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The forage and grain yield of cold-tolerant sorghum and maize as affected by time of planting in the highlands of Kenya

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Summary

In trials with *Sorghum bicolor* and *Zea mays* in the highlands of Kenya the effects of planting date on the forage and grain yields were studied. Yields were regressed on (1) time of planting in days after the start of the rainy season (2) mean air temperature during the first five weeks post-emergence and (3) planting date index in a yield stability analysis. Grain yields varied more than total dry matter (DM) yields, indicating that correct time of planting was more important if crops were harvested for grain than for forage. The sorghum cv. E 1291 gave the highest grain yields and the sorghum cv. E 6518 the highest DM yields under all conditions. The grain yield of 'E 1291' was less affected by delayed planting than the grain yield of the maize 'H 613'. In a dry year delayed planting was beneficial because it allowed a certain soil moisture reserve to be built up, but this beneficial effect disappeared if the duration of crop development exceeded the length of the rainy sason. If rainfall was heavy immediately after the dry season, delayed planting had a pronounced negative effect on yields. Under such conditions DM yields decreased with 1.0 t ha^{-1} for every week delay in planting for both 'E 6518' and maize 'H 613', grain yields decreased with 0.41 t ha^{-1} $week^{-1}$ and 0.47 t ha^{-1} $week^{-1}$ for sorghum 'E 1291' and maize 'H 613' respectively. All grain yields were positively correlated with average mean air temperatures and regression coefficients varied from 0.77 to 3.67 t $°C^{-1}$, but temperature was confounded with rainfall and more work is needed to separate temperature and rainfall effects.

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Introduction

It is well known that date of planting may have a substantial effect on the yield of field crops. In the semi-arid tropics, where seasonality is determined by rainfall, it is accepted that the physiological development of most annual crops should be closely in line with the precipitation curves. This means planting should take place immediately after the onset of the rains. Delay in planting usually leads to reduced yields. This is brought about by a rapid build-up of pests, by leaching of nutrients or by the fact that grain-filling has to take place in a period when rainfall has become insufficient. Indian research (Rao, pers. comm.) has shown a sorghum (*Sorghum bicolor* (L.) Moench) grain yield reduction of 50% if planting is delayed for 10 days only. In Kenya, Allan (1972) demonstrated that the planting date of maize (*Zea mays* L.) is the most important management factor for obtaining high yields.

In search of crops more drought resistant than maize but adapted to conditions prevailing in the highlands of Kenya, van Arkel (1977) demonstrated the potential of certain new introductions of cold-tolerant, high-altitude sorghum. But no information on the effects of time of planting on the yields of sorghum was available in Kenya. The experiments reported in this paper were, therefore, designed to evaluate the effect of planting date on the grain yields and total DM yields of two cold-tolerant sorghum cultivars in relation to two maize cultivars in the highlands of Kenya.

Materials and methods

The study formed part of a project jointly sponsored by the Kenya Government, UNDP and FAO, who provided funds and facilities. The field experiments were conducted during 1976 and 1977 at the Kenya Government Beef Research Station near Nakuru at an elevation of about 1900 m. During both years the experiments were conducted at two distinctly different sites of this station. The characteristics of these sites have been described in more detail elsewhere (van Arkel, 1978), but in short, they can be characterized as fertile (site 1) and unfertile (site 2) both in terms of nutrient availability and soil depth (water-holding capacity).

Rainfall was recorded daily from two standard rain gauges placed at about 100 m distance from the two trials. Maximum and minimum air temperatures were measured in a screened meteorological hut placed 1.5 m above ground level at the same place where the rain gauges were installed, and were recorded once a day at 09h00. Mean air temperature was determined by taking the average of maximum and minimum temperature.

The 1976 experiments were carried out with two cold-tolerant sorghum cultivars (cvs.) each at six planting dates, laid down in a randomized block design with three replications. In 1977, this was repeated, but two maize cvs. were added to each planting date of the experiment for comparisons.

The characteristics of the two sorghum cvs. chosen can be summarized as follows: 'E 1291' is a cold-tolerant cv. with a high grain and a good forage yielding potential, maturing in about 165 days, if grown in the Nakuru area. This cv. will be referred to in this paper as the grain sorghum. 'E 6518' is a cold-tolerant cv. which has given very high forage yields and acceptable grain yields. The latter cv. matures in about 215 days if grown in the Nakuru area and will be referred to in this paper as the forage sorghum. The two maize cvs. used were the commercial hybrid 'H 613' and 'Local Yellow', a Kenya adapted open pollinated selection which is said to be able to outyield the hybrids if growing conditions become unfavourable.

The first planting date (P1) approximately coincided with the start of the rainy season, which meant that the P1's in 1976 were planted on 7 April and in 1977 on 4 April. The second planting (P2) took place seven days later, and the interval between each subsequent planting was progressively increased by two days. P6 therefore took place 55 days after the onset of the wet season. The day prior to planting 15-15-0 compound fertilizer was incorporated in the seedbed at the rate of 150 kg ha^{-1}. The day after planting Atrazine at 2½ kg (a.i.) ha^{-1} was sprayed for weed control. When each entry reached a height of approximately 30 cm a top dressing in the form of C.A.N. (26% N) at the rate of 150 kg ha^{-1} was applied. The plant population for the forage sorghum 'E 6518' was established at 13.3 plants m^{-2}, whereas the plant population for the grain sorghum 'E 2191' was set at 20.0 plants m^{-2}. Both maize cvs. were planted at a population of 4.0 plants m^{-2}. The size of each plot was 15 m^2 (3×5) and sometime during the week that an entry had reached the hard-dough stage, the central 8 m^2 of the plot were harvested. All harvested plants were then taken to the laboratory for component analysis and dry matter (DM) determination.

Yield data for total DM yield and grain yield were first analysed with a conventional analysis of variance. Subsequently, yield data were subjected to a quadratic regression model fitting, where yield was regressed on the days of planting after the onset of the rains. To examine the planting date $\times$ cultivar interaction (i.e. the difference in reaction of the four cvs. to delayed planting) a yield stability analysis was used. Several yield stability analysis methods have been suggested during the past 15 years. Finlay & Wilkinson (1963) proposed a method to investigate the yield stability of varieties to different environments. This method was refined by Eberhart & Russell (1966) and this method has been used widely in many countries for the analysis of yield data from regional yield experiments.

This method has now been adapted to analyse our experimental data, where the yield data of each cv. are regressed onto a 'planting date index'. This index is calculated as the mean of all four genotypes at a particular planting date minus the grand mean over all planting dates. The obtained regression lines account for the average of the observed data but it was pointed out by Freeman & Perkins (1971) that it is wrong to consider the lines as regression lines because the basic statistical requirements have not been met in the calculation method. It is therefore not permissible to compare the slopes of the lines statistically. Statistical comparisons between slopes can only be made if the dependent and independent variables in the regression model are orthogonal to each other. This can be achieved by regressing the yield data of three genotypes onto the yield data of the fourth genotype which acts as the control. The lines which were constructed in this way may validly be considered as regression lines and statistical differences between their slopes or elevation were analysed with the Newman-Keuls multiple range test adapted for regression analyses (Zar, 1974).

Table 1. Total DM yield and grain yield in tonnes per ha of sorghum and maize at six different planting dates. (Site 1 = fertile; Site 2 = unfertile).

Planting date in days after the start of the rains	1976				1977			
	forage sorghum		grain sorghum		forage sorghum		grain sorghum	
	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2
Total DM yield								
0	8.8	6.9	7.8	4.0	18.6	14.9	15.8	12.9
7	10.6	6.5	6.2	4.8	17.0	13.2	13.8	10.7
16	10.6	5.8	9.0	4.6	15.5	13.9	12.7	8.7
27	10.3	6.4	9.2	4.4	13.1	10.5	11.1	7.8
40	8.5	6.8	7.2	5.4	12.0	9.2	10.0	7.7
55	6.9	3.5	6.1	4.4	10.0	7.2	8.5	6.6
Grain yield								
0	2.3	1.8	3.6	1.6	6.1	2.6	6.9	4.9
7	2.3	1.0	2.7	1.5	5.6	2.1	6.7	4.9
16	1.6	0.4	4.4	1.6	2.4	1.7	4.6	4.1
27	0.3	0.8	3.4	0.8	1.4	0.8	4.6	4.0
40	0.3	0.0	2.1	1.2	1.3	0.1	3.9	3.0
55	0.1	0.0	1.7	0.5	0.3	0.1	3.0	2.5

	1977			
	maize H 613		maize Local Yellow	
	Site 1	Site 2	Site 1	Site 2
Total DM yield				
0	18.1	13.0	13.6	12.4
7	17.0	11.5	11.7	11.4
16	13.9	11.1	12.3	8.5
27	10.9	9.5	10.9	7.6
40	9.6	7.5	8.9	7.2
55	8.0	7.3	8.0	6.1
Grain yield				
0	5.7	4.9	4.9	4.3
7	4.3	3.0	3.4	4.3
16	3.1	3.2	3.6	3.0
27	2.7	2.3	3.6	2.7
40	2.1	1.8	2.3	2.2
55	1.2	1.0	1.2	0.6

Results

Table 1 shows the total DM yields and the grain yields of all experiments. The yields of both sorghum cultivars grown during 1976 were appreciably lower than those reported before. This was probably related to the unusual low rainfall recorded during 1976 (Table 2). The sorghum DM yields recorded during 1977 were considerably higher than in 1976.

In all instances site 2 yielded significantly less than site 1 ($P<0.001$). The forage sorghum outyielded the grain sorghum in total DM production in both years ($P<0.01$), but the grain sorghum produced significantly more grain than the forage sorghum ($P<0.001$). Maize 'H 613' produced more DM than 'Local Yellow' ($P<0.05$), but the grain production between the two cvs. was not significantly different.

The analysis of variance (not shown in tables) further showed a significant effect for planting date ($P<0.01$). It appeared (Figs. 1 and 2) that in 1976 the total DM yield initially increased up to a maximum, which was reached when planting was delayed by between 17 and 34 days. After this point yields generally declined, but the forage sorghum more sharply than the grain sorghum. For grain yield the situation was a little different. The grain sorghum was able to maintain its yield level over a fairly long period of planting dates before yields dropped. The forage sorghum, by contrast, tailed off immediately and it can be deduced from the curves that a delay of planting of two weeks resulted in about a 40% reduction in grain yield. The reason that the forage sorghum reacted more sensitively on delayed planting was probably associated with the longer period required for normal crop development. Delayed planting caused the forage sorghum to extend its growing period into the dry season when normal plant development was curtailed due to moisture deficits.

Table 2. Rainfall in mm from March till November for the two experimental sites during 1976 and 1977.

	1976		1977	
	Site 1	Site 2	Site 1	Site 2
March	5	1	34	42
April	62	89	232	206
May	75	65	270	175
June	66	52	81	163
July	91	82	93	95
August	109	126	93	55
September	91	63	36	41
October	22	27	106	104
November	40	39	130	185
Total	561	544	1075	1066
Long-term average	745	690	745	690

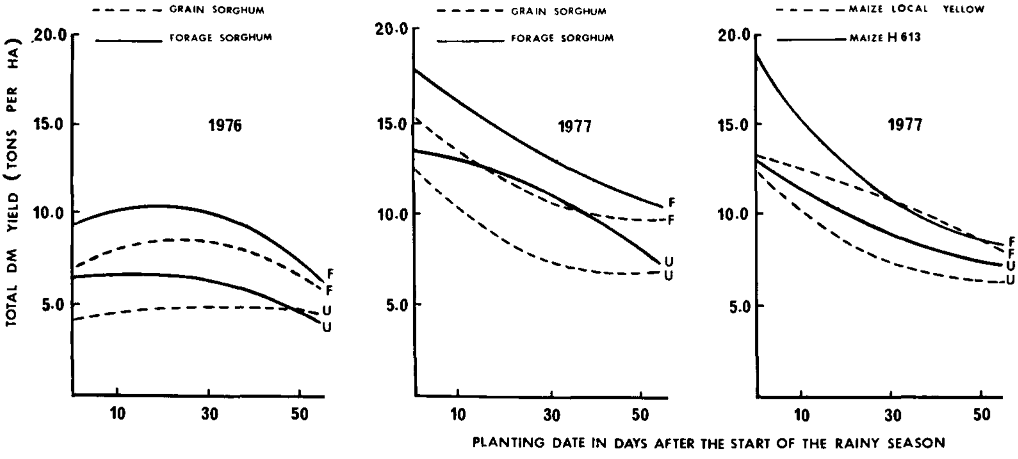

Fig. 1. Relation between total dry matter yield and planting date (data fitted to a quadratic model). F= Fertile soil (site 1); U = Unfertile soil (site 2).

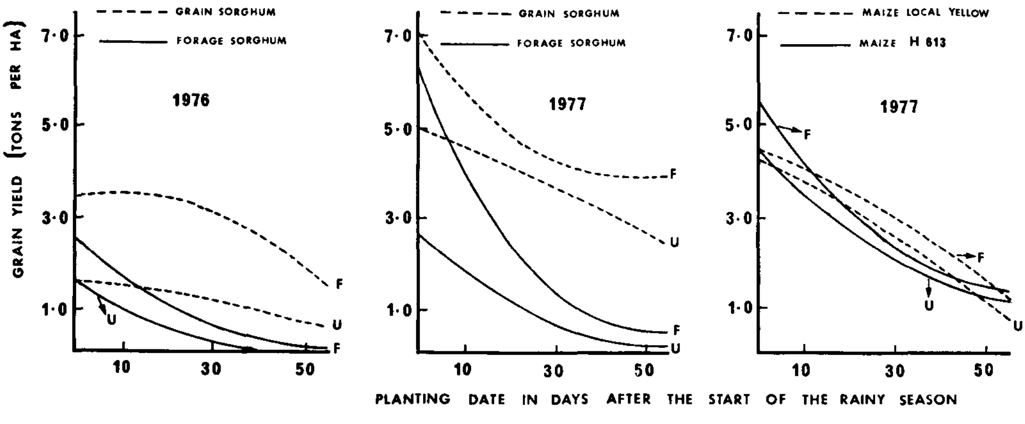

Fig. 2. Relation between grain yield and planting date (data fitted to a quadratic model) F = Fertile soil (site 1); U = Unfertile soil (site 2).

There did not seem to be a great difference in reaction to planting date between the total DM yield of maize and sorghum in 1977, when all yields dropped if planting was delayed. But the grain yields of the forage sorghum, the grain sorghum and the maizes reacted differently on delayed planting. The grain yields of the grain sorghum were highest at all planting dates and also appeared to be, marginally, less affected by delayed planting. The grain yield of the forage sorghum, by contrast, reacted sharply on delayed planting. If planting date was delayed by 14 days, grain yields were reduced by about half. A more detailed

Table 3. Average mean air temperatures for the 35-day period after 50 % crop emergence.

		Planting date					
		P1	P2	P3	P4	P5	P6
1976	Site 1	18.1	18.2	18.0	18.1	17.5	17.1
	Site 2	18.4	18.5	18.5	18.6	18.0	17.8
1977	Site 1	18.8	18.8	18.6	18.1	17.8	17.1
	Site 2	19.1	19.0	18.9	18.4	18.1	17.6

picture of the crop × planting date interaction can be obtained from the yield stability analyses.

Air temperature

The average mean air temperatures for the 35-day period following crop emergence showed a small range of variation for the six planting dates (Table 3). In the dry year of 1976, at both sites, temperatures remained relatively stable up to P4 after which they decreased by about 1 °C. This roughly coincided with the DM yields of the various planting dates which also did not decrease significantly up to about P5. The forage sorghum reacted differently, particularly for grain yield at side 2, but this was probably due to severe moisture limitations of

Table 4. Regression and correlation coefficients for the relation between grain yield (t/ha) and average mean air temperature (°C) of the first five weeks post-emergence for various groups of data.

			Regression coefficient	Correlation coefficient	Ref. No
Maize H 613	Site 1	1977	2.18	0.905**	1
	Site 2	1977	2.00	0.897**	2
	Site 1 + 2	1977	1.83	0.804***	
Maize Local Yellow	Site 1	1977	1.71	0.900***	3
	Site 2	1977	2.22	0.958***	4
	Site 1 + 2	1977	1.72	0.846***	
Grain sorghum E 1291	Site 1	1976	1.76	0.759*	5
	Site 1	1977	2.10	0.905**	6
	Site 1	1976 + 1977	2.38	0.846***	
	Site 2	1976	0.77	0.540n.s.	7
	Site 2	1977	1.56	0.956***	8
	Site 2	1976 + 1977	1.98	0.591*	
	Site 1 + 2	1976 + 1977	1.38	0.448*	

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$; n.s. = not significant.

the later planted treatments at the later stages of crop development, when the other crops were harvested already. In the wet year of 1977 temperature decreased almost immediately if planting was delayed, and so did crop yields. In the wetter year, temperatures started at a higher level than in the dry year but for P6 there was hardly any difference anymore.

It appeared that sorghum and maize grain yields were closely correlated with average mean air temperatures (Table 4). The response varied around 2 tonnes of grain yield reduction per ha for every °C temperature difference.

Yield stability

It appeared from the yield stability models (Figs. 3 and 4) that the average grain yields of all four genotypes at a particular planting date varied up to 67% from the grand mean, whereas the total DM yield varied up to 33% from the grand mean. This suggests that optimum time of planting was more important for grain crops than it was for forage crops.

The method employed to construct Figs. 3 and 4 does not permit to search for statistical differences between slopes or elevations of the lines. To enable such comparisons an independent measure of the planting date index must be used

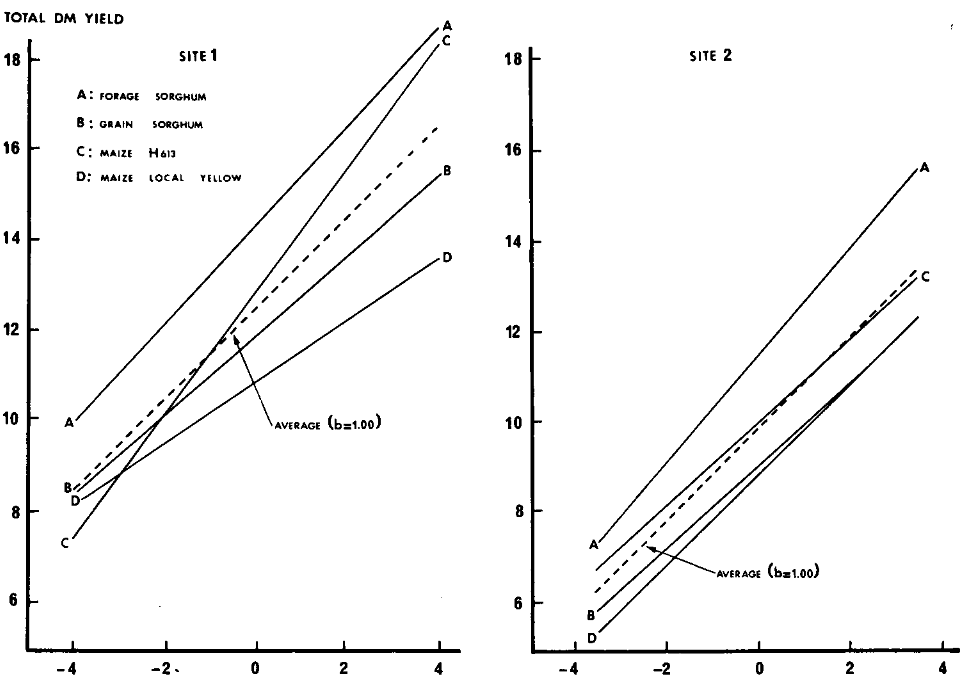

Fig. 3. The total dry matter yield response of two sorghum and two maize cultivars to different planting date conditions in 1977.

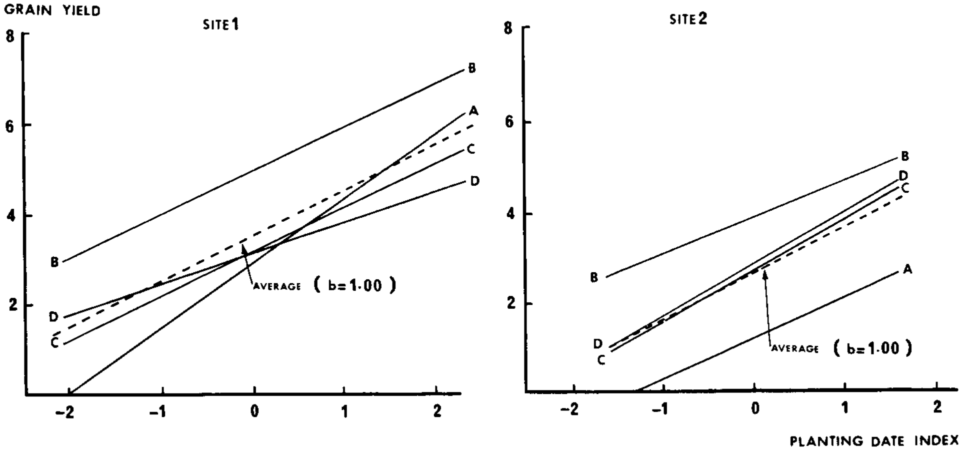

Fig. 4. The grain yield response of two sorghum and two maize cultivars to different planting date conditions in 1977.

and this can be achieved if the planting date index is replaced by the yield data of one of the four genotypes. Thus from Figs. 3 and 4 the least competitive or interesting genotype can be chosen to act as the control. For total DM yield 'Local Yellow' is taken at both sites, while for grain yield the forage sorghum is selected for both sites. The yields of the remaining three genotypes are now regressed on the yield of the control and this will allow to study how these three genotypes statistically differ in their reaction to planting date differences (Table 5).

The forage sorghum 'E 6518' yielded the most DM under all conditions at both trial sites. The next competitor for DM yield, the maize hybrid 'H 613', had a regression coefficient of 1.77 at site 1, significantly higher than any other, indicating that it may outyield the forage sorghum if growing conditions become

Table 5. Yield stability parameters for three of the four genotypes studied in 1977. (b = regression coefficient; y = mean yield).[1]

	Total DM yield				Grain yield			
	Site 1		Site 2		Site 1		Site 2	
	b	y	b	y	b	y	b	y
Forage sorghum	1.46[a]	14.37[a]	1.04[a]	11.48[a]	control			
Grain sorghum	1.20[b]	11.98[b]	0.92[a]	9.07[b]	0.63[a]	4.95[a]	0.87[a]	3.90[a]
Maize 'H 613'	1.77[c]	12.92[c]	0.85[a]	9.98[c]	0.64[a]	3.18[b]	1.18[b]	2.70[b]
Maize 'Local Yellow'	control				0.40[b]	3.17[b]	1.19[b]	2.85[b]

[1] Values with the same superscript do not differ at the 5 % probability level.

very favourable. But the maize hybrid suffered severely if planting dates were less favourable.

At site 2, none of the three cultivars tested had a regression coefficient significantly different from each other, indicating that there is no one to be preferred above another under different planting date conditions. The highest yielder, the forage sorghum, was the best under all conditions. This was in contrast with the findings from the dry year 1976 when it was found that under unfavourable, late, planting date conditions, the grain sorghum became the cultivar of choice.

For grain yield, the situation is somewhat similar to that of total DM yield. There was again one cultivar, the grain sorghum, which outyielded all the others at all planting dates. The low value of the regression coefficient for this cultivar indicated that it performed particularly well if conditions became less favourable.

Discussion

Effects of temperature

The pronounced negative effect of delayed planting on the yield of maize in East Africa is well documented (Goldson, 1963; Dowker, 1967; Akehurst & Sreedharan, 1965) and is again confirmed by the experiments reported here. A number of explanations have been published to account for the 'time of planting' effects. Hemingway (1955) suggested that early-planted maize was less susceptible to fungal diseases than maize planted later. Birch (1960) showed that large amounts of nitrogen become available immediately after the first rains following the dry season and suggested that this mineralized nitrogen is available to early-planted crops, but, due to leaching, not to crops planted later. Work by Allan (1972) carried out in Kitale showed that none of the above factors satisfactorily explained the time of planting effect for maize in the Kenya highlands. As a result of extensive field trials, watering experiments and a study of rainfall patterns he concluded that a progressive deterioration of the aeration of the soil was the most important factor responsible for the yield reduction of late-planted maize. But this conclusion was not based on aeration measurements and Cooper (1975) disproved the hypothesis by showing that aeration never limited maize growth in Kitale even when planted late in a very wet year.

Law (1974) showed that the grain yield differences resulting from planting date differences are very closely correlated with the dry matter weight of the maize at five weeks post-emergence.

Cooper (1974) showed that soil temperature during the dry season reached values well above the mean air temperature but that with the start of the wet season the soil temperature decreases rapidly and this decrease is closely correlated with solar radiation and with the frequency and intensity of wetting the soil by rain storms.

In a joint study Law & Cooper (1976) then successfully tried to artificially create soil temperature differences for varying periods of the growth of maize by covering the soil with polythene sheeting or with hay mulch. The results clearly showed that soil temperature differences during the first five weeks of growth resulted in corresponding differences in DM weight of five-week old plants which in turn were closely correlated with the final grain yield differences. Soil temperature differences after week five had no substantial effect on final grain yield This is probably due to the fact that the apical meristem stays below ground level for about five weeks. The importance of the temperature to which the apical meristem is exposed whilst below ground level was supported by experiments carried out by Brouwer et al., (1970).

In analyses combining three years of time of planting experiments, Cooper & Law (1977) tried to correlate the final grain yield data to the following environmental factors which were all taken as the average of the first five weeks of crop growth: solar radiation, mean air temperature, soil moisture availability, soil temperature and soil aeration. Again the average soil temperature was highly significant in explaining five weeks DM weight and final grain yield. Soil moisture stress together with soil temperature explained 82% of all grain yield differences. But mean air temperature and soil moisture stress explained even 98% of all grain yield differences. However, the authors suggest that it is still soil temperature which is the main factor responsible for the time of planting effect, but that air temperatures showed a higher correlation because mean air temperature values incorporate both a measure of soil temperature and solar radiation, and although the latter is not the main environmental factor controlling DM production, variation in solar radiation together with changes in air temperature will obviously affect the rate of DM production per unit leaf area.

Cooper & Law do not give simple linear regression equations for the relation average mean air temperatures — grain yield but these can be derived from their paper (Table 6). It then appears that their results agree closely with those from the experiments reported here (Table 4). The differences between regression coefficients (i.e. yield reaction to temperature differences) can be largely attributed to differences in average yield level (Fig. 5). This indicates that at higher yield levels yields are coming down more rapidly with temperature decreases than at lower yield levels, which can be seen from Fig. 6. It appears as if production increases linearly with increasing temperature once the minimum temperature requirement has been met up to a level which depends upon trial site and year.

Table 6. Regression and correlation coefficients for the relation between grain yield (t ha^{-1}) and average mean temperature (°C) of the first five weeks post-emergence of maize 'H 613'. (Data derived from Cooper & Law, 1977.)

Year	Ref. No	Regression coefficient	Correlation coefficient
1973	9	3.67	0.989**
1974	10	2.28	0.964**
1975	11	3.05	0.987**
1973-1975		2.85	0.943***

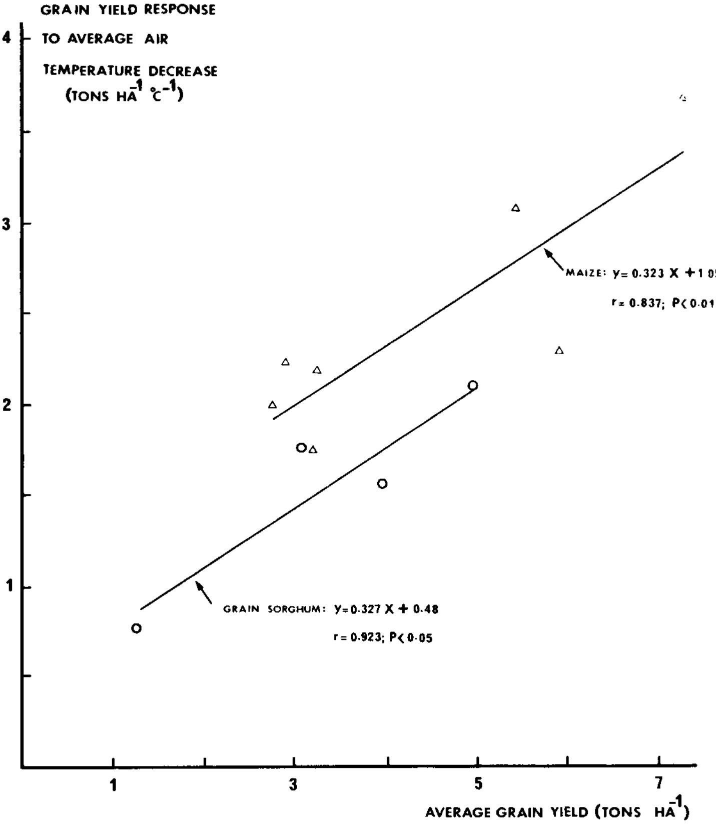

Fig. 5. The grain yield response of grain sorghum and maize to average mean air temperature differences during the first 35 days post-emergence as a function of the average yield level of the trial.

It is important to realise that temperature and rainfall differences are completely confounded. Later plantings are associated with lower temperatures, but also with a lower amount of rain. An analysis of the data collected in the trials reported here, did not lead to a useful calculation of the separate influences and in order to allow a meaningful comparision with the work at Kitale, the yield reduction was attributed to temperature only. This is, of course, an oversimplification, but in another study (van Arkel, 1980) an attempt was made to split the influences and demonstrate the relative sensitivity of sorghum and maize to temperature and rainfall.

The average grain yield reduction in 1977, calculated in a linear regression model, was 0.41 t ha^{-1} $week^{-1}$ for the grain sorghum and 0.47 t ha^{-1} $week^{-1}$ for maize 'H 613'. The latter is somewhat lower than the results published by Cooper & Law (1977), who showed that as an average over 10 years of time of planting experiments with maize hybrids in the Kenya highlands yields decreased

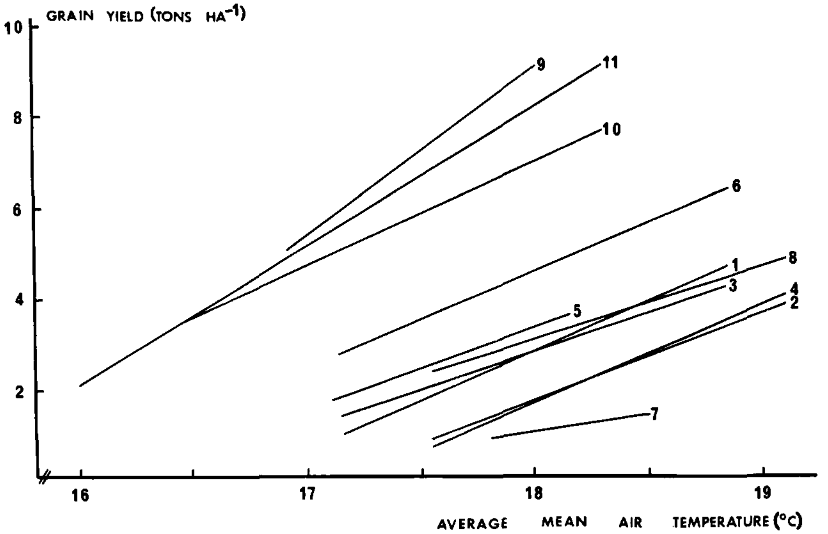

Fig. 6. Relation between grain yield of sorghum and maize as affected by average mean air temperature of the first five weeks post-emergence. (Numbers refer to the reference in Tables 4 and 6.)

0.6 t ha^{-1} with every week's delay in planting once the rain had started. But the average yield level of their experiments was also higher than here and a stronger yield depression is then to be expected (Fig. 5).

Application to different rainfall ecologies

Visual observations in the trials reported here and elsewhere in the highlands did not show any important relation between time of planting and disease or pest scores. This is an unusual situation because delayed planting of sorghum in the lowlands is normally strongly correlated with an increased damage by sorghum shoot fly (*Atherigona varia soccata* (Rond.).

Although most sorghum cvs. are short-day types, detailed data on crop development (not shown in Tables) showed no crop development reaction due to planting date differences. Such reaction is common if sorghum is grown well away from the equator (Andrews, 1973; Kassam & Andrews, 1975), but are not normally expected at our trial locations which were within 40 km of the equator, although Miller (1968) observed that an increase of 7 minutes in day length resulted in a 185-day delay in flowering of certain sorghum selections growing in Puerto Rico.

Consequently, the two main factors which appear to be responsible for the time of planting effects in the Kenya highlands are (1) total rainfall and its associated decrease in soil temperature and (2) the length of the rainy season in relation to the time required for undisturbed crop development. The results with the grain sorghum in 1976, when rainfall was low and when temperatures did probably not decrease significantly, confirm the results of Lal (1973), who found that a little delay in planting time sometimes increased yield because it allowed a certain soil moisture reserve to be built up thus reducing moisture stress during the early stages of plant growth. The results with the forage sorghum in 1976 clearly showed that Lal's results only apply if the rainy season is long enough to allow grain filling of later planted crops to occur when soil moisture reserves are still sufficiently high. Under conditions when rainfall is expected to be high immediately after the dry season, thus rapidly reducing soil temperatures, early planting proved to be of prime importance to achieve high yields. In the highlands of Kenya, the predominant rainfall pattern is either long, about 8 months, with high intensity or short, about 3 months, with low intensity (Anon., 1970). For both patterns the need for early planting is evident. The 1976 rainfall pattern must be considered exceptional and for all practical purposes early planting must be the general recommendation in the Kenya highlands.

Yield stability analysis

The analysis of the yield stability parameters proved a useful tool for the examination of the time of planting effects on yields, because it takes away the general trend of yield effects and particularly elucidates the relative response of each cultivar. The analysis provided a more sensitive method to test the significance of cultivar × planting date interactions than with the conventional analysis of variance.

An important component of the yield stability analysis is based on the presence or absence of statistically significant differences between sets of regression coefficients (Table 5). Hence the importance of the selection of the independent variable (i.e. the control) in the regression analysis. On the one hand, one would want to select a genotype which is not competitive with the top yielding entries, because the independent variable is automatically excluded from the statistical comparisons. On the other hand, a genotype which reacts similar to the top yielding entries on delayed planting is desired. Therefore, the total DM yield of the maize 'Local Yellow' was a better choice for the total DM yield stability analysis than the grain yield of the forage sorghum was for the grain yield stability analysis, since the latter was very differently affected by delayed planting than any other entry, particularly at site 2 where the yield approached zero already after 40 days delay in planting. This has increased the deviation from regression of the three remaining genotypes and consequently decreased the sensitivity of the analysis. It may be considered for future experiments to plant an additional set of replicates of those genotypes which are expected to rank among the top yielders, thus providing a more useful measure of the environment.

References

Anonymous, 1970. National Atlas of Kenya. Survey of Kenya, Government Printer, Nairobi.

Akehurst, B. C. & A. Sreedharan, 1965. Time of planting – a brief review of experimental work in Tanganyika 1956-62. *E. Afr. agric. For. J.* 30: 189-201.

Allan, A. Y., 1972. The influence of agronomic factors on maize yields in Western Kenya with special reference to time of planting. Ph. D. Thesis, University of East Africa.

Andrews, D. J., 1973. Effects of date of sowing on photosensitive Nigerian sorghums. *Expl Agric.* 9: 337-346.

Arkel, H. van, 1977. New forage crop introductions for the semi-arid highland areas of Kenya as a means to increase beef production. *Neth. J. agric. Sci.* 25: 135-150.

Arkel, H. van, 1978. Fertilizer response of cold-tolerant sorghums under semi-arid high-altitude conditions. *Neth. J. agric. Sci.* 26: 312-325.

Arkel, H. van, 1980. The adaptation of cold-tolerant sorghum and maize to different environments in the highlands of Kenya. *Neth. J. agric. Sci.* 28: 78-96.

Birch, H. F., 1960. Nitrification in soils after different periods of dryness. *Pl. Soil* 12: 81-96.

Brouwer, R., R. Kleinendorst & J. Locher, 1970. Growth response of maize plants to temperature. In: Plant response to climatic factors. UNESCO, Paris, pp. 169-174.

Cooper, P. J. M., 1974. Soil temperature under maize and bare fallow in Western Kenya. *Proc. 5th E. Afr. Cereals Res. Conf.* (Malawi).

Cooper, P. J. M., 1975. Studies on the soil atmosphere composition under maize, grass and bare fallow in Western Kenya. *E. Afr. agric. For. J.* 40: 313-331.

Cooper, P. J. M. & R. Law, 1977. Soil temperature and its association with maize yield variations in the Highlands of Kenya. *J. agric. Sci., Camb.* 89: 355-363.

Dowker, B. D., 1964. A note on the reduction in yield of Taboran maize by late planting. *E. Afr. agric. For. J.* 30: 33-34.

Eberhart, S. A. & W. A. Russell, 1966. Stability parameters for comparing varieties. *Crop Sci.* 6: 36-40.

Finlay, K. W. & G. N. Wilkinson, 1963. The analysis of adaptation in a plant breeding programme. *Aust. J. agric. Res.* 14: 742-754.

Freeman, G. H. & J. M. Perkins, 1971. Environmental and genotype-environmental components of variability. *Heridity* 27: 15-23.

Goldson, J. R., 1963. The effect of time of planting on maize yields. *E. Afr. agric. For. J.* 29: 160-163.

Hemingway, J. S., 1955. Effects of Puccinia polysora on yields of maize. *E. Afr. agric. For. J.* 20: 191-194.

Kassam, A. H. & D. J. Andrews, 1975. Effects of sowing date on growth, development and yield of photosensitive sorghum at Samaru, Northern Nigeria. *Expl Agric.* 11: 227-240.

Lal, R., 1973. Effects of seedbed preparation and time of planting on Maize *(Zea mays)* in Western Nigeria. *Expl Agric.* 9: 303-313.

Law, R., 1974. Investigation of the important growth stages of maize. *Proc. 5th E. Afr. Cereals Res. Conf.* (Malawi).

Law, R. & P. J. M. Cooper, 1976. The effect and importance of soil temperature in determining early growth rate and final grain yield of maize in Western Kenya. *E. Afr. agric. For. J.* 41: 189-200.

Miller, F. R., 1968. Some diversity in the world sorghum collection. *Proc. 23 Ann. Corn Sorghum Res. Conf.*: 120-128.

Zar, J. H., 1974. Biostatistical analysis. Prentice-Hall, Englewood Cliffs, N.J., pp. 228-235.