302 mm (at 50% depletion) and 531mm (at 25% depletion). On the other hand, TNI of pepper in sandy loam soils ranged from 353 mm (50% of deletion) to 554 mm (25% of depletion). Similar to onion, the highest yield losses of pepper were observed in sandy loam soils at all levels of soil moisture depletion (Fig. 3-7). The yield loss due to application of water at 25% of soil moisture depletion was about 3% for clay loam and loam soil types. The yield reductions at the application of 50% soil moisture depletion were 31%, 26%, and 33% in clay loam, loam, and sandy loam soils, respectively.

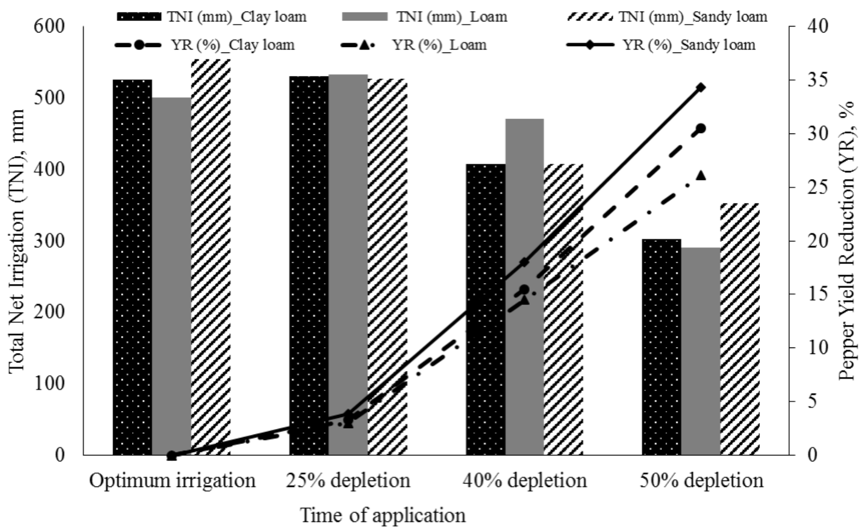


Figure 3-7. TNI and yield reduction at different levels of soil moisture depletion of pepper

Water productivity at different depletion levels

Water productivity was at its highest for tomato at 75% of soil moisture depletion and at 50% soil moisture depletion for onion and pepper under dry season irrigation. The loam (with highest water holding capacity) resulted in most efficient water productivity across crops. The average yield of tomato (40 t/ha), onion (20 t/ha) and pepper (10 t/ha) were used to estimate irrigation water productivity (MoFA, Ijoyah et al., 2008). On the average, loam soil has the highest water productivity (9 kg/m^3) as compared to clay loam (8 kg/m^3) and sandy loam (7 kg/m^3) of tomato (Fig. 3-8). The highest average irrigation water productivity of tomato (10 kg/m^3) was found in irrigation at 75% soil moisture depletion level.

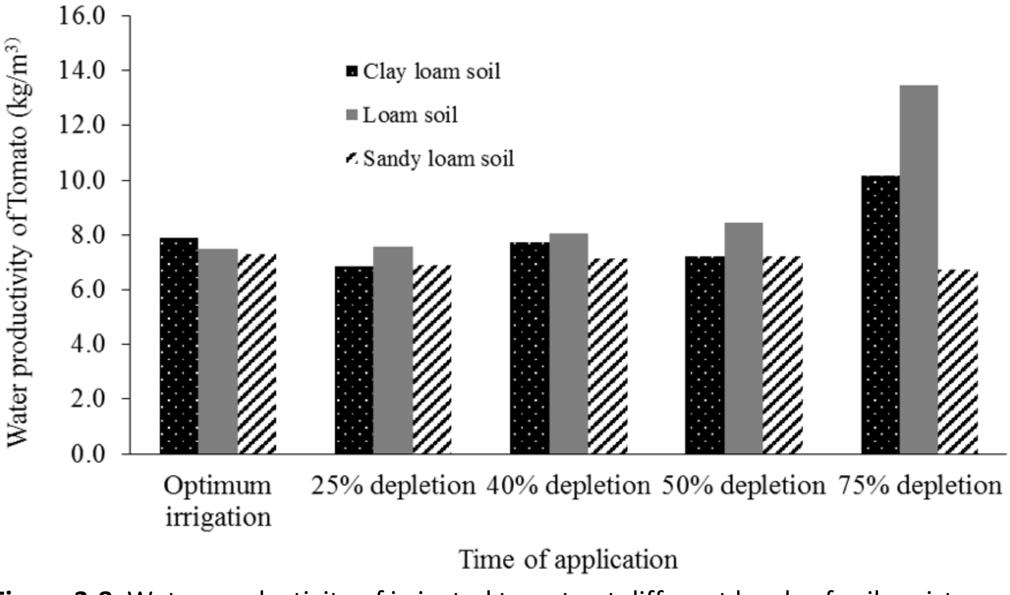


Figure 3-8. Water productivity of irrigated tomato at different levels of soil moisture depletion in three soil types

Unlike tomato, the highest average irrigation water productivity of onion (6.8 kg/m3) was recorded when the soil was irrigated at 75% soil moisture depletion (Fig. 3-9). The average irrigation water productivity was the highest (6.6 kg/m3) in loam soil types as compared with clay loam (5.6 kg/m3) and sandy loam soils (5.1 kg/m3). Generally, however, irrigation water productivity of onion is lower than tomato at all soil moisture depletion levels and in all soil types.

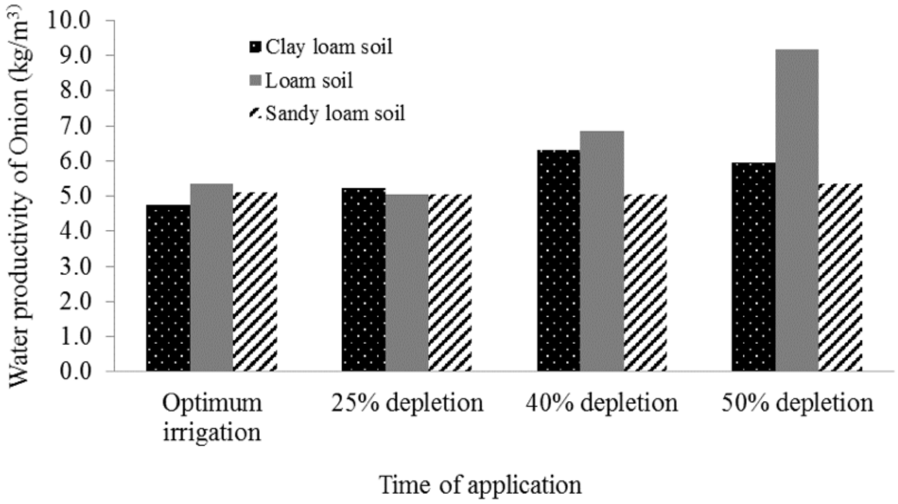


Figure 3-9: Water productivity of irrigated onion at different levels of soil moisture depletion in three soil types

The average irrigation water productivities of pepper were 2.03 kg/m3, 2.04 kg/m3, and 1.88 kg/m3 in clay loam, loam and sandy loam soils, respectively (Fig. 3-10). Generally, the average water productivity of pepper (dry) was the lowest (2 kg/m3) as compared to tomato and onion. This is mainly due to the low yield potential (10 t/ha) of pepper.

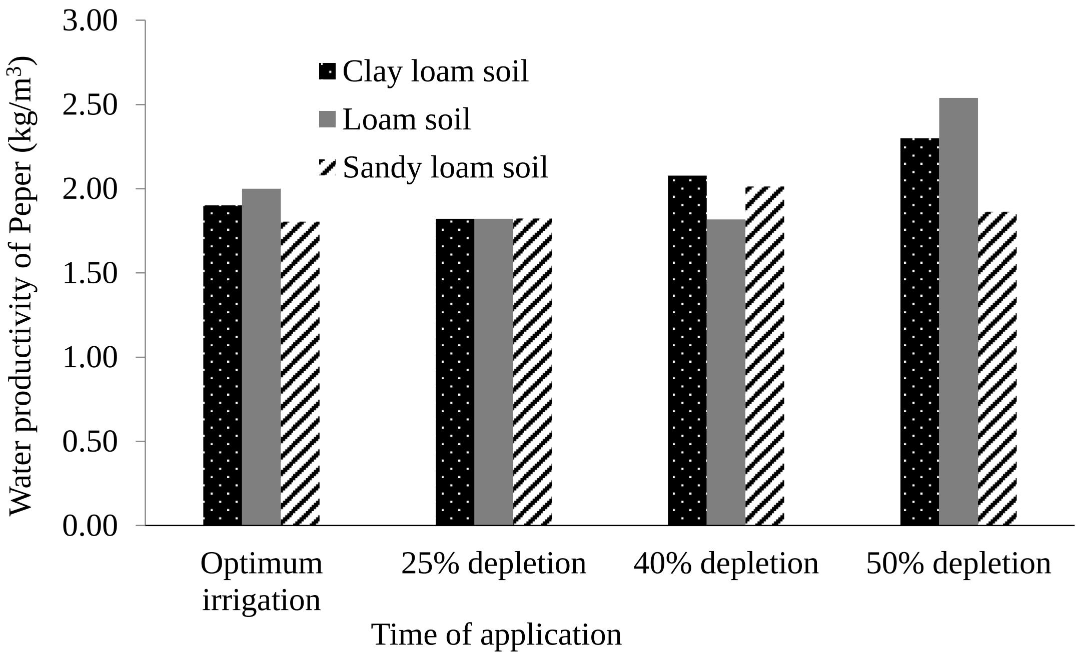


Figure 3-10. Water productivity of irrigated pepper at different levels of soil moisture depletion in three soil textural classes

Conclusion

Average annual rainfall (exceeding 1,000 mm/year) in the northern regions of Ghana is more than adequate to grow staple crops such as maize, millet and sorghum. However, dry spells within the growing season is affecting crop yields. Short dry spells exceeding 7-10 days have a high probability of 60-80% for dry spells exceeding seven days and 30-40% for dry spells exceeding 10 days. This means that 3 to 4 years out of 5 experience a dry spell exceeding 7 days, and almost 2 out of 5 years a dry spell of more than 10 days are observed. Such short dry spells can be overcome by applying infield agricultural water management practices, increasing the soil water holding capacity, and increasing infiltration and reducing runoff. However, longer dry spells exceeding 14 and 21 days, although occurring at much lower probability, require larger investments in water storage or irrigation techniques. For example, during long dry spells, maize yield reduced up to 25% in the study area. This implies the need for supplementary irrigation of 152 mm for maize.

Full irrigation is typically not most water productive but an application between 50-75% yields 70-90% of potential yield if well-scheduled for typical high value crops such as tomato, onion, and pepper.

To maximize incomes per unit water in dry season irrigation, farmers need good scheduling advice and /or devices. This also benefits sustainable intensification as water productivity is higher under 50-75 % of maximum crop water requirement as shown for smallholder farming systems in northern Ghana. Hence, we recommend assisting farmers in technologies and approaches to enhance infiltration and root depth to bridge natural variable rainfall, promote accessible water management technologies, and scheduling to maximize water benefits in dry season irrigation.

Acknowledgements

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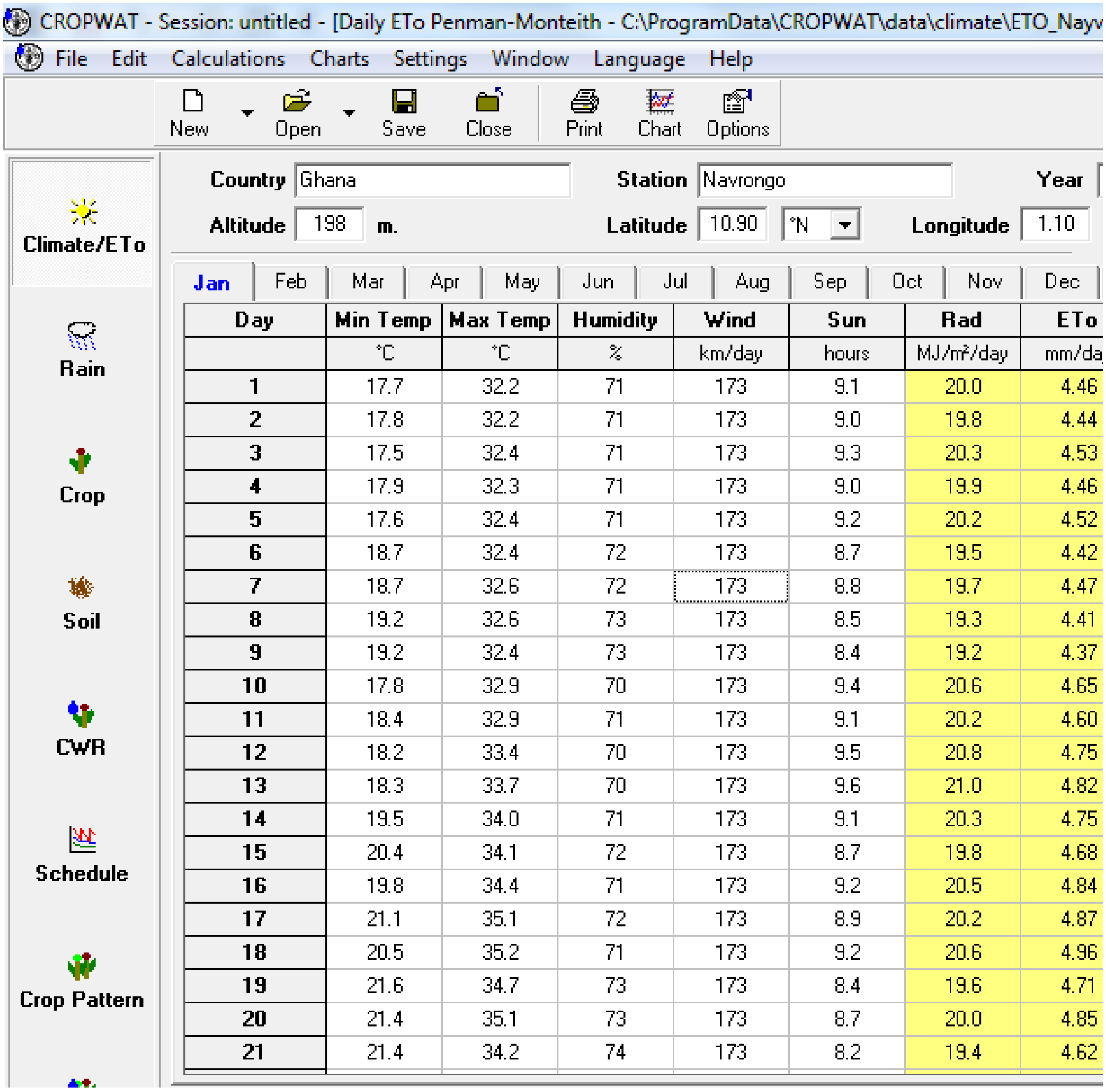
Annexes

Details on data and calculations used in CROPWAT 8.0 applications



Day	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/da
1	17.7	32.2	71	173	9.1	20.0	4.46
2	17.8	32.2	71	173	9.0	19.8	4.44
3	17.5	32.4	71	173	9.3	20.3	4.53
4	17.9	32.3	71	173	9.0	19.9	4.46
5	17.6	32.4	71	173	9.2	20.2	4.52
6	18.7	32.4	72	173	8.7	19.5	4.42
7	18.7	32.6	72	173	8.8	19.7	4.47
8	19.2	32.6	73	173	8.5	19.3	4.41
9	19.2	32.4	73	173	8.4	19.2	4.37
10	17.8	32.9	70	173	9.4	20.6	4.65
11	18.4	32.9	71	173	9.1	20.2	4.60
12	18.2	33.4	70	173	9.5	20.8	4.75
13	18.3	33.7	70	173	9.6	21.0	4.82
14	19.5	34.0	71	173	9.1	20.3	4.75
15	20.4	34.1	72	173	8.7	19.8	4.68
16	19.8	34.4	71	173	9.2	20.5	4.84
17	21.1	35.1	72	173	8.9	20.2	4.87
18	20.5	35.2	71	173	9.2	20.6	4.96
19	21.6	34.7	73	173	8.4	19.6	4.71
20	21.4	35.1	73	173	8.7	20.0	4.85
21	21.4	34.2	74	173	8.2	19.4	4.62

Figure 1. Daily ET_o calculation in CROPWAT 8.0

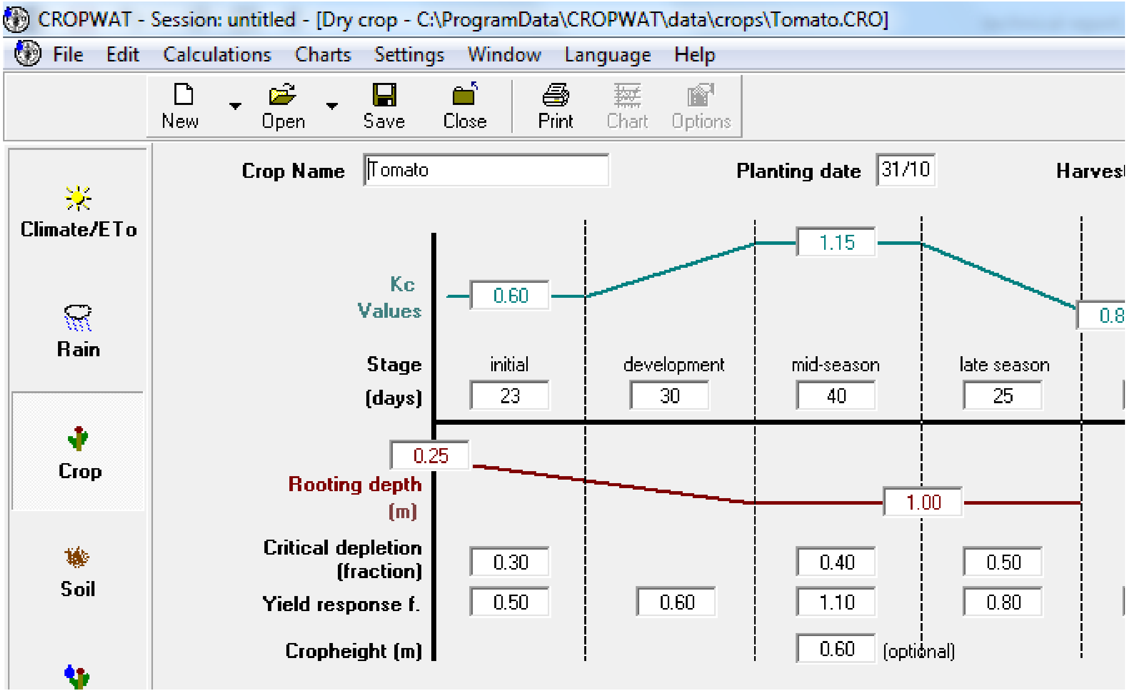


Figure 2. Crop parameters used in CROPWAT model

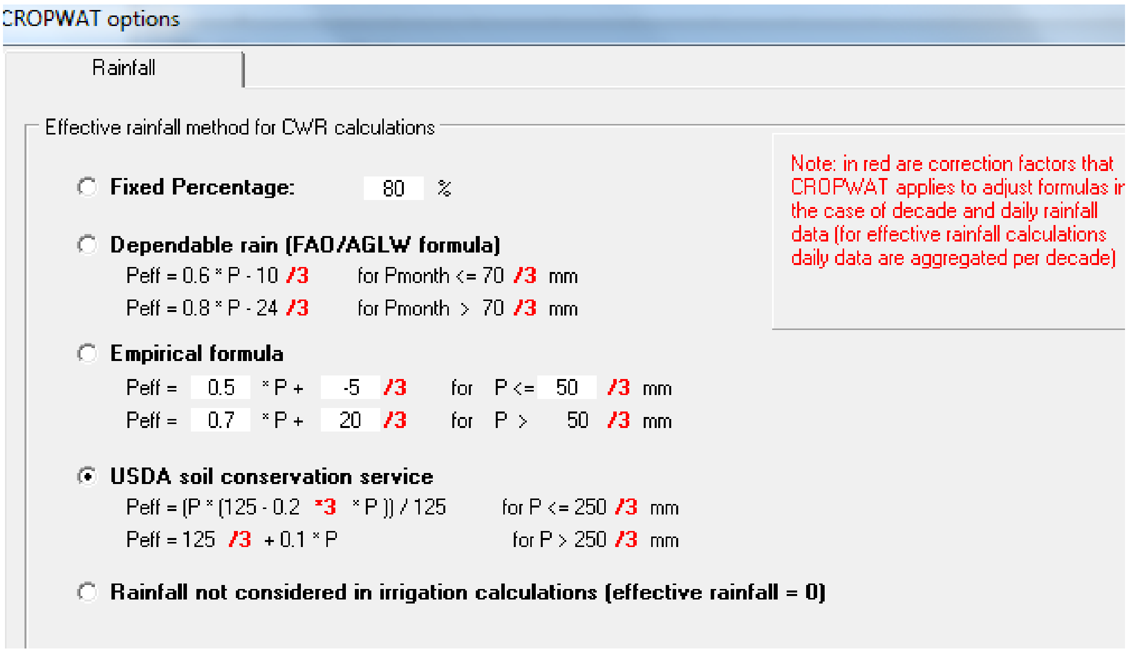


Figure 3. Effective rainfall estimation methods

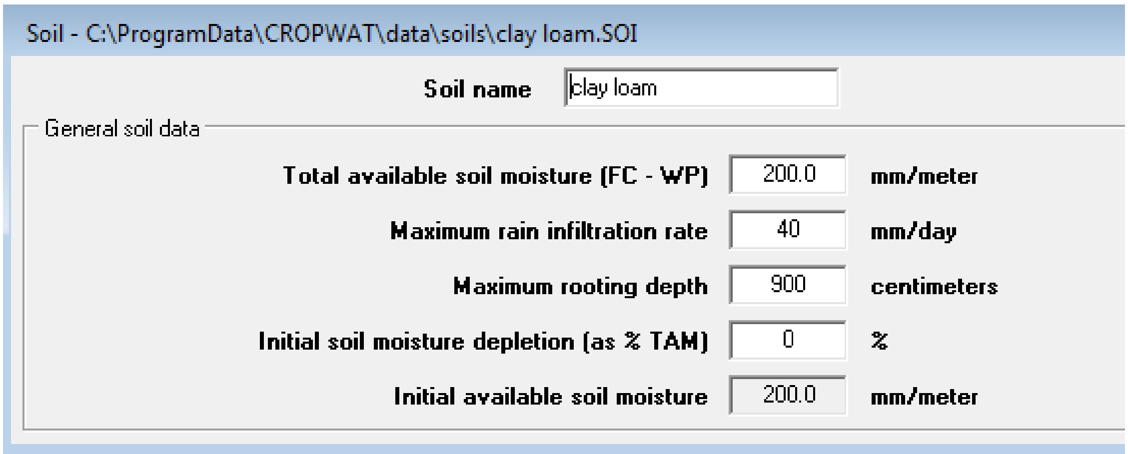


Figure 4. Soil parameters used in CROPWAT model

Table A1. Results of trend and homogeneity tests on maximum dry spell lengths.

Station	**Ave. max dry spell length**	**MK (trend) test- max dry spell length**			**Pettitt (change point) test- max dry spell length**			
		S sign	**p-value (two-tailed)**	**Interpretation**	**K**	**t**	**p-value (two-tailed)**	**Interpretation**
Babile	9.85	-	0.091	no trend	286	1983	0.067	no break
Bole	12.31	-	0.872	no trend	152	1964	0.443	no break
Bolgatanga	9.77	-	0.680	no trend	49	1997	0.898	no break
Lawra	11.94	+	0.816	no trend	113	1987	0.985	no break
Navrongo	9.94	-	0.105	no trend	204	1983	0.141	no break
Tamale	10.76	+	0.917	no trend	155	1964	0.464	no break
Vea	12.36	+	0.626	no trend	60	1982	0.151	no break
Wa	10.47	-	0.521	no trend	181	1992	0.162	no break
Yendi	**9.53**	**+**	**0.054**	**no trend**	**261**	**1973**	**0.039**	**significant break**
Zuarungu	11.12	-	0.889	no trend	132	1984	0.974	no break

MK test interpretation

- H_0: There is no trend in the series
- H_a: There is a trend in the series
- If the computed p-value is greater than the significance level α=0.05, accept the null hypothesis H_0

Pettitt test interpretation

- H_0: Data are homogeneous
- H_a: There is a date at which there is a change in the data
- If the computed p-value is greater than the significance level α=0.05, accept the null hypothesis H_0

Table A2. Results of trend and homogeneity tests on annual rainfall.

Station	**MK (trend) test- Annual Rainfall**			**Pettitt (change point) test- Annual Rainfall**			
	S	**p-value (Two-tailed)**	**Interpretation**	**K**	**t**	**p-value (Two-tailed)**	**Interpretation**
Babile	-	0.360	no trend	228	1980	0.230	no trend
Bole	-	0.730	no trend	118	1969	0.744	no trend
Bolgatanga	+	0.416	no trend	96	1987	0.172	no trend
Lawra	**-**	0.063	no trend	**520**	**1970**	**0.001**	**significant trend**
Navrongo	-	0.637	no trend	94	1979	0.932	no trend
Tamale	-	0.421	no trend	125	1968	0.677	no trend
Vea	+	0.504	no trend	41	1984	0.564	no trend
Wa	-	0.896	no trend	142	1969	0.369	no trend
Yendi	-	0.190	no trend	222	1979	0.108	no trend
Zuarungu	+	0.856	no trend	224	1950	0.553	no trend

Table A3. Results of trend and homogeneity tests on start of rains.

	MK (trend) test- Start of rains			**Pettitt (change point) test- Start of rains**			
Station	**S**	**p-value (Two-tailed)**	**Interpretation**	**K**	**t**	**p-value (Two-tailed)**	**Interpretation**
Babile	+	0.944	no trend	179	1982	0.539	no trend
Bole	-	0.433	no trend	146	1992	0.490	no trend
Bolgatanga	-	0.196	no trend	99	1990	0.186	no trend
Lawra	+	0.105	no trend	**474**	**1972**	**0.004**	**significant trend**
Navrongo	+	0.098	no trend	**263**	**1978**	**0.040**	**significant trend**
Tamale	-	0.369	no trend	131	1971	0.667	no trend
Vea	-	0.672	no trend	40	1980	0.591	no trend
Wa	-	0.286	no trend	166	1979	0.245	no trend
Yendi	+	0.966	no trend	119	1967	0.761	no trend
Zuarungu	-	0.461	no trend	330	1952	0.155	no trend

Table A4. Missing days in growing season at Lawra.

Year	Start of rains	End of 90 day season	No. of missing days in season
1940	9-Apr	8-Jul	0
1941	4-Aug	2-Nov	0
1942	-	-	-
1943	22-Jun	20-Sep	0
1944	29-Jun	27-Sep	0
1945	27-Apr	26-Jul	0
1946	6-Apr	5-Jul	0
1947	1-Jun	30-Aug	0
1948	16-Apr	15-Jul	0
1949	7-Apr	6-Jul	0
1950	20-Apr	19-Jul	0
1951	27-Apr	26-Jul	0
1952	18-May	16-Aug	0
1953	26-May	24-Aug	0
1954	15-Apr	14-Jul	0
1955	21-Jul	19-Oct	90
1956	3-Apr	2-Jul	0
1957	30-Apr	29-Jul	0
1958	1-Apr	30-Jun	0
1959	27-Apr	26-Jul	0
1960	10-Apr	9-Jul	0
1961	6-May	4-Aug	0
1962	17-Apr	16-Jul	0
1963	23-Apr	22-Jul	0
1964	6-May	4-Aug	0
1965	11-May	9-Aug	0
1966	15-Apr	14-Jul	0
1967	9-Apr	8-Jul	0
1968	24-Apr	23-Jul	0
1969	19-Apr	18-Jul	0
1970	7-May	5-Aug	0
1971	27-May	25-Aug	0
1972	19-Apr	18-Jul	0
1973	19-Jul	17-Oct	0
1974	13-Jun	11-Sep	0
1975	4-Jul	2-Oct	0
1976	22-May	20-Aug	0
1977	18-May	16-Aug	0
1978	1-Jun	30-Aug	0
1979	16-May	14-Aug	0
1980	6-Jun	4-Sep	0
1981	5-Jul	3-Oct	3
1982	22-May	20-Aug	0
1983	30-Jul	28-Oct	89
1984	10-May	8-Aug	90

1985	30-May	28-Aug	90
1986	18-May	16-Aug	90
1987	1-Jun	30-Aug	90
1988	24-Jun	22-Sep	21
1989	19-May	17-Aug	60
1990	18-Jul	16-Oct	76
1991	2-Jul	30-Sep	60
1992	5-May	3-Aug	57
1993	10-Jul	8-Oct	0
1994	30-Apr	29-Jul	0
1995	26-Apr	25-Jul	0
1996	8-May	6-Aug	0
1997	4-Apr	3-Jul	2
1998	17-May	15-Aug	90
1999	17-May	15-Aug	45
2000	15-Apr	14-Jul	0
2001	18-May	16-Aug	0
2002	13-Apr	12-Jul	0