Ethiop. J. Agric. Sci. 24:123-139 (2013)

Integration of Information on Climate, Soil and Cultivar to Increase Water Productivity of Maize in Semi-arid Eco-regions of Ethiopia

Girma Mamo[1], Mezegebu Getnet[1], Gizachew Legesse[1] and Takele Mitku[2]

[1]*Ethiopian Institute of Agricultural Research (EIAR),Melkassa Agricultural Research center, Agrometeorlogy Research Group, P. O. Box 436,*

[2]*Department of Soil and Crop Science, Texas A & M University, Texas USA.*

Abstract

*Climate related risks highly influence crop performance and thus water productivity in different eco-regions of Ethiopia. In view of its low rainfall and short growing period, the semi-arid eco-regions like the Central Rift Valley of Ethiopia (CRV) are the most affected. A study was conducted in Bofa, CRV to utilize climate information in guiding cropping and water management decisions. Tercile probability was computed to characterize rainy seasons into best (April), expected (May) and worst case (June) planting scenarios. Three independent experiments were designed to fit planting scenarios. In each set, one improved and one local maize cultivars (best: BH660 and Bolonde; medium: A511 and Limat; worst: Melkassa-1 and Shaye) were combined with three tillage practices: Modified-Moldboard Plow (MMP), Wing-Plow (WP) and local Maresha. Rainwater productivity and grain yield were compared. The results illustrate differences among planting scenarios and suggesting early planting decision is a possible practice in semi-arid CRV when soil water conserving tillage is integrated to escape climate associated risks. BH660 shows higher water productivity (9.46 kgmm^{-1} of rainfall) under 2*MMP tillage than late plantings in experimental years. About 84 % of the variability in grain yield (BH660), 88% (Bolondie), 76% (A-511) and 70% (Limat) can be explained by the available soil water in crop root zone at planting. Hence, integration of climate information, tillage practices and cultivar choice enabled not only successful aversion of climate related risks for long duration maize but also increased yield and rain water productivity in semi-arid areas. Furthermore, tailored rainfall forecast can help in selection of planting scenarios, tillage practices and crop cultivars in advance and further increase probability of success.*

Key words: Climate risk, tercile probability, tillage, planting scenario

Introduction

Climate variability and climate change are currently major factors influencing agricultural production and productivity worldwide, whereas the impact is acute in developing countries like Ethiopia where rain-fed cropping system accounts for more than 90% of the national food production (Temesgen et.al., 2008). In fact, the challenge is higher when rainfed farming is practiced in semi-arid zones where rainwater is inadequate to meet crop water requirements. Typical water inadequacy indicators in the semi-arid climate include; the delay in start of rains and early cessation of season; thus resulting in shortened length of growing period. Further, the declining number of rainy days and volume of rainfall, as well as extended dry spells during cop critical growth stages are typical characteristics of the semi-arid climates. The most likely rising temperature is also feared to enhance heat load, as well as increase soil water deficit through increased evaporation and reducing soil water balance.

Maize, a tropical crop on which millions depend for food and feed, is among those crops that highly respond to climate risks in semi-arid eco-regions. Despite too many the challenges in this respect, the current maize researches in Ethiopia focus mainly on the multi-location field trials in confirmation with its variety development-release chain, giving little or no room for climate risk management decisions that could provide better solution in improving rainwater productivity.

In Ethiopian dryland farming, agronomic research on improved soil water management practices backdates to three decades (Reddy and Kidane, 1994). For example at time, much applaud has been accorded to ‘tied ridge’ as a proven technology in conserving *in situ* soil water and increasing the depth of wet soil. While crops grown under tie ridging practice are responsive in particular during poor rainy seasons (Reddy and Kidane, 1994; Tewodros, 2004), arguments are many, for example ‘why efforts are limited to make improvements over tie ridging and to diversify rainwater management practices, particularly under semi-arid climate.

In selecting cultivars, the prevailing perception in dryland crop breeding research also places much focus on the genetically low yielding short cycle cultivars that fit into the short growing season during June-July-August-September (JJAS). In practice such a strategy masks the values of any rain events before June that could have substantially contributed to improved dry matter yield and therefore rain water productivity via: growing a genetically high yielding long cycle maize cultivars. Arguably, this biases towards a dependable rainy season per se has been grounded in the concept of 'once-for-all' classification of a given agroecological zone either into arid, semi-arid, sub/moist climate categories (MoARD, 2005), with sidelining its temporal dimension. Our argument here is, even semi arid areas could exhibit moist or wet seasons in some years of early onset that can be exploited to enhance yield level and water productivity.

Recent advancement made by dryland farmers shows their need to utilize any ensuing growing season according to its potential. In practice, gambling with growing long cycle crop cultivars in the event of early rains; or opting for a short cycle variants of the same crop or another in case of late start of rainfall is taking a common place. Farmers also prefer to take a stock of advantages from the long rains through growing a tall and high yielding crop cultivars for a suite of reasons i.e grain, feed and construction (Mosisa et al. 2012). Obviously, this thought results in divergence of ideas among the crop breeders who study the system and the farmers who manage the system. Thus, it would not be surprising if farmers in the semi-arid farming zones build a *'risk averse'* behavior and remain skeptic in adopting improved maize cultivars developed by crop breeders.

The challenges to the conventional research is therefore, to appreciate the gaps noted above in general and building an institutional capacity to frame historical climate data into wet, normal and dry seasons (tercile probability) in particular. Such exercises would help in searching for and availing alternative technologies fitting either of these seasonal rainfall categories.

In this paper we report, results that aimed at showing how increased water productivity could make part of key response options in the semi-arid maize farming zones. Measured in kg grain mm^{-1} of rainfall or actual crop evapo-transpiration/ETa (Melesse, 2007; Barron, 2004), water productivity (WP_R) represents a valuable indicator for assessing crop yield in semi-arid climates (Bennie and Hensley, 2001). This presumes that WP_R could be increased through adopting soil water conservation tillage to ensure the availability of rainwater in the crop root zone (Barron, 2004; Tewodros, 2004; Melesse, 2007). In context, rain making is impossible, but making soil water directly available to the crop is feasible through water conservation tillage practices (Araya and Stroosnijder, 2010). The knowledge of integrated cultivar choice, soil water, climate, and crop management in the target locality is also becoming a key to success. The objective of this research was therefore to contribute to the concept and practices of enhancing water productivity of maize through integration of cultivar by environment (soil and climate) and crop management practices; including planting date and population density.

Materials and Methods

The study area

The study was conducted in the Central Rift Valley (CRV) of Ethiopia (Fig.1). On-farm experiment was piloted at Bofa village (8^{0}27’46”N, 39^{0}26’58”E) found in Boset district and 15 kilometer southeast of Melkassa Agricultural Research Center (MARC). Bofa represents the semi-arid CRV of Ethiopia (MoARD, 2005).

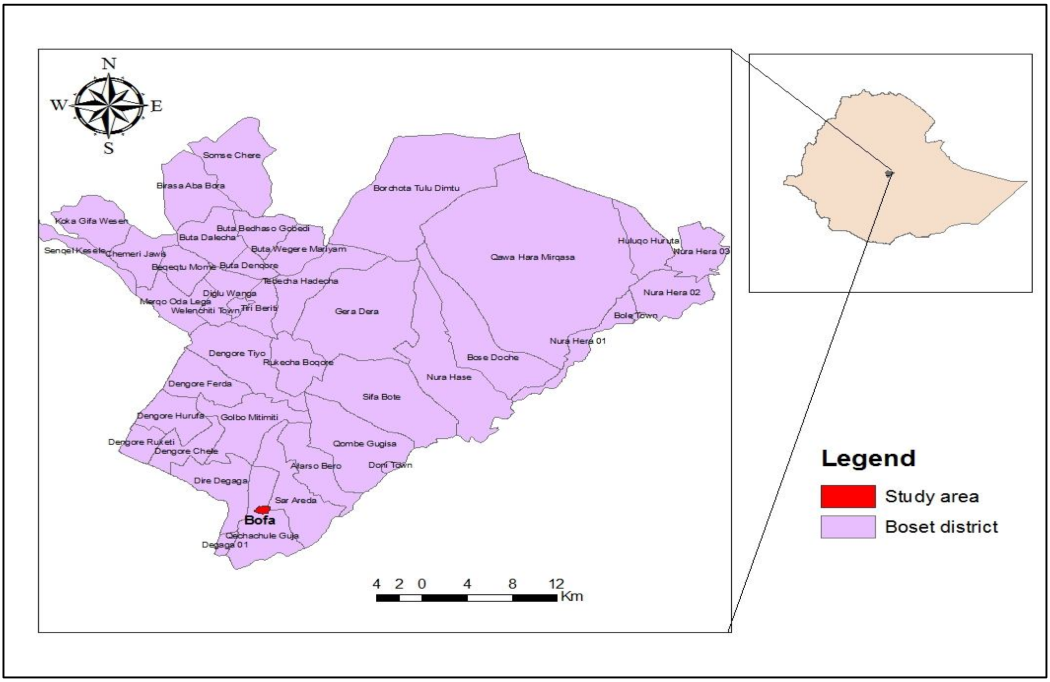


Figure 1. Location map of the study sites

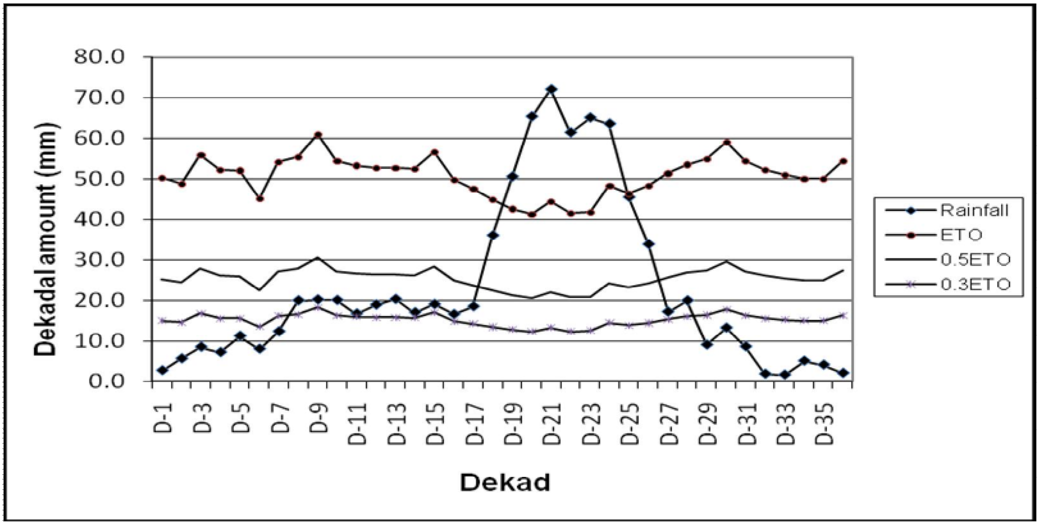


Figure 2. Average dekadal (ten days total) rainfall (mm) and reference evapotranspiration/ETo (mm) at the study sites (1977-2011)

The mean daily maximum and minimum temperatures are 28 °C and 14°C respectively, while average annual rainfall is 795 mm. Generally, rainfall follows a bimodal pattern, which includes the short rainy season of March-April-May (MAM) and the main rainy season of June-July-August-September (JJAS) (). The MAM season is highly variable and too short to support economic crop farming under rainfed mainly due to high evaporative demand of the atmosphere i.e reference evapotranspiration (ETo) (Fig.2) On the other hand, the main rainy season is relatively dependable, but short to grow the genetically high yielding long cycle crops. In some case, when the two seasons merge, there also exist opportunities to grow long cycle maize.

The soil is pumice type and sandy loam in texture which has unique water retention capacity. It looks to exhibit self-mulching that it appears dry from top starting from few hours after rain, however, it stays wet for several days few centimeters below,. Farmers observe the soil moisture on tip of the local "Maresha" to detect if the wetness of the soil at that depth is sufficient enough to make planting decision. Depending on when this condition is satisfied, decision on selection of cultivars that fit into the plausible length of growing period is made.

Climatic analyses

Historical daily rainfall data of thirty three years (1977-2011) was used to characterize the study area in terms of above normal, normal and below normal rainfall categories that concurs *'best', 'expected' and 'worst case'* planting scenarios respectively. Moreover, characterization was made in terms of important rainfall derivatives i.e start of rainy season (SOS) and end of rainy seasons (EOS), length of growing period (LGP), seasonal rainfall total and probability of dry spells, using a defined criteria in INSTAT software (Instat+™, 2006) . Such analyses help to apply the concept of response farming approach.

The SOS was set as any day after first of March when cumulative rainfall total of 20 mm is recorded over three running days and not followed by the consecutive dry spells of longer than 10 days during the subsequent 30 days from planting (Sivakumar, 1988). Likewise, EOS was defined as any day after first of September, when soil water starts to be at permanent deficit. The LGP was then computed by deducting SOS from EOS. Seasonal total rainfall was sequentially computed as:

$$RFs = \sum_{i=1}^{n} RFi \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Equation.1$$

Where *RFs* is seasonal rainfall total (mm), RF_i is the rainfall of the ith day from date of SOS, n is the count from date of SOS to EOS. Tercile probability analysis was then conducted to classify years into three scenario classes: best case (early onset), expected case (normal onset) and worst case (late onset) as a benchmark in defining the three independent sets of planting scenarios. Moreover, analysis of the risks of dry spells for continuous periods of longer than 5 , 7 , 10 and 15 days duration were conducted using Markov Chain process in order to explain the role of various useful soil water management practices in reducing the risks associated with it.

The experiments

Three sets of independent experiments, based on planting scenarios in April, May and June, were designed to fit into: best case, expected case and worst case climate scenarios, respectively. The first set was April planting comprising two long cycle (180 days) maize cultivars: BH660 (an improved hybrid) and Bolonde (a local cultivar for longer LGP). The second set was May planting: comprising two medium cycle (140 days) maize cultivars: A511 (improved open pollinated variety) and Limat (local cultivar for medium LGP). The third set was planned for June planting, in which short cycle (90 days) maize comprising Melkassa-1 (an improved drought escaping cultivar and Shaye (local cultivar for shorter LGP) were used.

Firstly, all the experimental plots were invariably plowed using Local Maresha. Then, three subsequent tillage implements were imposed as treatments: (1) Modified Moldboard Plow (MMP) for the second and third tillage (2) MMP for the secondary tillage and Wing Plow (WP) for the third tillage practice and, (3) indigenous practice, known as closed plowing or '*Nish qebera*' (hiding soil water) using Local Maresha. In '*Nish qebera'* practice, the furrow of one line is closed by the ridges of the next pass that aims at reducing the surface area of evaporation loss.

Split plot in a randomized complete block design was used with three replications, where tillage practices were assigned to the main plots and maize cultivars to the sub-plots. Recommended fertilizers and other management practices were kept constant. For each of the three independent planting scenarios, a combined analysis of variance was computed for the main plot effects, sub-plot effects and their interactions.

Crop root zone soil water content at planting was determined at MARC soil laboratory using gravimetric method. Rainfall productivity was computed as the ratio of grain yield (kg) to the total amount of rainfall between the SOS and EOS (Eq.2). Rainwater productivity, on the other hand was estimated as the ratio of grain yield to the seasonal actual crop evapotranspiration (ETa) using Equation 3 given below.

$$RFpr = \frac{Y}{RFs} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathit{Equation}.2$$

$$WPr = \frac{Y}{ETa} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathit{Equation}.3$$

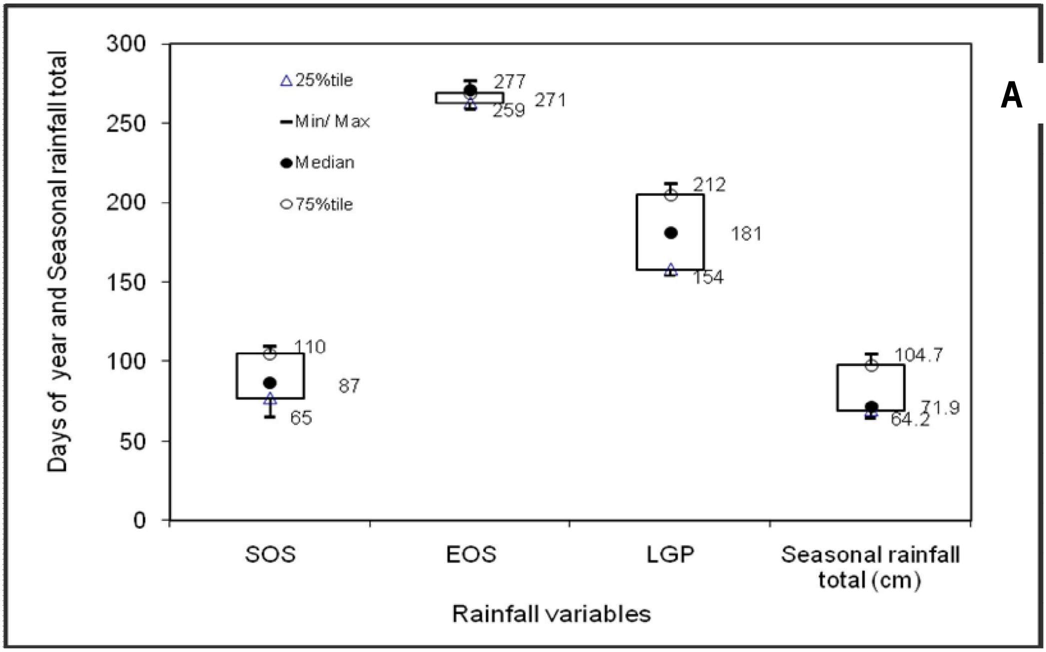
Where, RF_{pr}= Rainfall productivity, WP_r= rainwater productivity, Y=grain yield (kg/ha), RF_s = Total rainfall (mm) between SOS and EOS and ETa= Actual seasonal crop evapotranspiration (mm).

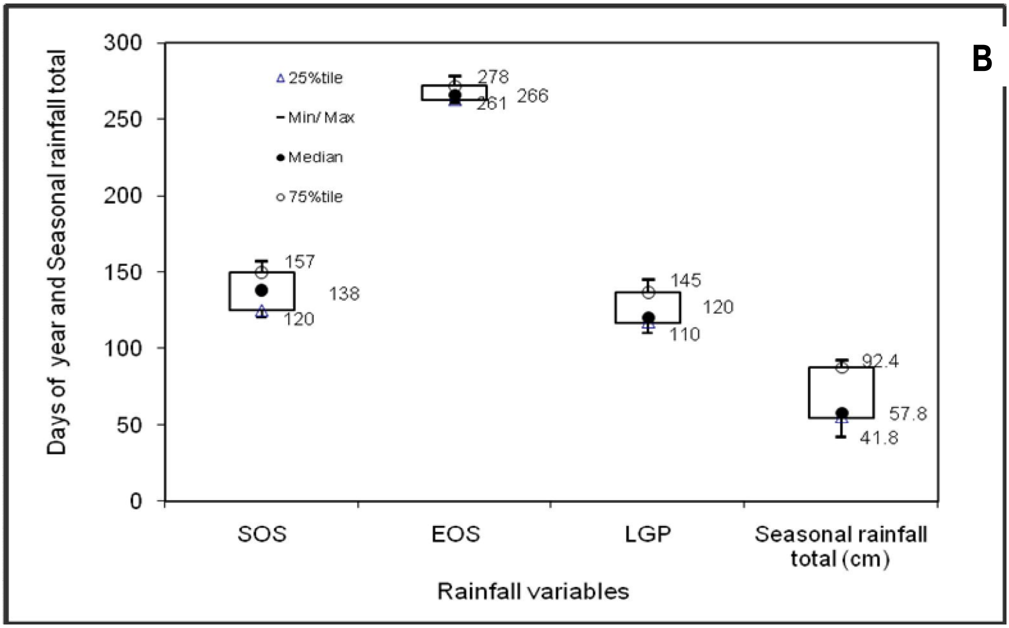
Results and Discussion

Seasonal rainfall characterization

Start of rainy season

The median start of rainy season for the best case planting scenario is determined to be 87th Days of Year (DOY) (Fig. 3A); whereas the corresponding starts of rain for the expected and the worst case scenarios are 138th and 177th DOY, respectively (Fig.3B and Fig.3C).


A
Days of year and Seasonal rainfall total
25%tile
Min/ Max
Median
75%tile
277
271
259
212
181
154
110
87
65
104.7
71.9
64.2
SOS
EOS
LGP
Seasonal rainfall total (cm)
Rainfall variables


B
Days of year and Seasonal rainfall total
25%tile
Min/ Max
Median
75%tile
278
266
261
157
138
120
145
120
110
92.4
57.8
41.8
SOS
EOS
LGP
Seasonal rainfall total (cm)
Rainfall variables

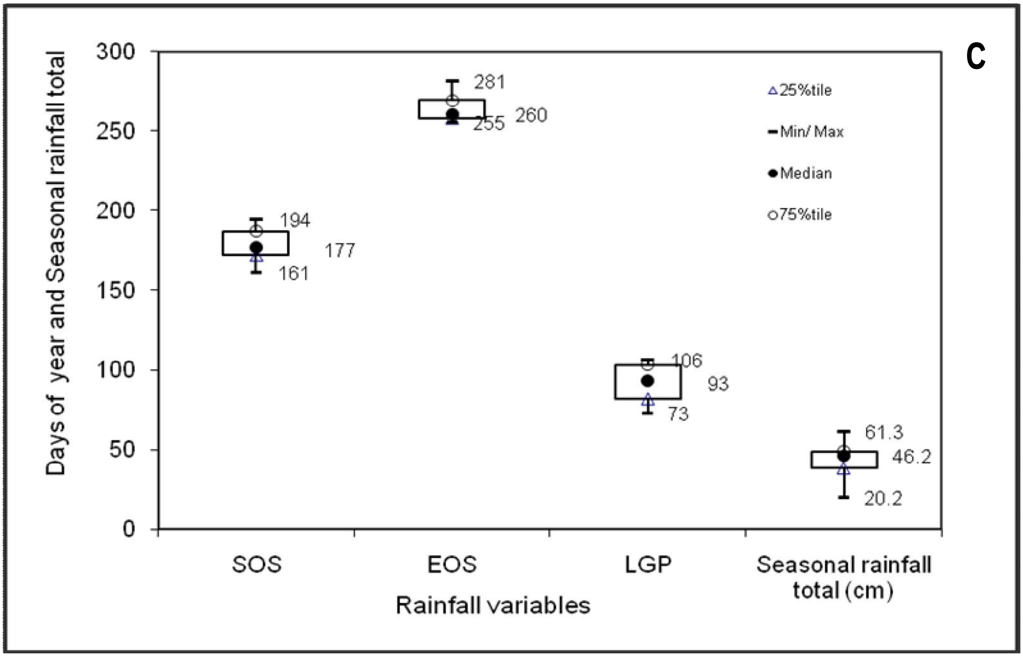


Figure 3. Percentage points of seasonally important rainfall variables for best case (A), expected case (B) and worst case (C) scenario at Bofa (1977-2011)

Note: SOS= Start of the season; EOS=End of the season; LGP= Length of growing period

End of rainy season and length of growing period

Median end of the rainy season is on 271th DOY (end of September) for the early (best case) planting scenario. For the expected case, DOY 266 signals end of rains, while DOY 260 signals the earliest cessation date for the worst case. Overall, the length of growing season for the best, expected and worst case planting scenarios are 181, 120 and 93 days, respectively. It is exciting to see that there is sufficiently long LGP (median=181days) in at least 33% of the years, and moderately long LGP (median=120 days) or more in about 66 % of the years in such a semi-arid environment. This explains that there is an ample opportunity to grow longer duration cultivars in the normal and best case scenarios in the area to ensure food security. It has to be noted that the onset window is wider and hence more variable than cessation window (Fig.3) indicating that any delayed onset is not compensated by equivalent length of delay in cessation.

Seasonal rainfall total

The median seasonal rainfall total for the early season is 719 mm, whereas 578 mm for the normal and 462 mm for the late season (Fig.3). These rainfall characteristics illustrate that seasonal performance is different among the three scenarios, hencedifferential response actions (response farming) are required for wet, medium and dry seasons. Fig.3 also depicts other rainfall percentage points; including the minimum, maximum caps, 25 (once out of four years) and 75 percentiles (three out of four years). For example, the minimum seasonal total rainfall received in the series was 202 mm in 2002 which is the worst of the worst case scenario. It coincides with a widespread stressful phenomenon of the year across the nation (FAO, 2003). The median seasonal rainfall amount looks suffice, as long as its availability follows normal distribution within the season.

Risk of dry spell

The probability/risks of dry spell longer than 5, 7, 10, and 15 days was analyzed (Fig. 4). There is about 60 % probability of dry spells of 15 days or more in the months of March and April, which gradually declines with the progress of the growing season. It converges to the lowest probability during the peak of the rainy season (July-August). It could also be noted that the probability of dry spell longer than 5 days is almost close to unity during most parts of the growing season and never falls below 50 % even during the peak part of rainy season. Furthermore, the probability of dry spell of 7 days, drops to as low as 20 % along the growing season. Similar trends could be noted for the 10 days longer dry spells. Eventually, all curves of dry spells show a steep upward slopping in September, signaling the abrupt end of rainy season.

Generally, the risk of dry spell is highest in short rainy season (MAM) limiting successful agricultural production compared to the main rainy season (JJAS). It has to be noted that although the probability of longer dry spells is less than that of shorter dry spells in a particular time of the season, the impact on crops could be quit higher as it may be difficult for crops to escape the pressure from stresses over longer duration of dry spell. Therefore, management practices to minimize risks of longer dry spells are as important as managing risks related to drought.

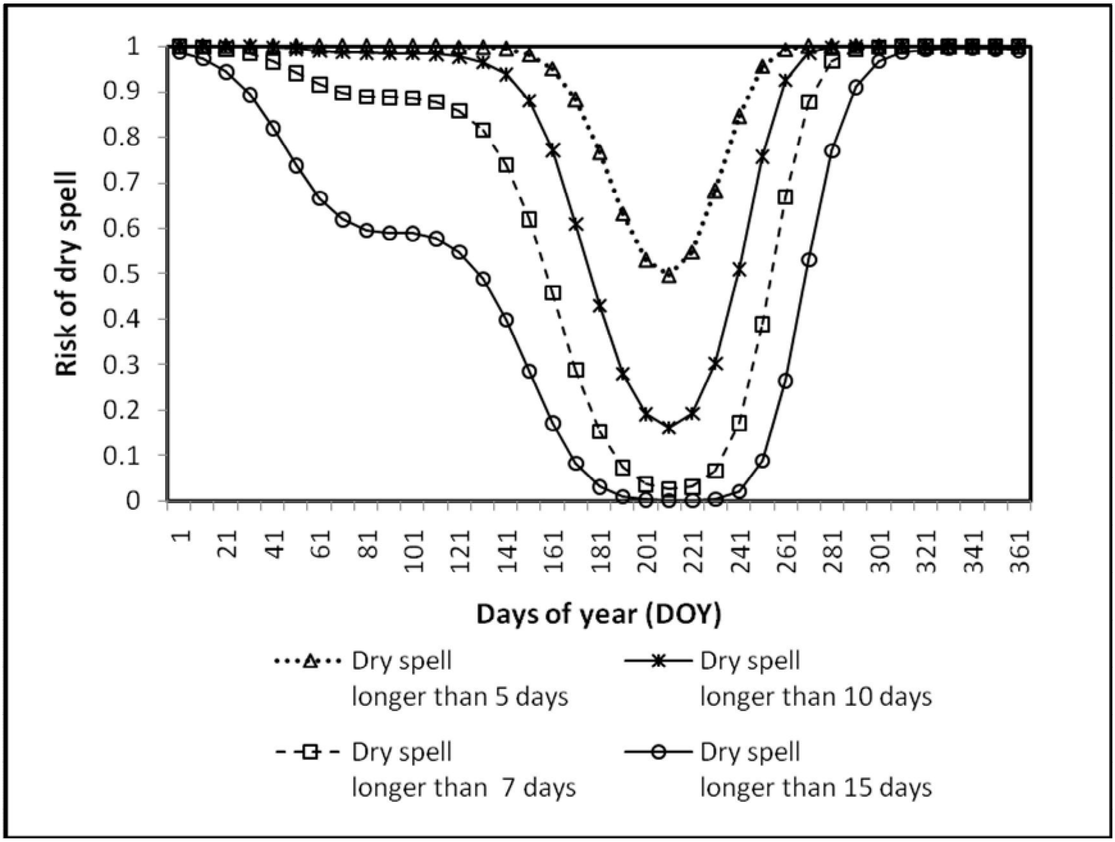


Figure 4. Risk of dry spell based on the historic climatic condition (1977-2011)

Interaction effect of maize cultivars and tillage practices on water productivity

The 180 days cycle hybrid BH660 planted in April yielded 5470 kg ha^{-1} under 2 * MMP tillage practice. On the other hand, same cultivar yielded 4214 and 4116 kg ha^{-1} under WP and the local '*Nish qebera*' practices respectively (Fig.5). Likewise, the corresponding local cultivar *'Bolondie'* yielded less than BH660 under all tillage practices, but better than medium duration cultivars. Such differences could be due to the possibility of early planting that ensured more rain water availability, particularly when moisture conserving tillage practices were employed. The medium cycle improved maize cultivar, A511 performed well (2820 kg ha^{-1})where 2 * MMP employed while the local cultivar 'Limat' yielded better (2960 kg ha^{-1}) under '*Nish qebera'* practice.

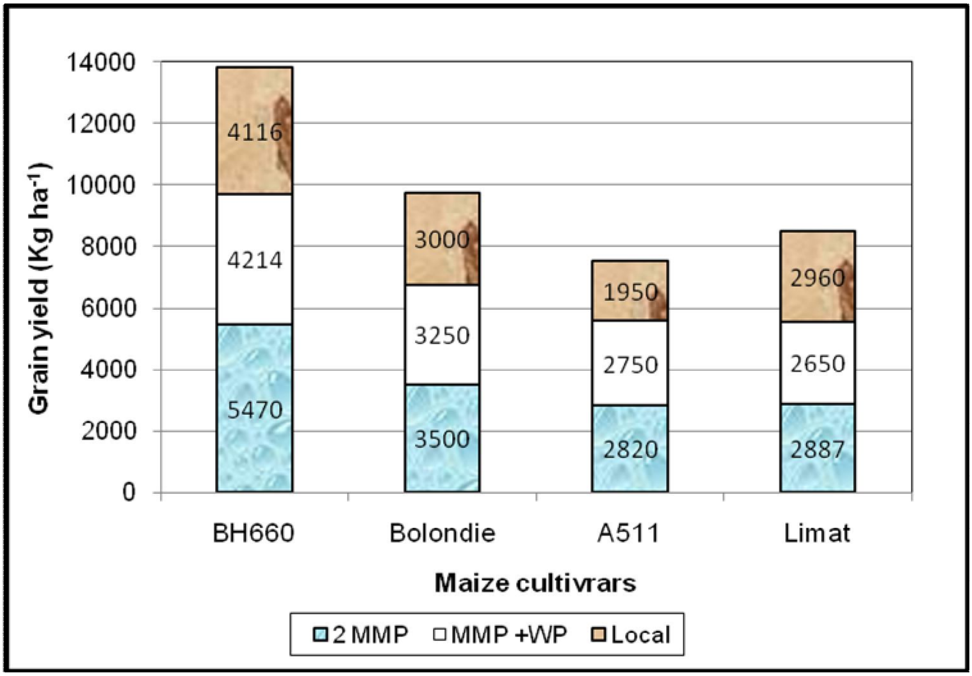


Figure 5. Grain yield of maize cultivars planted under various tillage practices

The BH660 realized high water productivity (9. 46 kg mm^{-1} of rainfall and 12.72 Kg/mm of ETa) under 2 * MMP tillage practices, while it realized 7.29 kg mm^{-1} and 9.8 Kg/ETa under MMP + WP (Table 1). When chances are high for extended dry spells particularly for longer LGP, the tillage practices might have helped to get soil water distributed evenly over the season.

Table 1. Water productivity of various maize cultivars of varying growth cycle under different tillage practices

Tillage practices	Rainwater productivity (Kg grain/mm of rainfall)				Water productivity (kg grain/mm of ETa)			
	Early planting (April)		Medium Planting (May)		Early planting (April)		Medium Planting (May)	
	BH660	Bolondie	A511	Limat	BH660	Bolondie	A511	Limat
2*MMP	9.46	6.06	4.88	4.99	12.72	8.14	6.56	6.71
MMP +WP	7.29	5.62	4.76	4.58	9.8	7.56	6.40	6.16
Local/Closed plowing	7.12	5.19	3.37	5.12	9.57	6.88	4.53	6.88

Note: 2*MMP= 2 times Modified Mould board Plow; MMP +WP = 1 times Modified Mould Board Plow and 1 times Winged Plow; Local/closed plowing = local tillage practice that involves closing of furrows to conserve soil water ; BH660= Improved maize hybrid developed for high rainfall areas; Bolondie = Local long duration maize Cultivars; A511= Improved maize variety developed for intermediate rainfall area; Limat= Local maize Cultivar for intermediate rainfall areas.

Similarly, water productivity of the corresponding local cultivar 'Bolondie' was 6.06 kg mm^{-1} for rainfall and 8.14 kg mm^{-1} for ETa using2 * MMP. Under 'Nish qebera' tillage, water productivity for BH660 was 7.12 kg mm^{-1} of rainfall and 9.56 for the ETa, and that of 'Bolondie' was 5.19 kg mm^{-1} and 6.88 kg mm^{-1} respectively.

Similarly, water productivity was 4.88 kg mm^{-1} and 6.56 kg mm^{-1} of rainfall and ETa, respectively for A511 under 2*MMP tillage; and 4.76 kg mm^{-1} (of RF) and 6.40 kg mm^{-1} (of ETa) using MMP + WP tillage. The water productivity for the same cultivar with '*Nish qebera'* was 3.37 kg mm^{-1} and 4. 53 kg mm^{-1}. For the medium duration local cultivar, 'Limat', water productivity was 4.99 and 6.71 kg mm^{-1} of RF and ETa, respectively under 2XMMP; 4.58 and 6.16 kg mm^{-1} of RF and ETa under MMP + WP tillage practice, and 5.12 and 6.88 kg mm^{-1} of RF and Eta under '*Nish qebera'* practice. This suggests that even the local tillage practices and crop cultivars could be rewarding under such climate scenario.

Except for April planting there is no statistically significant difference (α =0.05) among factors (Table 2). In April planting, the response of BH660 was highest due to improvement in soil water availability under 2XMMP, coupled with the contribution from genetic potential of BH-660. However, the interaction between tillage practices and maize cultivars was not significant for both April and May planting, which could be due to the compensation effect. This shows how research focusing on resource use optimization through integration of Genetics, Environment and Management (GxExM) could result in new asset class of success in terms of both yield and knowledgebase. In May planting, water productivity is low, relative to April planting, as this could also be an attribution of the lower genetic potential and relatively shorter LGP of A511 and 'Limat', compared to BH660 and 'Bolonde'. For June planting, both improved and local cultivars were failed, owing to the impounding effect of the lashing-type June rain on the already water saturated soils from the early (April) and medium (May) rains. Hence, late planting decision, while rain starts well early in the season could result in overall low yield, or even, likely complete failure under such a scenario.

Table 2. Combined analysis of variance for grain yield of maize Cultivars grown under different tillage practices and planting scenarios at Bofa

Factors	April Planting				May Planting			
	Standard error	Level of significance (α=0.05)	LSD (kg ha^{-1})	CV (%)	Standard error	Level of significance (α=0.05)	LSD (kg ha^{-1})	CV (%)
Between Cultivars	3.3	Sig	960	29.8	7.3	NS	-	10.0
Between Tillage	4.0	Sig	1180	19.5	8.9	NS	-	6.6
Interaction	5.7	NS	-	30.0	7.3	NS	-	8.0

Sig: Significant NS: Non Significant (α=0.05)

Eighty four percent of the variability in grain yield was explained by the crop root zone available soil water content at planting for BH-660, while 88%, 76% and 70% corresponds to '*Bolondie*', A-511 and '*Limat'*, respectively (Fig.6). The non-significant difference between grain yield of BH660 and '*Bolondie'* suggests that even local cultivars could result in improved water productivity if early onset is achieved particularly when tillage that favours effective soil water management is integrated.

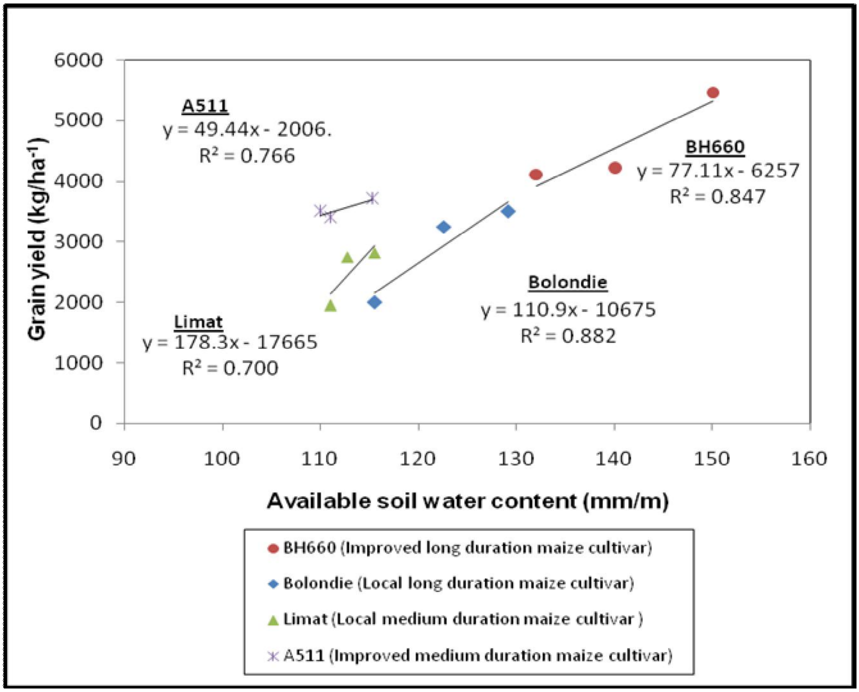


Figure 6. Relation between available crop root zone soil water content at planting and grain yield of maize cultivars

Given the prevailing variability in the start and cessation of rainfall, no single best bet crop, land and water management technologies can avert climate associated risks in semi-arid eco-regions Therefore, basket of options should be availed while integrating climate forecast information with optimal mix of alternative management practices in order to exploit the potentials of best and normal case scenarios, rather than depending only on the *early/extra early cultivars* that only fit into the worst case scenarios, particularly under semi-arid climate.

In general, the tercile probability analysis of seasonal rainfall has formed a strong background in formulating and implementing onset-scenario based planting decisions that introduces success for long duration cultivars and hybrids to attain higher yield and enhance rain water productivity. This demonstrates the added values of climate information on maize production when integrated with scenario-based agronomic decisions, including choice of suitable soil water conserving tillage practices, cultivars/varieties and planting dates.

We can also conclude that opting for short duration cultivars is not the only adaptation strategy in semi-arid eco-regions in reducing the adverse impact from climate associated risks; rather, understanding of the local climate and adjusting decisions to the plausible onset, dry spell and cessation scenarios can enhance rain water productivity, and reduce vulnerability of crop production to climate associated risks.

Furthermore, tillage practices should be optimally mixed with cultivar choice and crop management practices as part of integrated use of agricultural technology towards improving yield levels and rain water productivity. Hence, equal attention need to be paid to the identification of the potential of both the seasons (environment) and cultivars (genotypes), and preparation of management packages well in advance. In this regard, we suggest that tailored rainfall forecast products and efficient communication strategies can guide scenario selection (early, medium or late onset of seasons) and input/package preparation for a particular season.

Building soils, crop and climate database, and institutional partnership mainly among National Meteorological Agency for forecast; research institutes for translation of climate information into agricultural practices; and development organizations for wider reach is very important for successful operationalization of such a flexible approach.

Cost-benefit analysis for smallholder farmers to implement optimal mix of cultivars and improved tillage/ soil water management techniques is also critical towards transforming smallholder farming into commercial orientation.

Policy makers may also look forward to link climate knowledge into agricultural technology package in the extension and technology transfer process, as well as into current attempts in agricultural weather risk insurance.

References

Araya Alemie and L. Stroosnijder. 2010. Effects of tied ridges and mulch on barley (Hordeum vulgare) rainwater use efficiency and production in Northern Ethiopia, Agricultural Water Management 97: 841–847.

Barron, J. 2004. Dry spell mitigation to upgrade semi-arid rainfed agriculture: Water harvesting and soil nutrient management for smallholder maize cultivation in Machakos, Kenya. PhD. thesis in Natural Resource Management, Department of Systems Ecology. Stockholm University, Sweden. pp39.

Bennie, A.T.P and M. Hensley. 2001. Maximizing precipitation utilization in dry land agriculture in South Africa–A review. Journal of Hydrology, 241: 124-129.

Food and Agricultural Organization (FAO). 2003. Ethiopia: drought-hit farmers receive emergency aid. URL: http://www.fao.org/english/newsroom/news/2003/18548-en.html (accessed 10 June 2003).

Instat+™. 2005. An interactive statistical package University of Reading, Statistical Services Centre UK.

Melesse Temesgen. 2007. Conservation tillage systems and water productivity implications for smallholder farmers in semi-arid Ethiopia, PhD thesis, Delft University of technology. pp113.

Ministry of Agriculture and Rural Development (MoARD). 2005. Major Agro-ecological zones of Ethiopia. Forestry, Land Use and Soil Conservation Department.P.1-18.

Mossisa Worku, Twumasi-Afriyie, S., Legesse Wolde, Berhanu Tadesse, Girma Demisie, Gezehagn Bogale, Dagne Wegary and Prasanna, B.M. (Eds.) 2012. Meeting the Challenges of Global Climate Change and Food Security through Innovative Maize Research. Proceedings of the Third National Maize Workshop of Ethiopia. Addis Ababa, Ethiopia.

Reddy, M.S., and Kidane Georgis.(Eds) 1994. Development of technologies for the dryland farming areas of Ethiopia, Proceeding of First National Workshop on farming research in Ethiopia. Organized by IAR, 26-28 Nov, Nazreth, Ethiopia.

Temesegen Deressa. R. M. Hassan and C. Ringler, 2008. Measuring Ethiopian farmers' vulnerability to climate change across regional states. International Food Policy Research Institute (IFPRI) discussion paper 00806.

Tewodros Mesfin. 2004. Effects of insitu water harvesting on growth, yield and rain water productivity of sorghum. MSc thesis, Alemaya University, Alemaya, Ethiopia. pp107.

Sivakumar, M.V.K., 1988. Predicting rainy season potential from the onset of rains in southern Sahelian and Sudanian climate zones of West Africa. Agricultural and Forest Meteorology, 42: 295-305.