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Effect of climate variations on maize yields across Abeshge district in Ethiopia

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ABSTRACT

The mean onset date, cessation date and length of growing period of the main rain season remained May 5, September 14 and 133 days, respectively across Abeshge district in Ethiopia. The dry spell is minimum during the peak rainy season (June to August or DOY 153-244) and switch upward once more around DOY 247 (September 4), indicating end of the season). Rainy days have a strong positive relationship (r=0.72) with maize yield, whereas total rainfall and rainfall cessation have moderately negative (r=-0.56) and positive (r=0.58) correlation, respectively. Increase in total rainfall caused a decrease in maize yield. However, increased rainy days, length of growing period and maximum temperature will result to increase in maize yield. Therefore, to minimize the effects of total rainfall, cutoff drain should be considered along the farmland.

Key words: Climate variability; rainfall; temperature; maize yield; correlation

Agriculture plays a great role in the rural livelihoods across the many African countries. Rainfall is important determinant of crop harvests and unfavorable realizations of either the amount or the temporal distribution of rainfall certainly trigger crop failure. Increase in surface air temperature and decrease in rainfall may reduce crop yield and threatens food security in low income and agriculture oriented economies (Meybeck *et al.*, 2012; Patil *et al*., 2018). According to Mintewab *et al*. (2010) higher temperatures and changing rainfall level further influence agricultural production in many arid and semi-arid regions *viz*., India (Balvanshi and Tiwaria, 2018) and Ethiopia (Mintewab *et al*. (2010). In the agriculture sector, the consensus is that changes in temperature and rainfall will result in changes in land and water regimes that will later affect agricultural productivity (Misgina and Simhadri 2015).

Abeshge district, where this study was conducted, rain-fed crop production is the basis of livelihood as well as accounting for more than 70% for the land area cultivated annually. However, rainfall in much of the study area is erratic and unreliable, with ever fluctuating trends, resulting in increased food shortages and famines. The district has two traditional agro-ecological zones (low and mid altitudes). Mixed crop-livestock farming involving rain-fed system is used as the major sources of food and income for livelihood making in the area. Besides, evidences in the study area have shown that there is no research conducted as yet, on climate linked with crops. Therefore, it is logical to analyze the climatic variables in the area to obtain precise estimates and to fill the information gap. Characterization of this variations is helpful in rain-fed agriculture to devise site-specific adaptation responses against to climate risks. Therefore, the major objective of this study was to characterize the variability of past rainfall, temperature and their impact on maize crop yield.

MATERIALS AND METHODS

Datasets

The study was conducted in Abeshge district, Gurage Zone of SNNPRS, Ethiopia. The geographical coverage of the study area is 8° 17’ 22.6 “ N and 37° 46’ 55.98” E at an elevation ranging from 1050 to 1883 m.a.s.l (Fig. 1). It has a total area of about 57313.85 ha of which 40119.7 ha is cultivated. Data on major climatic parameters (daily rainfall and temperature) was collected for 30 years (1986-2015) from NMA. The data on annual maize yield for 16 years (2000-2015) were collected from CSA for the main production season. The variability of seasonal rainfall was analyzed for its onset date, end date, LGP, amount and the number of rainy days. To determine the onset, cessation date and length of growing period the standards set by Stern *et al*. (2006) used. Day with accumulated rain of 20 mm over 3 consecutive days that weren't followed larger than nine days of dry spell length inside thirty days from planting day was supposed to create ensuing growing season. The condition of getting no dry spell of quite nine days once begin of season eliminates the likelihood of a false begin of the season. April first taken as a possible planting date for long cycle belg season crops like maize. Missing values were patched using first order Markov chain model of Instat version 3.37 software. The cessation date adopted in this study is any day after the first of September, when the soil water balance reaches zero (Stern *et al.*, 2006). Additionally, estimated average ETO (3.6 mm per day) and 65 mm m^{-1} of the maximum soil water holding capacity were used to determine cessation date. Length of growing period (LGP) determined by deducting onset date from cessation date. For the analysis of dry spell probability, daily rainfall fitted to the simple Markov Chain model with varying length exceeding 5, 7, 10, and 15 days. Minimum rainfall threshold value suggested by Zewdu and Lamb (2005) was adopted. Major rainfall characteristics and temperature components were examined. From the rainfall data collected, date(s) of onset (in DOY), date(s) of end (in DOY), LGP (in days), number of *kiremt* rain (in days), *kiremt* total rainfall (mm) were derived. *Kiremt* maximum, minimum and mean temperature (^{0}C) were considered. Correlation and multiple linear regression analysis were used. Variables indicating significant correlation ($P \leq 0.05$) with maize yield were used in regression analysis. The regression model computed is as follows:

$$Y = a + b1x1 + b2x2 + b3x3 + b4x4 + bnxn + e$$

Where, Y = the value of the dependent variable (maize yield q ha^{-1}),

a = Y intercept and $b1, b2, b3, b4, \ldots bn$ = regression coefficients (each b represents the amount of change in Y (maize yield q ha^{-1}) for one unit of change in the corresponding x-value when the other x values are held constant; $x1, x2, x3, x4, --xn$ = the independent variables (*i.e.* number of *kiremt* rain days, *kiremt* total rainfall, LGP and *kiremt* maximum temperature, respectively); and e= the error of estimate or residuals of the regression.

Percentage of the climatic parameters explained jointly/together was determined by considering four independent variables such as number of *kiremt* rain days, *kiremt* total rainfall, LGP and *kiremt* maximum temperature using coefficient of multiple determinations (R^2).

If P-value of F exceeds 0.05 (confidence level) the explanatory variable does not predict the response variable. Similarly, Student t-test in a multiple regression was used to assess whether the independent variable adds unique and predictive value as a predictor for statistical significance (Odekunle *et al.*, 2007). Variance inflation factor (VIF) ($1/1-R^2$) is basic tool that can guide a researcher for identifying multi-co-linearity (Obrien, 2007). To assess how severe the multi-co-linearity problem is, the variance inflation factor (VIF) was used. If the VIF is less than 10 there is weak multi-co-linearity (not correlated) on the other hand, if the VIF is large such as 10 or more co-linearity is serious problem. Stata version 149.12.0.870 software was used for analyzing correlation and regression test.

RESULTS AND DISCUSSION

Rainfall data consistency

The reliability of the rainfall data set was tested by the single mass-curve method (Fig.2). The single mass curve was plotted by using the annual cumulative total rainfall of the Indibir station as ordinate (y) and the years of data/observation as abscissa (x) (1986-2015)

Homogeneity test

Data homogenization is defined as means the removal of non-climatic changes. Next to changes in the climate itself, raw climate records also contain non-climatic jumps and changes for example due to relocations/changes in instrumentation (WMO, 2017). Inline to this, Buishand's homogeneity testing (1982) method was used. The basic statistics associated with this test are summarized in Table 1. The test of homogeneity of the rainfall and temperature data series based on the hypothesis made, the computed P-values of rainfall and maximum temperature were found to be greater than the significance level (alpha = 0.05), hence the annual rainfall and maximum temperature data series revealed trendless and can be decided the data was homogenous. On the contrary, minimum temperature was found to be less than the significance level (alpha = 0.05), accordingly the minimum temperature data shown trend in the series and can be concluded the data series was not homogenous.

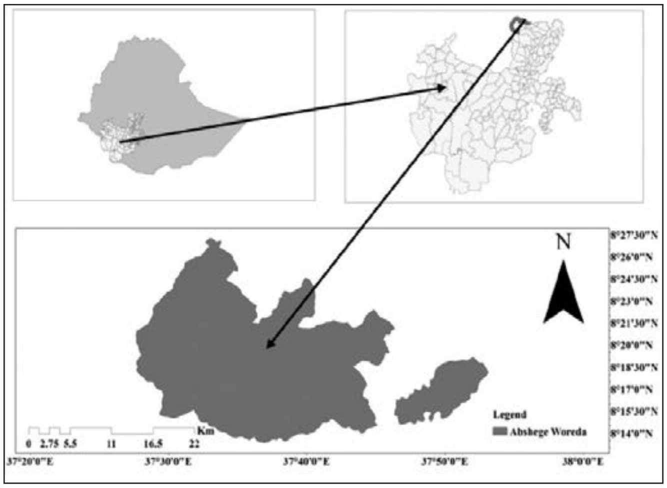

Fig. 1: Location map of the study area

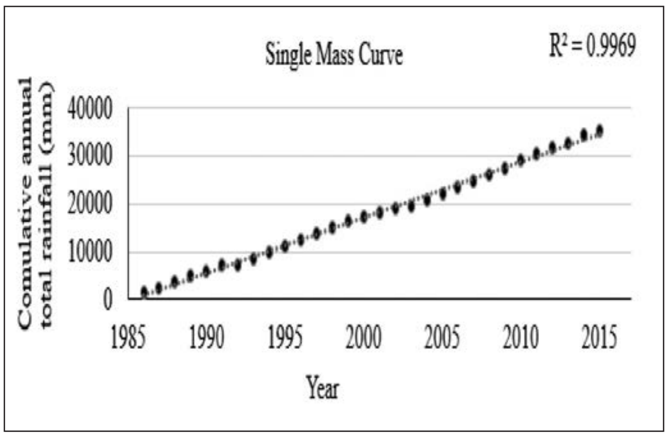

Fig. 2: Single mass curve on rainfall data for Indibir station

Table 1: Homogeneity test for rainfall, maximum and minimum temperature

Statistics	Rainfall	Max temperature	Min temperature
R	5.97	6.53	9.76
P-value	0.107	0.06	0.0001
Alpha	0.05	0.05	0.05

R, range; p value, probability value at 0.05 significant level

Table 2: Descriptive statistics of onset, cessation and LGP for Abshege Woreda

Descriptive statistics	Onset date (DOY)	Cessation date (DOY)	LGP (days)
N	30	30	30
Min	93	246	75
Q1 (25%)	106	246	109
Q2 (50%)	121	246	139
Q3 (75%)	142	266	149
Max	171	312	205
Mean	126	258	133
Trend	-0.19	0.41	0.6
R^2	0.01	0.03	0.03
SD	22	21	30.8
CV (%)	18	8	23.2
P- Value	0.6924	0.3578	0.3647

N = number of dataset, min = minimum value, Q1 (25%) = first quartile, Q2 (50%) = second quartile, Q3 (75%) = third quartile, max = maximum value, SD ($\pm$) = standard deviation, P-value = probability value, R^2 = coefficient of determination, CV = coefficient of variation

Start of rainy season

The result in the Box and whisker plot in Fig. 3 revealed that, on average, the long rainy season starts on May 5 (126 DOY) at Indibir weather station with CV of 18 per cent. The respective lower and upper quartile of the onset date fall between 106 DOY (15th April) and DOY 142 (21st May) and varies between 93 DOY (minimum) and 171 DOY (maximum). This implies that the chance of rain onset date on 142 DOY (May 21) or below is 75 per cent (3 out of 4 years) i.e. 22.5 years out of 30th years the onset of the season was earlier than May 21 and can expect the situation at 106 DOY (April 15) in 1 out of 4 years. The earliest onset date of the main rainy season at Indibir station was 93 DOY (April 2) while the latest date was 171 DOY (June 21) and the optimal planting date (the ideal planting period) was 126 DOY (May 5).

Late onset is the least preferred situation, obviously because it shortens the available length of crop growing period and the potential to satisfy the crop water requirement. However, the historical data for onset date showed less variability as compared to LGP, but highly variable than cessation date and also the changes are not significant ($P \leq 0.05$) throughout the 30 years' time period. Onset date has less standard deviation as compared to length of growing period (LGP), but higher than cessation date. The higher standard deviation of the onset date of the seasons indicates that patterns could not be easily understood and consequently decisions relating to crop planting and related activities will be made under high uncertainty. Study conducted by Abiy *et al*. (2014) on average, the *kirem*t rainy season started in DOY 84, 117 and 92 at Gato, Wolkite and Hossana stations, respectively.

End of the rainy season

Rainfall end date analysis showed that on average the long rainy season was ceased on 258 DOY

Table 3: Pearson correlation matrix of maize yield with rainfall and temperature characteristics

X	Maize	KRDs	KTR	Onset date	End date	LGP	KT_{max}	KT_{min}	KT_{mean}
Maize	1								
KRDs	0.723^{**}								
KTR	-0.557^{*}	0.841^{**}							
Onset date	0.201^{*}	-0.107^{NS}	-0.158^{NS}						
End date	0.576^{NS}	0.491^{NS}	0.375^{NS}	-0.142^{NS}					
LGP	0.267^{*}	0.405^{NS}	0.358^{NS}	-0.735^{**}	0.776**				
KT_{max}	0.39^{*}	-0.723^{NS}	-0.498^{*}	0.134^{NS}	-0.221^{NS}	-0.3^{NS}			
KT_{min}	0.199^{*}	0.161^{NS}	0.341^{NS}	-0.149^{NS}	0.029^{NS}	0.15^{NS}	-0.217^{NS}		
KT_{mean}	0.061^{NS}	-0.101^{NS}	0.163^{NS}	-0.066^{NS}	-0.052^{NS}	0.01^{NS}	0.146^{NS}	0.934^{*}	1

**significant at alpha = 0.01; *significant at alpha = 0.05; ^{NS} non-significant; Maize yield was measured in qt/ha, *kiremt* rainfall days measured in total number of rain day in the *kiremt* season, *kirem*t total rainfall measured in mm, onset date and end date were measured in DOY (day of the year), LGP was measured in days, *kiremt* maximum, minimum and mean temperature were measured in ^{O}C. KRDs = *kiremt* rainy days, KTR = *kiremt* total rainfall, LGP = length of growing period, KT_{max}= *kiremt* maximum temperature, KT_{min} = *kiremt* minimum temperature and KT_{mean} = *kiremt* mean temperature.

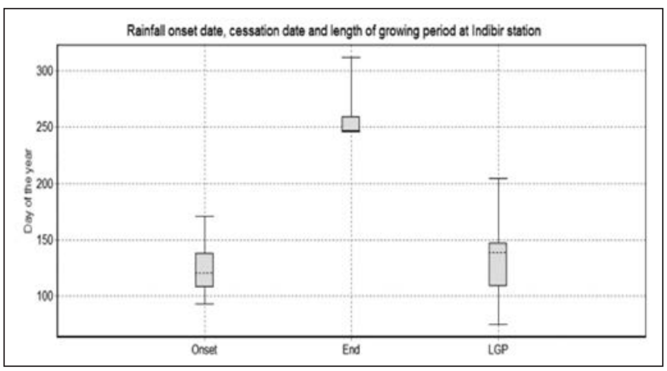

Fig. 3: Box and whisker plots of onset date, cessation date and length of growing period (April 1 was taken as potential planting date)

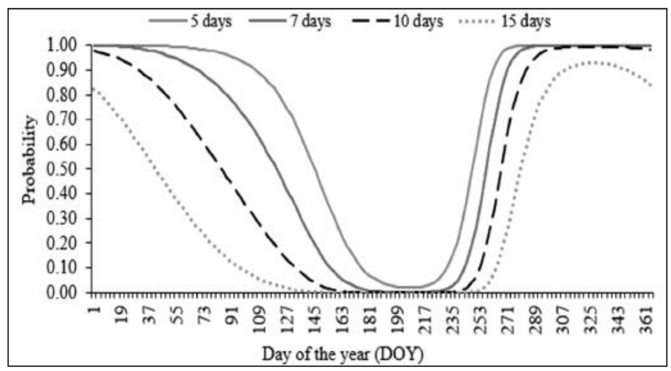

Fig. 4: Probability of dry spells exceeding 5, 7, 10 and 15 days, give 1st of April potential planting date

(14th September) at Indibir weather station with CV of 8 per cent (Table 2). The upper quartile, lower quartile, minimum and maximum for the cessation date were 266 DOY (22ndSeptember), 246 DOY (2nd September), 246 DOY and 312 DOY respectively. Upper and lower quartile indicates that the chance of rain to end before 266 DOY (22nd September) or below is 75 per cent (3 out of 4 years) i.e. 22.5 years out of 30th years the cessation of the season was earlier than 22nd September and can expect the situation at 246 DOY (2nd September) in 1 out of 4 years, respectively. The earliest date of cessation of the rainy season at Indibir was on DOY 246 (2nd September) while the latest date was DOY 312 (7th November) and the average cessation date was DOY 258 (14thSeptember). However, the historical data of rain cessation showed less variability as compared to onset date and LGP at a lower rate yet the changes were not significant ($P \leq 0.05$) throughout the study period and only 3 per cent of the variation in cessation date was explained by the time.

Length of growing period

The LGP for localized maize production in the rainy season ranged from 75-205 days and the mean LGP of the station was 133 days with CV of 23.2 per cent. Quartile 3 (75%) and Quartile 1 (25%) showed that the chance experiencing 149 days of LGP orbelow is 75% (3 out of 4 years) i.e. 22.5 years out of 30th years LGP of the season was less than or equal to149 days and can expect at 109 days in 1 out of 4 years (Fig. 3). This range was important and potential LGP for maize in the study area. Abiy *et al*. (2014) found out the *kiremt* rainy season has LGP of 62, 169 and 193 days at Gato, Wolkite and

Table 4: Regression result of the effect of rainfall and temperature characteristics on maize yield

Model	Coeff	Std. Error	t	Sig.
Constant	-50.38	65.522	-0.77	0.458
Number of *kiremt* rainy days	0. 682	0.259	2.62	0.024
Kiremt total rainfall	-0.01	0.0121	-0.82	0.430
LGP	0.004	0.0444	0.1	0.923
Kiremt maximum temperature	2.762	2.2905	1.21	0.447

Number of *kiremt* rainy days was measured in total number of rain day in the *kiremt* season, *kiremt* total rainfall was measured in mm, onset date was measured in DOY (day of the year), *and kiremt* maximum temperature was measured in ^{O}C

Hossana stations respectively. However, the historical data of LGP showed a high variability compared to onset date and cessation date in the study area. It showed that the LGP in the study area was variable which needs more attention for scheduling of agricultural production, crop management practices, farm inputs, select crop that is matching with this growing period, and early maturing variety for sustainable crop production to ensure local food security. Analysis of result indicated that LGP increased by a factor of 0.60 and 6 days per year and per decade, respectively. The variability in the LGP was large, but it was not statistically significant during growing period. The proportion of variation in LGP in the study area explained by the course of time was 2.94%.

Probability of dry spell length

Fig. 4 shows that the chance of a 15 day dry spell in April is very low relative to 5, 7 and 10 day dry spell, it is around 0.11, but the chance of a 10 days, 7 days and 5 days dry spell is about 0.41, 0.75 and 0.95, respectively. The risk of 5, 7 and 10 days long dry spell in 30 days in a year was highest in January, February, November and in December almost 100 per cent. From mid-February, the probability decreases due to the onset of rain, but the risk of having 15, 10, 7 and 5 days dry spell increases again at the start of September (247 DOY). During the maize growing season there is a higher probability of 5 days long dry spells compared to the 15, 10 and 7 days long dry spell in 30 days of a given period in a year. All the dry spell length probability curves converge to their minimum only during the peak rain period (June to August or DOY 153-244) and turn upward again around DOY 247, indicating the end of the growing season (termination of rainy season). All dry spell probability curves converge to their minimum during the peak rain season (days 184-244) and increase again around September (days 245-274), signaling the end of the growing season at Bulbula, Debre Zeit and Ziwaystations (Belay *et al*., 2014). In rain-fed farming, recurrent dry spell becomes critical during seedling establishment and after planting. Dry spell of any length could occur at any stage of crop growth, but it is potentially damaging if it coincides with flowering and grain filling stage. Evidence on the probability of such a range of dry spell lengths is useful for risk taking farmer (resource rich) and risk averse (resource poor). The underlying reason behind including the 'dry spell length' conditions into the later months of the growing season is to provide a complete picture of how the dry spell length of various magnitudes are distributed during the entire growing season and to examine the associated risk. If a crop is sensitive to drought at a particular growth stage, then this type of plot can help to timely planting to minimize such risks and damage.

Correlation with maize yield

The result of the multiple correlation showed that number of *kiremt* rainy days was strongly positive correlation with maize yield (r= 0.72), whereas *kiremt* total rainfall has moderately negative correlation (r= -0.56). Onset date of rainfall has a moderately weak positive correlation (r= 0.20), while rainfall cessation has positive correlation (r= 0.58). LGP has a moderately weak and positive correlation (r= 0.27) and the *kiremt* maximum temperature also has moderately weak and positive correlation (r= 0.40) with maize yield. The *kiremt* minimum and mean temperature have very weak and positive relationship (r= 0.20, r= 0.06) with maize yield in the study area (Table 3). Therefore, *kiremt* rainy days, *kiremt* total rainfall and cessation date has the greatest relationship with annual maize yield in the study area.

Multiple regression model

Table 4 demonstrate the multiple linear regression model in which three rainfall variables i.e. number of *kiremt* rainy days, *kiremt* total rainfall, LGP and one temperature variables i.e. *kiremt* maximum temperature were principal predictors. The constructed model takes the following form:

Y= -50.38 + 0.682 *x1 - 0.01* x2 + 0.004*x3 + 2.762*x4

R^2=0.78; R^2 adjusted 0.59 (P=0.032)

Where, Y = Predicted maize yield (q ha^{-1}), x1 = Number of *kiremt* rainy days (days), x2 = *Kiremt* total rainfall (mm), x3 = LGP (days) and x4 = *Kiremt* maximum temperature (^{O}C)

As shown in Table 4 all the predictor variables contribute positively, except the *kiremt* total rainfall that contributed negatively to the observed maize yield and the most likely explanation that the prevailing *kiremt* rainfall (934.9 mm) is more than the water requirement. Thus, resulted in localized water logging during maize growing period. Water logged (soils when pores are filled with water for an appreciable length of time) affects germination and survival of young plants. In very poorly drained soils (soils with excessive water conditions), large crop production losses are commonly expected. Adugna (2005) analyzed maize yield and rainfall data from four provinces in Ethiopia and found *kiremt* rainfall (-0.032 unit) is negatively contributing variable on maize.

From the positive contributing predictors, the *kiremt* maximum temperature is the most contributors (at the rate of 2.762 units), this might be due to maximum temperature (23.4-29^{0}C) of study area fit with maize optimum temperature requirement. Maize requires an optimum temperature for growth and development range between 20 and 30^{0}C. The second positively contributing rainfall variable is the number of *kiremt* rainy days (0.682 unit) followed by LGP (0.004 units) (Table 4). The rainfall cessation date, onset date and *kiremt* minimum and mean temperature were omitted from the model due to the multi-co-linearity effect. The result of the multiple regression analysis showed that 59 per cent of variation in maize yield has been really explained by the joint contribution of local climate variables. Variance inflation factor and the multiple regression result reveals fair R^2 value which indicated that there is no multi-co-linearity problem among the selected predictor variables.

Among the rainfall and temperature components included in the regression model, number of *kiremt* rainy days had statistically significant positive effect on maize yield (Table 5). Overall, the input variables went into the model construction and the specifications coined were adequate; implying that this model could be successfully employed in estimating the local maize production.

CONCLUSION

The result showed that earliest potential onset date of the growing season is DOY 93 (April 2), the latest is DOY 171 (June 21) and optimal planting data is DOY 121 (April 30). The variability in the start of the season is non-significant and showed a declining trend by a factor of -0.19 days per year. The main rainy season terminated during the last days of 246 DOY (September 2) once in four years' time and terminates earlier than 290 DOY (September 22) in three out of four years whereas the earliest and latest possible end date of the growing season is 246 DOY (September 2) and 312 DOY (November 7), respectively. The respective minimum and maximum possible length of growing period is 75 day and 205 day. The chance of getting LGP on 149 rainfall days or below is 75 per cent (3 out of 4 years) and can expect the situation at 109 rainfall days in 1 out of 4 years in the area.

The probability of occurrence of longer dry spells of 5, 7 and 10 day long in 30 days in a year was highest in January, February and November, December close to unity. From mid-February, the probability of occurrence decreases due to the onset of rain and the risk of 15, 10, 7 and 5 days dry spell increases to the start of September (247 DOY). All the dry spell length probability curves come across to their minimum only during the peak rain period (June to August or DOY 153-244) and go upward again at 247 DOY, indicating the end of the growing season. The result of the multiple correlation between maize yield and number of *kiremt* rainy days showed a strongly positive relationship (r= 0.723), whereas the *kiremt* total rainfall has moderately negative correlation (r= -0.557). Rainfall cessation showed a moderately positive correlation (r= 0.576) with the yield of maize. Multiple regression analysis predicted that an increase in *kiremt* total rainfall caused a decrease in maize yield. However, an increase in *kiremt* number of rainy days, LGP, *kiremt* maximum temperature will result increase in maize yield.

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