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Risks associated with dry soil planting time in Ethiopia

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Abstract

Dry soil planting is practiced in response to variable rainfall onset in Ethiopia to maximize use of the full season. Rainfall data of >30 years for seven locations were used to evaluate dry soil planting opportunities on Vertisols. Three rainfall related risks were evaluated: (i) seed lies in dry soil without imbibing water for >20 days (Risk I); (ii) rainfall causes germination but fails to support growth and many seedlings die (Risk II); and (iii) when planting is delayed until after onset of rains by not dry soil planting sorghum or maize and because the fields are too wet to prepare and plant (Risk III). Risk I and II are associated with potential failure of dry soil planting while Risk III is associated with negative consequences of not dry soil planting. Mean probabilities of occurrence of risks associated with dry soil planting were, respectively: ≥50% and ≤30% for Risk I in 25% and 56% of the timeframe; ≥50% and ≤30% for Risk II in 35% and 22% of the timeframe; and ≤30% for Risk III in 90% of the timeframe. The cumulative value of the three risk types were represented by two risk indexes. Dry soil planting was found to have a high probability of success, even when done before the expected onset of rainfall for several locations. Farmers cannot avoid all risk types and risks occur with wet soil planting as well. Guidelines to timeliness of dry soil planting for early crop establishment were developed for each location.

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Introduction

Adverse food security and economic consequences faced by farmers due to seasonal climate variability commonly occur with rainfed agriculture in Ethiopia with direct impact on crop yields and indirect impacts by triggering insect pest, disease and weed infestations (Gadgil *et al.*, 1998; Bekele, 2000). Lansigan (2000) reported significant crop yield losses due to prolonged dry or wet periods coinciding with critical stages of crop growth and development. Van de Steeg *et al.* (2009) indicated that the growing season in some parts of Ethiopia could be 20% shorter by 2050 relative to the current baseline period (1960–90), which would have negative repercussions on food production. In addition, Kassie *et al.* (2013) found an increase in total duration of periods of soil water deficit during the crop growing season of 0·8 days per decade resulting in more crop stress in semi-arid areas of Ethiopia. They concluded that climate trends, especially for rainfall amount and variability and temperature, indicate greater risks to rainfed agriculture in Ethiopia. They suggested designing of specific adaptation strategies to cope with the risks, sustain farming and improve food security. Climate variability concerns include variability for onset and cessation of rainfall, rainfall amount, and frequency and duration of periods of soil water deficits. This variability greatly affects rainfed crop yield, is a major disincentive to adoption of yield improving practices, and challenges researchers in developing adoptable practices and varieties (Stewart, 1991; McCown *et al.*, 1991; Fujisaka *et al.*, 1996). Therefore, knowledge of the seasonal climate variability and associated risks is important to improvement crop management. Stewart and Faught (1984) recommended an approach of response farming in which crop management is systematically adjusted in response to specific rainfall indicators in the early part of a season.

In the semiarid areas of Ethiopia, where onset of the rainy season is highly variable (Kassie *et al.*, 2013; Mamo, 2005), rainfed sorghum [*Sorghum bicolor* (L.) Moench] and maize (*Zea mays* L.) are the main crops for food, feed and income (Mitiku and Kidane, 1994), including for pastoralists (Agriculture in Ethiopia, 2014). Sorghum and maize are cultivated mostly in warmer areas along western, southwestern, northern, and eastern peripheries of the Ethiopian lowlands and highlands. Sorghum prevails over maize where rainfall is less reliable and altitude is <1900 m while maize is grown chiefly between elevations of 1,500 and 2,200 meters and with better rainfall. Farmers relate rainfall onset to seasonal length, and risks increase with delayed onset, perceiving good to normal seasons to have relatively early onset (Habtamu, 2004). Farmers' management decisions vary from season to season to conform with received and expected rainfall (ICRA, 1999; Fujisaka *et al.*, 1996). Farmers practice dry soil planting of sorghum and maize in parts of Ethiopia (Merga *et al.*, 2014).

Dry and wet soil planting refer respectively to planting in dry soil and in soil where the surface 20-cm depth or more has been wetted by rainfall (Merga *et al.*, 2014). Risk of longer dry periods in the months of May and June is increasing with increased risk to sorghum and maize establishment (Merga, 2013). In addition, Merga *et al.* (2014) reported on the effects of soil water deficit regimes on establishment of dry planted sorghum and recommended risk analysis for dry soil planting to improve success of dry soil planting. Farmers dry soil plant for early crop establishment and to reduce the workload once onset occurs. Furthermore, dry soil planting also spreads out the land preparation and planting time, enabling the farmers to manage more area of crop production while reducing yield losses due to delayed planting relative to the onset of rainfall (http://www.kasetsartjournal.ku.ac.th/kuj_files/2009/pdf). Dry soil planting is most appropriate on vertic clay soils which are difficult to work after rain resulting in much delayed wet soil planting (Kipkorir *et al.*, 2007). Therefore, the objectives of this study were to (i) evaluate three types of risk associated with dry soil planting times and (ii) identify dry soil planting times with low risk of failed crop establishment but early enough to take full advantage of the season for vertisols in Ethiopia.

Material and methods

Environments

Seven locations in semiarid areas with Vertisols were considered in this study (Table 1). The central (Miesso and Welenchiti) and northern (Kobo and Sirinka) Rift Valley has a long season with a weak bimodal rainfall pattern with rainfall received during March to April for land preparation and rainfall of June through October considered the main rainy season for sorghum and maize production. The eastern lowlands (Dire Dawa and Jigjiga) have bimodal rainfall but July to October is the main season for maize and sorghum. The southern lowlands (Ya'abalo) have bimodal rainfall with maize and sorghum production during February to May (Fig. 1).

Data sources and data quality assessment

Daily meteorological data from 13 stations were obtained from the National Meteorological Agency of Ethiopia. The seven selected stations (Table 1) had > 30 years of weather records with less than 10% missing values (Seleshi & Zanke, 2004; Rosell, 2011). The daily time series from each station and for each year were plotted to identify obvious outliers, which were removed from the data series. Outliers were detected using the Tukey fence approach (Tukey, 1977). The rules of this approach are that inner fences are located at a distance 1.5 times the interquartile range below and above the lower and upper quartiles, respectively, and outer fences are located at a distance of 3 times the interquartile range below the lower and above the upper quartiles. Values outside the Tukey fences are considered as outliers. With this procedure, one, three and four daily rainfall values at Dire Dawa, Jigjiga, and Ya'abalo, respectively, were replaced with values estimated from neighboring stations using statistical regression techniques as described by Allen *et al.* (1998) and applied in various studies (Seleshi and Zanke, 2004; Vergni and Todisco, 2011).

Onset date criteria and analysis

In order to define the commencement of effective rainfall, statistical analyses of historical rainfall data of the seven locations were conducted using INSTAT statistical package (Instat+ v3.36; University of Reading, UK). The onset of the rainy season as defined by Raman (1974), which is adapted and modified by the software INSTAT+ (INSTAT+Climatic guide, 2001), has been used with some modification in this study. Therefore, the onset of rainfall was considered to be the first occasion with >30 mm in a 5 day period after 1 March for Ya'abalo, and after 1 June for the rest of the locations with no dry spell of consecutive 10 days or more within the following 30 days. Dry spell length was identified as the duration of consecutive days with <2 mm rainfall. Rainfall $\leq$2 mm day^{-1} is taken as threshold value since water availability below half of the daily ETo of many crops is not enough for important physiological process (Doorrenbos and Kassam, 1979). Note that for onset definition, >2 mm day^{-1} of rainfall is considered hereafter as wet.

Scenarios and their risk analysis

Historical rainfall data of >30 years were used for all locations (Table 1). Three major rainfall scenarios important to assess risk of dry soil planting were set. Their occurrence were determined for 5-day intervals during day of year (DOY) 50-110 at Ya'abalo and DOY 140 to 200 for the other six locations; dry soil planting timeframe. Scenario I is that seed lies in dry soil without imbibing water for >20 days, and assumes <15 mm of rainfall within any 5 day period until >20 days after planting. Maize and sorghum seed can stay in the soil for 15 days (Merga, 2013), but a longer stay leads to reduced seed viability. Scenario II is when rainfall causes germination but fails to support growth and many seedlings die. Scenario II was as the condition of receiving >15 mm rainfall within any 5-day period after planting that is followed by a period of >10 days with <15 mm rainfall. Scenario II is applicable to wet soil planting as well, and was considered to be of equal risk for wet and dry soil planting beginning on the day of 50% probability for the onset of the rainfall. Scenario III occurs when planting is delayed until well after onset of rainfall by not dry soil planting sorghum or maize and because the vertisols fields are too wet to prepare and plant. Scenario III was defined as the rainfall condition when an area receives >35 mm rainfall within a 7-day period. Scenario I and II are associated with potential failure of dry soil planting while Scenario III is associated with negative consequences of not dry soil planting. The occurrence of the scenarios were calculated using Excel© for the timeframe of dry soil planting for each year. The risk (probability) of each type of scenario was determined as the percent of number of observed occurrences of each scenario to total years considered for the study at each station. Regression functions were fitted using Statistix 10 (Analytical Software, Tallahassee FL) for each scenario type relating risk (probability of occurrence of each scenario) to dry soil planting time. Risk of Scenarios I, II, and III are named Risks I, II, and III, respectively.

Interpretation of the risks required integration of the three risk types associated with dry soil planting with Risk I and II considered negatives for dry soil planting but Risk III considered a positive for dry soil planting. Therefore, the sum of the percent of occurrence of Risk I and II minus the percent for Risk III gave a risk index value of risk associated with dry soil planting with a lower value being more favorable (Risk Index A = Risk I + Risk II – Risk II). However, Risk III may be of greater economic concern as it means risk of loss of yield potential rather than risk of loss of investment in planting. Planting costs are often not great as the seed sown in these environments is commonly of open-pollinated cultivars and taken from the previous harvest. Therefore, Risk III might carry twice the value of each of the other risks (Risk Index B = Risk I + Risk II – 2*Risk III). We assumed that farmers are equally likely to wet soil planting as to dry soil planting at the DOY of 50% probability of onset (Fig. 2; Fig.3); therefore, after that DOY, Risk II is equally a risk of wet and dry soil planting and was treated as zero in the risk indexes. Risk Index values of <30% were considered acceptable for dry soil planting.

Results

Miesso

Risk I and II decreased with dry soil planting from DOY 140 and 163, respectively. Risk III increased from DOY 167 but had a lower probability of occurrence compared with Risk I and II in most of the dry planting window at Miesso. Risk I was 43 to 45% between DOY 141 and 157 but <34% in 69% of the planting window considered (Fig. 4a). Risk II was >40% in 54% of the planting window between DOY 151 and 181, and then decreased to 20% on DOY 191. Risk III was <28% throughout the planting window and <18% in 85% of the planting window. Risk Index A and B were 44 and 35% beginning DOY 181, the day of 50% probability of onset of rainfall (Table 2; Fig. 2a), but the index values specific to dry soil planting were <30% after this date with Risk II equally applicable to dry and wet soil planting.

Table 1. Seven locations and years of historical weather data considered in the assessment of dry soil planting on Vertisols in Ethiopia.

Station	*Years*	*Latitude*	*Longitude*	*Altitude (m)*	*Represented Vertisol Type*
Miesso	1973-2012	9°13'N	40°45'E	1320	Chromic Vertisols
Welenchiti	1964-2011	8°39'N	39°25'E	1460	Vertic Luvisols
Kobo	1980-2012	12°08'N	39°37'E	1500	Pellic Vertisols
Sirinka	1980-2012	11°45'N	39°36'E	1870	Pellic Vertisols
Dire Dawa	1980-2012	9°36'N	41°51'E	1290	Chromic Vertisols
Jigjiga	1980-2012	9°21'N	42°47'E	1650	Vertic Luvisols
Ya'abalo	1981-2012	4°53'N	38°06'E	1700	Vertic Luvisols

Welenchiti

Risks at Welenchiti showed similar trends as Miesso except that Risk III start increasing earlier at Welenchiti. Risk I was 0% after DOY 171 (Fig. 4b). Risk II was >50% between DOY 146 to DOY 171. Risk III was <20% until DOY 176, but >35% after DOY 181. Probability of onset of rainfall was 50% on DOY 181 (Table 2; Fig. 2b) when Risk A and B were 14 and 0, respectively. Risk Index A and B were <30% beginning DOY 173 and 168, respectively (Table 2).

Table 2. Day of the year (DOY) when risk composite index of the three water deficit scenarios were <30% for the seven semiarid lowlands of Ethiopia.

Location	*Risk Index (DOY)*		*Rainfall onset (DOY)*
	Risk Index A†	Risk Index B‡	
Miesso	181	181	181
Welenchiti	173	168	181
Kobo	196	191	188
Sirinka	187	183	195
Dire Dawa	200	195	205
Jigjiga	217	212	217
Ya'abalo	89	89	89

†Risk Index A before onset date = Risk I + Risk II – Risk III;

‡Risk Index B before onset date = Risk I + Risk II – (2*Risk III); Risk I: seed lies in dry soil without imbibing water for >20 days (assumes <15 mm of precipitation within any 5 day period until >20 days after planting); Risk II: precipitation causes germination but fails to support growth and many seedlings die (>15 mm precipitation within any 5 day period that is followed by a period of >10 days with <15 mm precipitation); Risk III: when planting is delayed until well after onset of rains by not dry soil planting (precipitation is >35 mm within 7 day period).

Kobo

Risk I was higher than Risks II and III at Kobo and higher than at any other locations early during the dry soil planting window (Fig. 4c). Risk II increased throughout the dry soil planting window. Risk I was >55% until DOY 181 and declined to 0% on DOY 201. Risk II was <30% until DOY 191, but increased to 54% on DOY 201. Risk III was <25% until late in the dry soil planting window, and was of no risk between DOY 161 and DOY 181. Probability of onset of rainfall was 50% on DOY 188 (Fig. 2c; Table 2). Risk II continued to be high after DOY 188, but it is assumed that this risk is equally applicable for wet and dry soil planting beginning with the DOY that marks 50% probability for onset of rainfall. Crop production in Kobo is of relatively high risk given the short duration of the rainy season with both dry and wet soil planting (Fig. 1), and dry soil planting should commence at least by DOY 188 given the potential to increase the growing period and reduce impacts of terminal drought.

Sirinka

The trends of Risk I and III at Sirinka were similar to Kobo, but Risk II was nearly constant for most of the dry soil planting window (Fig. 4d). Risk I was 70% on DOY 157 and declined to <30% after DOY 171. Risk II was <40% in 70% of the planting window. Risk III was relatively high before DOY 151 and after DOY 186, but only 0-7% between DOY 157 and DOY 181. Probability of onset of rainfall was 50% on DOY 195 (Fig. 2d; Table 2) when Risk Index A and B were <0. Risk Index A and B were <30% beginning DOY 187 and 183, respectively.

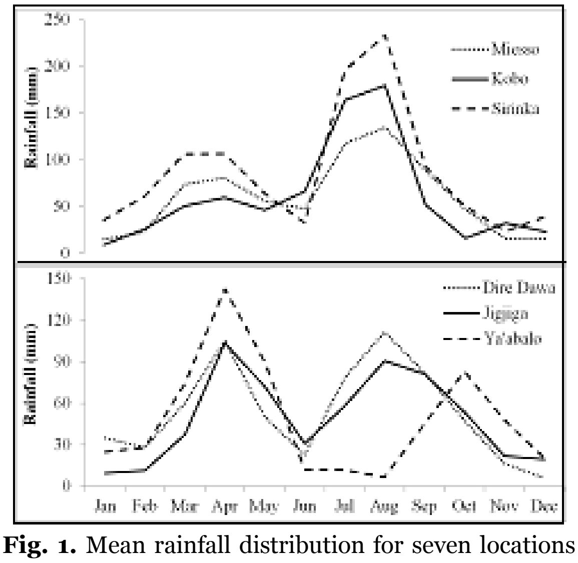

Fig. 1. Mean rainfall distribution for seven locations considered in the assessment of dry soil planting on Vertisols in Ethiopia.

Dire dawa

Risk I was higher than Risk II and III before DOY 175, after which Risk II was higher (Fig. 5a). Risk I was 70% on DOY 161 and dropped to 3% on DOY 201. Risk II increased slowly throughout the window ranging from 37 to 53%. Risk III was <17% throughout the planting window and only 3-7% between DOY 146 and DOY 176. Probability of onset of rainfall was 50% on DOY 205 (Fig. 3a; Table 2) when Risk Index A and B were 20 and 12%. Risk Index A and Risk Index B were <30% beginning DOY 200 and DOY 195, respectively.

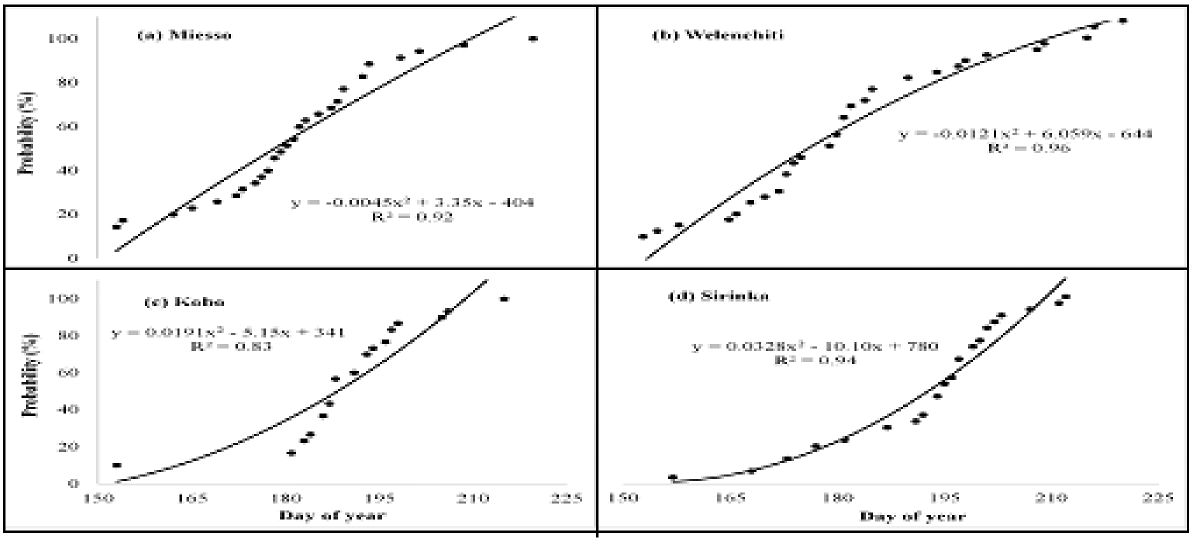

Fig. 2. Cumulative probability of onset dates of planting rain in the semiarid (a & b) central and (c & d) northern Rift Valley of Ethiopia.

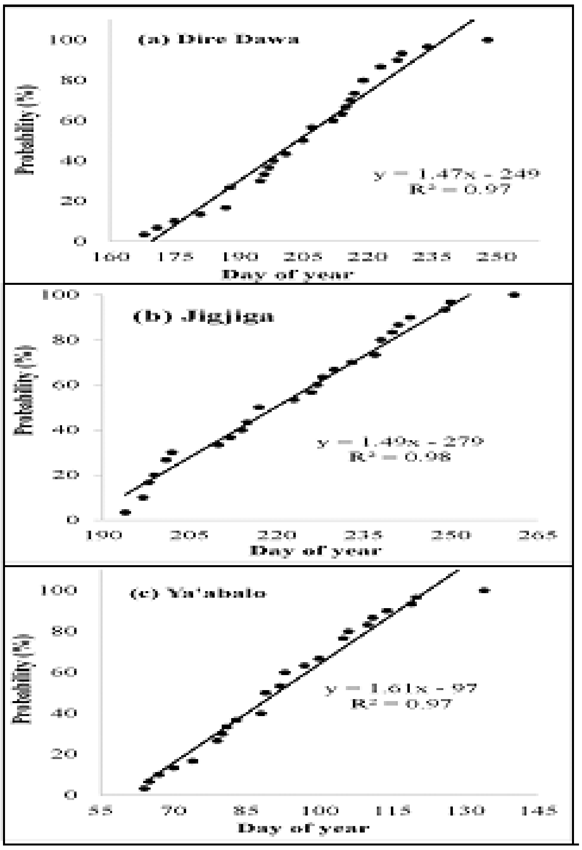

Fig. 3. Cumulative probability of onset dates of planting rain in the (a & b) eastern and (c) southern semiarid areas of Ethiopia.

Jigjiga

Risk II was higher than the other risks especially during the latter part of the dry soil planting window at Jigjiga (Fig. 5b). Risk I peaked at 50% on DOY 166 and dropped to <35% after DOY 171. Risk III was <13% throughout the window. Probability of rainfall onset was 50% on DOY 217 (Fig. 3b; Table 2). Risk Index A was lowest at 58% ON DOY 207 but Risk Index B was 34% DOY 217. As with Kobo, it needs to be accepted that crop production at Jigjiga is of relatively high risk and that much of the risk of planting failure at 50% probability of rainfall onset is with Risk II, and that Risk II is important to both wet and dry soil planting. Therefore dry soil planting should commence at least by DOY 217 to minimize the loss of the potential length of growing season.

Ya'abalo

Like Jigjiga, Risk II for Ya'abalo was high compared with Risk I and III and >49% throughout the dry soil planting window (Fig. 5c). Risk I decreased from 56% on DOY 50 to 9% on DOY 110. Risk III ranged from 4-13% between DOY 50 to 85. Probability of onset of rainfall was 50% on DOY 89 (Fig. 3c; Table 2) when

Risk Index A and B were 64 and 44%, respectively. However, the high index values are due to Risk II which is also a concern with wet soil planting. Therefore, dry soil planting should commence at least by DOY 89 if onset of rainfall has not yet occurred.

Discussion

Periods of soil water deficit constrain crop productivity in semi-arid areas of Ethiopia and frequency and severity of these deficits are expected to increase (Conway and Shipper, 2011). Improved adaptive management is needed such as through improved pro-active practices like dry soil planting, better response to conditions as the season unfolds, and strategically through more risk buffering polices and improved genetics and practices (Adger *et al.*, 2007; Vermuelen *et al.*, 2013).

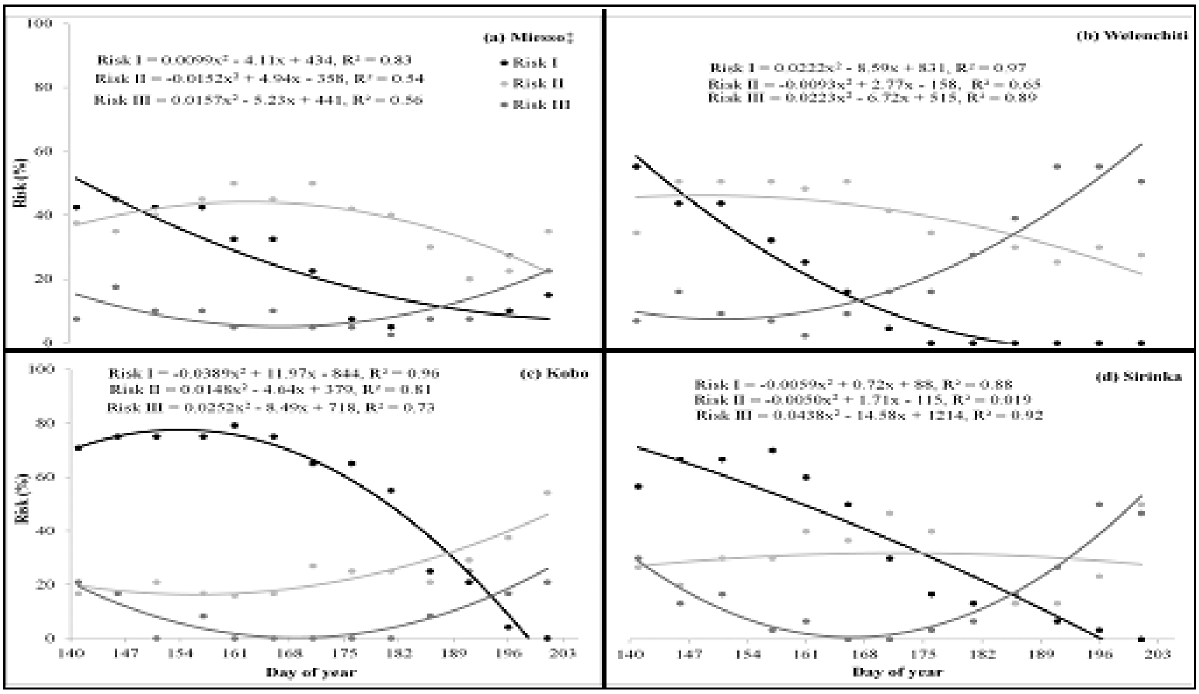

Fig. 4. Cumulative probability of three dry soil planting risks occurring in the semiarid (a & b) central and (c & d) northern Rift Valley of Ethiopia.

‡Risk I: seed lies in dry soil without imbibing water for >20 days (assumes <15 mm of precipitation within any 5 day period until >20 days after planting); Risk II: precipitation causes germination but fails to support growth and many seedlings die (>15 mm precipitation within any 5 day period that is followed by a period of >10 days with <15 mm precipitation); Risk III: when planting is delayed until well after onset of rains by not dry soil planting (precipitation is >35 mm within 7 day period).

The results of the current research demonstrate high probability for some locations of successful crop establishment with dry soil planting before the DOY of 50% probability for onset of rainfall. For other locations, the risk of failed establishment remains relatively high at the DOY of 50% probability for onset of rainfall but Risk II is then prevalent and it is important both for wet and dry soil planting. These higher risk locations also have relatively short growing seasons and therefore much potential to benefit from early crop establishment. The benefits of dry soil planting are likely to be greatest when the onset of rainfall is later than normal. If partial or full failure of establishment occurs with early planting, farmers are likely to have more response farming (Stewart and Faught, 1984) or adaptive management options available to them compared with failed later planting, possibly including replanting or gap-filling with a shorter-season crop or cultivar (Fujisaka *et al.*, 1996).

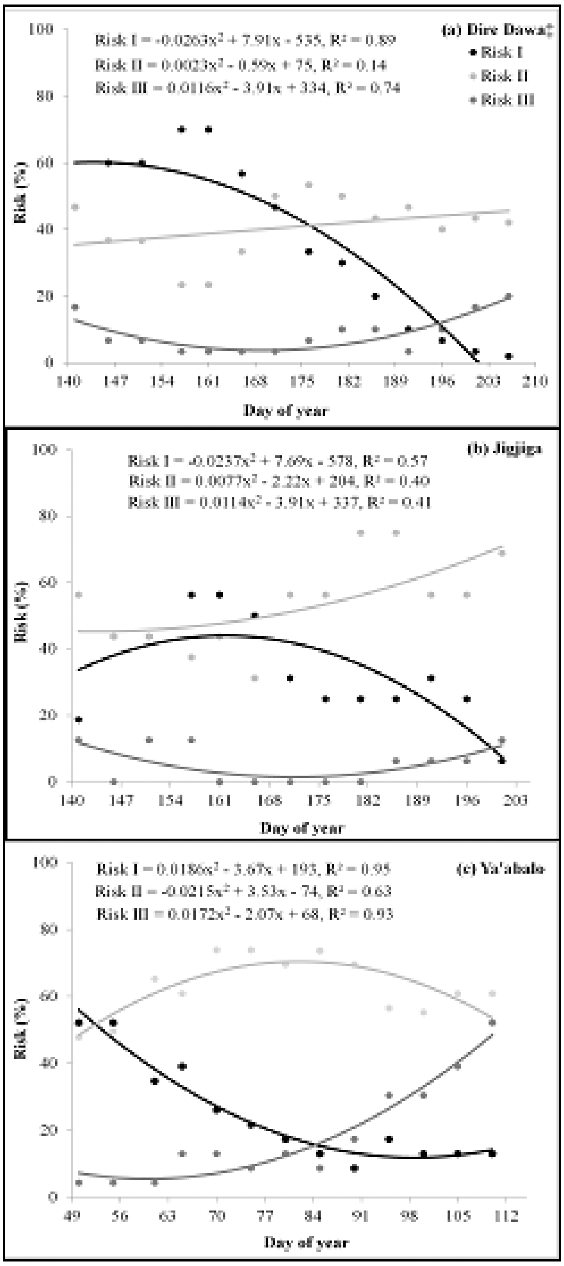

Fig. 5. Cumulative probability of three dry soil planting risks occurring in the (a & b) eastern and (c) southern semiarid areas of Ethiopia.

‡Risk I: seed lies in dry soil without imbibing water for >20 days (assumes <15 mm of precipitation within any 5 day period until >20 days after planting); Risk II: precipitation causes germination but fails to support growth and many seedlings die (>15 mm precipitation within any 5 day period that is followed by a period of >10 days with <15 mm precipitation); Risk III: when planting is delayed until well after onset of rains by not dry soil planting (precipitation is >35 mm within 7 day period).

Kipkorir *et al.* (2007) found a mean of nine days earlier germination of maize with dry sowing as compared with wet sowing, and this difference was about 15 days for seasons with a late onset of rainfall in most of their study sites in Kenya. The findings of Merga *et al.* (2014) and Merga (2013) regarding optimal depths for dry soil planting maize and sorghum need to be applied together with the timeliness of dry soil plantings as indicated above. Merga *et al.* (2014) also reported sorghum cultivar differences for response to dry soil planting; in that case, a local cultivar derived from natural and farmer selection had better establishment than a released variety.

Conclusion

Farmers have a good chance of successful dry soil planting of maize and sorghum in semi-arid areas of Ethiopia, thereby increasing their chances of taking full advantage of the rainy season and reducing risk of terminal drought stress. In all cases, farmers should dry soil plant maize and sorghum at least beginning on the DOY of 50% probability of rainfall onset, but often early, if onset has not yet occurred. In the Central Rift Valley, farmers should do dry soil planting in the central and eastern parts beginning in mid and late June, respectively, if onset of rainfall has not already occurred. Similarly, maize and sorghum should be dry soil planted in early to mid-July at Kobo and Sirinka. In eastern semiarid areas, dry soil planting should commence by the third and fourth week of July, at Dire Dawa and Jigjiga, respectively. The growing season is earlier in the year at Ya'abalo compared with the other six locations and dry soil planting should begin in late March. The risk of failure with both dry and wet soil planting is relatively high at Kobo, Jigjiga, and Ya'abalo while dry soil planting offers a higher probability of taking full advantage of the total rainfall for the season. Success with timely dry soil planting is likely to be enhanced by planting at the proper depth. In the riskier and lower potential situations, farmers may opt to reduce planting costs by planting good quality seed from their own harvest of open pollinated cultivars.

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Abbreviations

DOY, day of year.

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