The identification and introduction of a new crop in the highlands of Kenya

Promotor: ir M.L. 't Hart, oud-hoogleraar in de leer van de landbouwplantenteelt en het grasland

'Development does not start with goods: it starts with people and their education, organization and discipline. Without these three, all resources remain latent, untapped, potential.

There are prosperous societies with but the scantiest basis of natural wealth, and we have had plenty of opportunity to observe the primacy of the invisible factors after the war. Every country, no matter how devastated, which had a high level of education, organization and discipline, produced an 'economic miracle'. In fact, these were miracles only for people whose attention is focussed on the tip of the iceberg. The tip had been smashed to pieces, but the base, which is education, organization and discipline, was still here. Here, then, lies the central problem of development. Here lies the reason why development cannot be an act of creation.'

E.E. Schumacher (1973)

*To my father who taught me farming*
*(Aan mijn vader die mij het boerenvak leerde)*

## Curriculum vitae

De auteur, geboren op 11 augustus 1946 in de Haarlemmermeer, volgde een 3-jarige HBS-opleiding te Heemstede. Vervolgens ontving hij van 1962 tot 1965 een opleiding aan de Hogere Landbouw School te Ede (thans gevestigd te Dronten). Hij begon zijn studie aan de Landbouwhogeschool in Wageningen in 1965 en behaalde het ingenieursdiploma in 1972 met als hoofdvak Landbouwplantenteelt en als bijvakken Bemestingsleer, Grondbewerking en Landbouwwerktuigkunde. In datzelfde jaar aanvaardde hij een functie bij de Wereld Voedsel Organisatie van de Verenigde Naties (FAO) en werd voor twee jaar gestationeerd in Oeganda. Van 1973 tot 1979 werkte hij in diverse functies voor de FAO in Kenia, waar het veldonderzoek waarop dit proefschrift is gebaseerd, werd uitgevoerd. Hierna werkte hij nog een jaar voor de FAO met als standplaats Egypte.

In 1981 werd hij benoemd tot directeur van het Nederlands Instituut voor Afzetbevordering van Akkerbouwprodukten (NIVAA) gevestigd te Den Haag en Wageningen.

H. van Arkel

# The identification and introduction of a new crop in the highlands of Kenya

Proefschrift
ter verkrijging van de graad van
doctor in de landbouwwetenschappen,
op gezag van de rector magnificus,
dr. C.C. Oosterlee,
hoogleraar in de veeteeltwetenschap,
in het openbaar te verdedigen
op woensdag 29 september 1982
des namiddags te vier uur in de aula
van de Landbouwhogeschool te Wageningen.

## Abstract

Arkel, H. van (1982). The identification and introduction of a new crop in the highlands of Kenya. Doctoral thesis, Wageningen, 58 p., 15 figs., 7 tables, English and Dutch summaries, including reprints from Neth. J. agric. Sci. 25(1977): 135-150, 26(1978): 181-190, 312-325, 28(1980): 63-77, 78-96.

African range cattle respond well to intensive feeding in feedlots, when maize silage based rations are fed. Maize is not drought-tolerant and is lodging-susceptible, which makes it less attractive as a forage. In a search for alternative forages, a new group of plant material is introduced: high-altitude, cold-tolerant sorghum. Some of the cultivars in this group appear to outyield maize both in terms of total dry matter and grain yield, over a large range of environmental conditions in the Kenyan highlands. Crop husbandry trials with the new sorghums and maize are reported. In an animal feeding trial the cattle performance of maize and sorghum silage based rations is compared. The introduction of new high-altitude, cold-tolerant grain type sorghums may eventually lead to a substantial increase of the area under arable agriculture in Kenya, because it will make grain production feasible in areas which were previously considered too dry for reliable grain production. A discussion of the typical problems of working on agricultural development in a developing country is given.

STELLINGEN

1. Het feit dat er nu koude-tolerante sorghums gevonden zijn die qua korrelopbrengst met mais kunnen concurreren in de drogere hooglanden van Oost-Afrika, opent de mogelijkheid tot aanzienlijke graanproduktieverhogingen.

Dit proefschrift.

2. Het gebruik van sorghum in plaats van mais als de basis van rantsoenen voor het afmesten van zeboes afkomstig uit de semi-aride gebieden van Oost-Afrika in 'feedlots', kan de vleesproduktie met 40% verhogen.

Dit proefschrift.

3. Het succes met de verbeterde methode van vleesproduktie in Kenia, zoals aangegeven in dit proefschrift, waarbij de traditionele nomadische leefwijze van de bevolking in de droge gebieden en hun traditionele veehouderijsystemen niet essentiëel worden aangetast, geeft aanleiding om de toepassingsmogelijkheden van deze methode elders in Afrika, met name in de Sahel-landen, te onderzoeken.

H. Breman. Landbouwkundig tijdschrift/pt 93 (1981) nr 10: 263-270.

4. De idee om middels het introduceren van Europese veerassen de vleesproduktie in de savanne van Afrika te verhogen, dient als achterhaald te worden beschouwd.

Dit proefschrift.

5. De ten tijde van de ambtsperiode van drs J. Pronk als Minister voor Ontwikkelingssamenwerking ingestelde verandering in de arbeidsvoorwaarden voor Nederlandse deskundigen werkzaam in ontwikkelingslanden, heeft een negatief effect gehad op de effectiviteit van de Nederlandse ontwikkelingshulp.

J. Pronk. Brief van 22 juni 1977, kenmerk DTH/PK-140604.

6. In het belang van daadwerkelijke landbouwkundige vooruitgang in Afrikaanse ontwikkelingslanden dient de Nederlandse regering zo snel mogelijk haar technische ontwikkelingsinspanning los te maken van het Ministerie van Buitenlandse Zaken.

7. Bij het opzetten van internationale ontwikkelingshulpprojekten wordt door Nederland een toetsingsbeleid gehanteerd. Hierbij dient aan het criterium van 'een blijvend effect op de produktiviteit van de landbouw' een veel hogere prioriteit gegeven te worden.

8. De 'Yield stability analysis', die dikwijls gebruikt wordt voor het analyseren van regionale gewasopbrengstproeven, heeft minder opbrengst voorspellende waarde dan is aangegeven door Darrah.

L.L. Darrah. *E. Afr. agric. For. J.* (1976) 41: 273-288.

9. Maisrassen vertonen grote verschillen in stengellengte. Een tekortkoming van vele opbrengstproeven met mais is daarom dat zij slechts bij één plantdichtheid worden uitgevoerd.

J.C.S. Allison, 1969. *Ann. appl. Biol.* 63: 135-144.
M.N. Harrison, 1970. Maize improvement in East Africa. In: Crop improvement in East Africa. Ed. C.L.A. Leakey. C.A.B., England.
L.L. Darrah & L.H. Penny, 1974. *E. Afr. agric. For. J.* 40: 77-88.

10. De korrelopbrengst van hybridesorghums is constant hoger dan die van niet-hybriden, ongeacht de hoogte van het opbrengstniveau. Het verdient daarom aanbeveling om ook in veredelingsprogramma's gericht op ongunstige teeltomstandigheden de ontwikkeling van hybriden meer prioriteit te geven dan tot nu toe gebruikelijk is.

Annual Reports 1973-1979 ICRISAT, Hyderabad, A.P., India.
H. Doggett, 1967. Yield increase from sorghum hybrids. *Nature*, 216: 798.

11. De grote bevolkingsmigratie van de Bantu's naar zuidelijk Afrika is mogelijk gemaakt dank zij de aanwezigheid van sorghum.

S. Cole. The prehistory of East Africa. 1963. Weidenfield and Nicolson, London.
R. Oliver. The problem of the Bantu expansion. *J. Afr. History*. (1966) 7: 361-376.

12. In die gebieden van de Afrikaanse savannes waar begrazingsdruk niet effectief kan worden geregeld, hebben de methoden die hebben geleid tot de grote produktiviteitsverhogingen van natuurlijke graslanden in Australië, weinig toepassingsmogelijkheden.

H.J. van Rensburg, 1969. Introduced legumes in natural grassland. Min. of Rural Dev. Lusaka, Zambia.

13. De 'Scharreleieren Controle Commissie' draagt bij tot de bewustwording dat alternatieve produktiemethoden in de landbouw een extra uitgave van de consument vragen. Hiermede bewijst zij de landbouw een goede dienst.

14. De produktie van aardappelen in de ontwikkelingslanden is, in de periode van 1961 tot 1979, sneller toegenomen dan van enig ander belangrijk voedingsgewas. Dit is voor een belangrijk deel te danken aan de Nederlandse kwekers van aardappelrassen, aan hen die zich bezighouden met het verspreiden van die rassen in de wereld en met het verbeteren van de teeltmethodes. Deze opmerkelijke bijdrage aan de verbetering van de wereldvoedselsituatie dient met een Nobelprijs gehonoreerd te worden.

Proefschrift van H. van Arkel
The identification and introduction of a new crop in the highlands of Kenya.
Wageningen, 29 september 1982

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I would like to acknowledge the Food and Agriculture Organisation and the United Nations Development Programme for granting me permission to use the data collected for this thesis. Thanks are due to the Kenyan Government and in particular to the Director of Research of the Ministry of Agriculture and to the Officers-in-charge of the Beef Research Station and other Government Stations where experimental work was carried out, for their support. So much field work was done by the Kenyan labourers with whom I had the pleasure of working. They put in many extra hours under conditions which were not always ideal. 'Asante sana mabwana, kazi mzuri kabisa.' It is also with great pleasure that I acknowledge the help from all those Kenyan farmers on whose farms trials were laid down. Without their keen interest and encouragement the work would certainly not have come as far as it has now. Without the able assistance of mr H.J. Enserink, who supervised much of the field work during the last stage of the experimental period, thus allowing me time for analysis, this work may not have been completed.

I am grateful to the Ministry of Finance in Nairobi for letting me make use of their computer installation. The assistance of the Directorate of International Technical Assistance (DITH) of the Netherlands Government is appreciated for the financing of some of the nutritive value analyses, while the help of the Department of Field Crops and Grassland Husbandry, Agricultural University, Wageningen, which carried out these analyses, is gratefully acknowledged.

I am very grateful indeed to my parents, who suggested and supported my line of study. My family provided a cheerful and encouraging background throughout the study and gave me emotional and practical support. Stans, Marianne and Meeuwis, thank you.

# Contents

The greater part of this thesis is contained in five papers which were published in the Netherlands Journal of Agricultural Science and of which reprints are appended. In the following text they will be referred to as Paper I to V.

Paper I : New forage crop introductions for the semi-arid highland areas of Kenya as a means to increase beef production. *Neth. J. agric. Sci.* 25(1977): 135-150

Paper II : The forage and grain yield of sorghum and maize as affected by soil moisture conservation, lodging and harvesting losses. *Neth. J. agric. Sci.* 26(1978): 181-190

Paper III : Fertilizer response of cold-tolerant sorghums under semi-arid high altitude conditions. *Neth. J. agric. Sci.* 26(1978): 312-325

Paper IV : The forage and grain yield of cold-tolerant sorghum and maize as affected by time of planting in the highlands of Kenya. *Neth. J. agric. Sci.* 28(1980): 63-77

Paper V : The adaptation of cold-tolerant sorghum and maize to different environments in the highlands of Kenya. *Neth. J. agric. Sci. 28(1980): 78-96*

## Preface

The initial terms of reference of my Kenyan assignment were to find an alternative crop for maize for silage and introduce this crop - whatever it may be - to the farming community for which it was intended. The scientific identification and introduction of a new crop must always be based upon a logical analysis of the requirements which the crop must meet and the physical and economic environment for which it is intended. Having then determined potentially suitable plant material, there follows a series of systematic trials and experiments which must progressively define not only the crop, but the system of husbandry whereby it can be shown to make its most effective contribution to the farming system for which it is defined.

The work described in this thesis was aimed at a specific commercial sector of farming in a developing country: cattle fattening in Kenya. At the same time as the experimental work was unfolding, dynamic changes were taking place in the industry for which it was being designed as well as in government policies. Thus, while a plan of work was originally prepared, it was essential that the programme of work should be flexible and responsive to evolving conditions. There is every reason to expect that these pressures will be most acutely felt in a section of modern agriculture in a developing country, and that to this extent the presentation of this work as a case study is an extreme example. For this reason I have also discussed some specific aspects of working in a developing country (Section 2).

With hindsight to assist, some of the activities have inevitably been accorded a more rigid framework than they had at the time. For example, in the Section describing the objective of forage quality determination (3.3.2), I imply that the initial plan called for the establishment of forage quality in three stages: 1. published data, 2. laboratory analyses, and 3. actual feeding trials. Naturally, feeding trials were only planned when the first stage of the programme had proved that certain forages appeared economically viable in actual animal trials. Had such forages not been found, feeding trials would not have been needed and the programme would probably have concentrated on improving present cultivation methods of maize. The planning of laboratory analyses also had a low priority in the beginning of the programme, partly because funds were limited, partly because there was, as yet, no crop to justify the planned expenditure. It was only two years later, when it appeared that some critical analyses could be carried out at the Department of Field Crops of Wageningen University, that in-vitro digestiblity analyses became a reality. The reader must realize therefore that the above was written after the results of the crop introduction trials were known and after additional funds had become available.

The experimental body of the work has been reported in ten papers of which five are appended to this thesis and five are referred to in the literature list. The Sections 1 to 5 preceeding the papers were written to place the experimental work in a wider context. They aim to show the reader how and why the problem was formulated, how the programme of work evolved as more and more experimental results became available and how the work was evaluated against its objectives. Section 5 finally shows which research questions have arisen from the work.

The problems encountered when working in an aid project can be manyfold and this is discussed in Section 2.2. Nevertheless the programme on which this thesis is based, met only with relatively minor problems. This was partly due to the excellent support I received from the Kenyan Government and also because I was allowed to work with such excellent people as Joseph Kimani and Peter Onyango Odipo, among others. It was also, and not in the last place, because I was so lucky to work under dr Michael J. Creek as the FAO Project Manager. He understood that apart from administrating and guiding a project, it is a distinct duty of a Project Manager to provide optimal working conditions for the experts working with him.

Permission from the FAO has been obtained to publish this work. This does not mean, however, that the views expressed are necessarily shared by the FAO. Similarly, the Kenyan Government has kindly given me permission to use the experimental data for the publications and thesis. But the conclusions drawn are solely mine and do not necessarily represent the views of the Kenyan Government or of any of their staff members.

Fig. 2. The traditional semi-nomadic system of cattle husbandry in the driest parts of Kenya. This system now needs to be converted into a cow-calf operation (i.e. stratum 1), whereby male animals are sold for grazing elsewhere.

– which tried to induce a beef cattle production stratification. This, with the aim to eleviate the problem of overgrazing and to increase the national beef production, without drastically changing the way of life of the semi-nomadic pastoralists.

The first stratum is formed by the (same semi-nomadic) system of the driest parts of the country (Fig. 2). However, male cattle are now sold when they are still young and when their quality as beef animals is not yet spoiled, to ranchers who also operate a normal cow-calf ranching system in areas where rainfall is higher than in stratum one. Here in stratum two the male cattle are kept until they have reached the minimum feedlot entry weight. At a live weight of between 280 and 300 kg the animals are transferred to a feedlot (i.e. stratum 3) where they are finished in about 90 days during which they grow, on average, 1 kg per day (Fig. 3).

To create grazing places for the pastoral male cattle from stratum 1 (i.e. Beef supply class 3; Table 1 of Paper I) at the ranches (Fig. 4), it is also possible to transfer steers which were bred at the ranch, to the feedlot. The latter steers are usually of superior genetic potential (see Section 2.1.4).

In 1973 fourteen feedlots were in operation which had a total capacity of finishing close to eighty thousand beef cattle steers annually. These feedlots were essentially complexes of simple yards within which cattle were confined and fully fed to appetite. The one time capacity of any of the Kenyan feedlots varied from 1000 to 2500 head of cattle. The finishing rations were composed of agro-industrial by-products and maize silage. More technical details of the set-up of Kenyan feedlots and their operation is given in Paper I and by Creek (1971, 1973) and Creek & Squire (1976).

The feeding system developed was successful from the technical viewpoint, but the use of maize for silage making had four major disadvantages:

– Maize only grows well under relatively wet conditions and high rainfall areas are scarce in Kenya. Further growth of the feedlot industry therefore had to take place in lower rainfall areas.
– Maize crops sometimes severely lodge thus making mechanical harvesting difficult and inducing substantial harvesting losses.
– Maize grain is the staple food in Kenya and although Kenya has enjoyed excess production for quite some time, using maize for animal feed is not well appreciated.
– Theft of maize cobs prior to harvesting considerably reduces the feeding value of the forage.

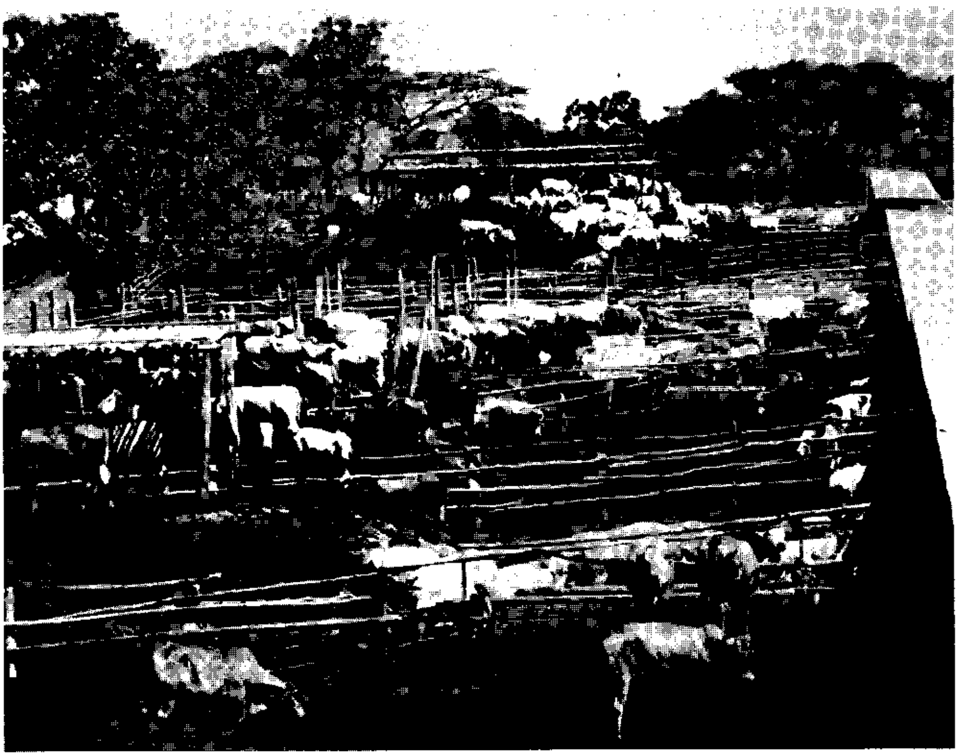

Fig. 3. A view of part of a Kenyan feedlot (stratum 3).

Fig. 4. A view of a cattle ranch in the medium potential parts of the country. Such ranches now need to buy male cattle from the driest areas and provide grazing until the animals reach minimum feedlot entrance weight (stratum 2).

From the above four disadvantages of maize it follows that maize was considered less suitable for both the existing maize using feedlot farms and for feedlot farms newly to be developed in drier areas.

Consequently, the identification of a crop that could replace maize in both these target areas without having the disadvantages of maize became a problem for the beef industry.

This thesis deals with this problem and is presented as a case study of crop introduction in a Third World country. It describes the process and method which was followed to screen, evaluate, identify and introduce the most suitable crop under the prevailing conditions.

# 2 Problem specification

## 2.1 Agro-technical aspects

### *2.1.1 Farmers' requirements*

At the outset of the study all silage made by feedlots used a maize crop, and in identifying the best suitable crop for the target areas the highest priority was accorded to the farmers' needs. Did they need an alternative crop? If so, what crop characteristics were they looking for? Yield and quality of course, and cost and effort of production had to compare favourably with maize. But there was more: the spreading of risk. Feedlot farmers faced cropping risks in two ways: planting and application.

The planting risk for maize, the traditional feedlot crop, has two aspects, both related to the unpredictable and erratic rainfall in Kenya. It has been shown by Kenyan research stations that early planting, i.e. immediately upon the start of the rainy season, is essential for obtaining a high maize yield. This leads to a recurrent farmers' problem: after the first good rainstorm in February, March or April he asks himself: Is this the start of the rainy season or only an isolated shower? Shall I plant or shall I wait? This problem becomes more pressing as the farming areas become more marginal due to a low total annual rainfall. Planting too early may result in total crop failure, if the rains disappear again and crops are not drought resistant. Planting too late sacrifices yield potential.

The second planting risk is even less predictable. As may be implied from Fig. 5, midway through the growing season a period of relatively lower rainfall usually occurs. If this period coincides with pollination, seed-set is affected and grain yield reduced. It is known (Glover, 1959) that once maize has been seriously struck by a period of water deficiency, the crop will never regain full growth even if normal water supply is restored.

Therefore, farmers were looking for crops which could be planted early with safety and which were able to withstand a midseason drought in order to reduce their cropping risks.

The erratic and unpredictable rainfall pattern is not only found in Kenya but is a common phenomenon throughout the drier tropics (ten Have, 1977).

The application risk relates to the farmers' capitalization and the financial returns that he needs to remain solvent. Planting crops specifically for silage making entails a far reaching commitment from the farmer. The

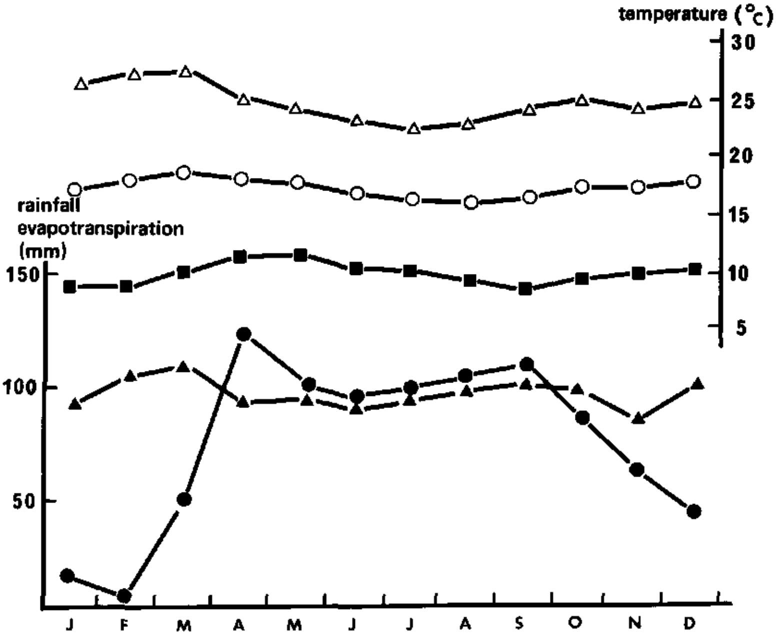


Fig. 5. Monthly averages for some climatic characteristics at the Lanet project site.

△——△ Maximum temperature
○——○ Mean temperature
■——■ Minimum temperature
▲——▲ Potential evapotranspiration
●——● Rainfall

time between planting and the day the farmer receives payment for the slaughtered cattle fed on his silage crop, takes around 18 months. During this time agricultural markets may change drastically. Farmers, therefore, strongly favour dual purpose crops. Here maize has a clear advantage over e.g. grasses. Up to the day of maize harvesting, farmers have the option not to harvest for forage but to let the crop ripen for grain harvesting. This dual purpose adds greatly to the appeal of maize for feedlot farmers, and any crop to replace maize without having this dual application will – on this count – be less attractive.

A further consideration was that if a crop were to replace maize, it should preferably be handled by harvesting and feeding machinery similar to that in present use. This was because feedlot farmers already had this machinery available and to require a new range of machinery for a crop would be to increase the capital requirements of the farm and thus the risk.

### *2.1.2 Crop conservation*

The uneven rainfall distribution with about seven wet and five dry months (Fig. 5), imposes a strong seasonality on crop production. Although beef fattening is a recognized ranching system (Ruthenberg, 1976) and animal live weight gains of 0.5 kg per day from grazing Rhodes grass (*Chloris gayana*) pastures during the wet season have been obtained with growing beef steers in Kenya at 2.5 animals per ha (Beef Research Station, annual reports), the almost total lack of grass growth during the dry season makes it impossible to build a highly productive, high-quality, non-seasonal beef production system around the grazing concept. Further, the amount of land – potentially – available for this type of animal production, 'the medium potential areas', constitutes only about 5.5% of the total land area (Paper I; Table 1).

The idea of green chop was rejected, partly, on the same grounds: lack of rainfall did not permit a year-round system of production. Secondly, the management of a feeding system whereby forage has to be harvested in the field every day was found to be complex.

Feeding from a stock pile next to the feedlot however has considerable organizational advantages. The most important ones perhaps being that the quality of stock pile forage can be determined before it is fed and that the quality remains fairly constant. In a feedlot animals of different breeds and ages require different rations. Feedlot management would be complicated if the quality of the ration ingredients were too variable thus requiring frequent ration reformulation. Simplicity is a key factor for the success of a modern highly productive agricultural enterprise. This is particularly so in a developing country, where the level of training and motivation of local personnel may leave something to be desired.

Hence it was considered necessary to conserve the forage and stock pile it prior to feeding.

There are two possibilities to economically conserve forage: hay making and silage making. The need for constant quality forage makes hay making a less attractive proposition. Every harvest produces hay of different quality, depending on age, fertilizer application and the development stage of the crop. In addition, the weather during the period of hay making has a very important effect on the quality of the hay.

### *2.1.3 Silage making*

The reason why silage making was the conservation technique in use by the project at the start of this study, was that the crop of choice, i.e. maize, is ideally suited to be turned into silage. In addition, machinery to make, mix and feed silage is efficient and easy to operate. Proper mixing of the various ration ingredients is important to ensure optimum animal performance. Incomplete mixing often leads to the fact that within a batch of cattle not all animals eat the same. Further, the use of urea as a protein supplement makes complete mixing essential, because an overdose of urea may have adverse effects. The finely chopped maize pieces, in a feeder-mixer wagon, are easy to mix with other ingredients.

The use of silage also facilitates the mixing of different batches of forage, thus producing a mixture of fairly constant quality silage. This is because chopped forage can be put into a trench silo, where one layer is piled upon another to a total height of about 4 m. So, forage from different fields, ages, cultivars and thus quality are piled on top of each other. The silage loader cuts a vertical slice about 1.5 m wide and 25 cm deep from top to bottom through this pile. By doing so a blend of average silage is obtained that does not change much as emptying the silo progresses.

Irrespective of which crop is to be ensiled, a silo must always be airtight to avoid spoilage. Trench silos must also be covered to keep out rainwater and prevent air from re-entering the stack. The size of the silos in use, about 5000 tonnes per pit, made excellent conservation possible. Partly because the percentage of forage in touch with the outsides was small in comparison with smaller silos; partly because the size permitted tractors to continuously drive on top of the forage, thus achieving excellent compaction and minimum air content. So, the size of the operation in Kenya provided first-class conditions for silage making with minimum conservation losses.

There are various aspects of silage making, that determine its success. It appears important to consider these aspects to be able to assess the suitability of each crop for silage making.

An adequate lowering of the pH by lactic acid bacteria within the stack of silage is essential for successful natural preservation. The lactic acid bacteria use soluble carbohydrates (s.c.) as their digestible substrate. Crops with a high content of s.c. therefore, ensile more readily than crops with a low s.c. content. Tropical grasses usually have a lower non-structural carbohydrate content than sorghum and maize in their above-ground parts. This is because sorghum and maize tend to store non-structural carbohydrates in above-ground plant parts, whereas grasses use their roots as the main storage place. Non-structural carbohydrates can consist of s.c. or of starch. However, lactic acid bacteria do not live on starch and consequently sorghum and maize crops harvested late do not necessarily ensile well, although maize and sorghum are known as easy-to-ensile crops.

The moisture content of a crop at harvest is important in that seepage will be produced if the moisture content is too high. The moisture percentage above which effluent will be produced depends on the size of the silage pit, but was assumed to be around 75% for the type of silos used in Kenya.

### *2.1.4 Forage quality*

*General* Ration formulation which is concerned with the selection of the appropriate energy concentration is as much an economic as an animal nutrition exercise: one weighs the cost of various ingredients against the expected trade off in animal performance. The correct protein, mineral and vitamin feeding levels, however, are so crucial, that the economic question hardly ever arises: they simply have to be at their correct level. Supplementary vitamins and minerals, if needed, can easily be added to the ration at a relatively low expense. They are, therefore, not considered important for the purpose of this thesis.

Voluntary dry matter (d.m.) intake of a forage is highly important because a small difference in d.m. intake may result in a substantial difference in live weight gain. Many factors inherent to a forage are known to have an effect on d.m. intake (Waldo, 1970). Digestibility, taste and morphological composition are frequently mentioned in the literature as important aspects. Laredo & Minson (1973) have shown that grass leaves have a much greater passage rate than stems, even when there is no difference in digestibility. As a rule, animals select for the leaves and as a result the voluntary intake of a forage may vary considerably with the amount of excess which is offered (Zemmelink, 1980). With silage made of chopped forages which are fed to cattle, the possibility of selection between leaves and stems is smaller. Therefore, the effect of level of excess feed is likely to be less important. Even so, the leaf/stem ratio of the forage may be an important factor determining intake.

However, at the start of this study many of the factors determining d.m. intake and their interactions were still so obscured by lack of precise data, that no detailed requirements for forage crops could be established. Hence it was considered only practical to obtain empirical evidence of the d.m. intake of new forages in actual feeding trials to be conducted with representative feeder cattle under commercial conditions.

Ward et al. (1966) and Richards (1975) demonstrated the positive correlation between d.m. % and d.m. intake of silages. Since d.m. % also depends on the harvesting method and the stage of maturity of the crop at harvest, crop differences in d.m. % between species were not considered a main factor at the initial stage of the programme.

*Energy value* The energy value of a ration is usually negatively correlated with the proportion of roughage in that ration. Consequently six different rations were devised, at the early start of the project, ranging from 84% maize silage (ration 1) to 16% maize silage (ration 6). The remainder was made up of grains, grain derivatives, molasses and cotton seed cake; in short: concentrates. It soon became clear that only rations 3, 4 and 5, containing 66, 50 and 33% maize silage respectively on a dry matter basis, were economically realistic feeding propositions.

Creek (1973) summarized the results of a number of feeding trials in which these three rations were fed to Zebu, Boran and crossbred cattle. The average daily live weight gain data of these trials (some of which are published in more detail by Redfern, 1973), involving a total of 7625 animals, is shown in Table 1.

Zebus (*Bos indicus*) are native African cattle and are predominantly kept in the 'low potential areas' (Table 1 of Paper I), where overgrazing is common.

'Boran' or, as they are sometimes referred to, 'improved Boran', is an East African breed of cattle derived from Zebus. Some eighty years ago,

Table 1. Average daily live weight gain during feedlot finishing of three types of cattle fed three rations (after Creek, 1973).

| | Ration 3 (67% silage, 33% concentrates) | Ration 4 (50% silage, 50% concentrates) | Ration 5 (33% silage, 67% concentrates) |
|---|---|---|---|
| Zebu *(Bos indicus)* | 993 | 1012 | 906 |
| Boran *(Bos indicus)* | 734 | 1044 | 915 |
| Large exotic X Boran *(Bos taurus X B. indicus)* | 855 | 1077 | 1200 |

These data are the averages obtained from several controlled experiments in which it was regularly found significantly ($P < 0.05$) that (1) there is an interaction between type of cattle and ration; (2) there is an effect of rations for the crossbred cattle.

early colonizing settlers started to establish 'elite' herds by selecting the fastest growing and heaviest animals from their Zebu stock. It is not entirely unlikely that some blood from European cattle breeds entered the Boran breed, but detailed records are not available. The result today is a breed of cattle with all the visual characteristics of the Zebu, but with an allegedly genetically superior potential for beef production. Borans are mainly kept on commercial ranches in the 'medium potential areas' (Table 1 of Paper I).

On these ranches it has become common practice to make crosses between the Boran and European cattle such as Friesian, Charolais and other *Bos taurus* breeds. The Boran X exotic is not usually maintained as a separate breed but used as F1 or F2s (with 25, 50 or 75% exotic blood).

As expected, the Large exotic X Boran crossbred cattle performed better when their ration contained less forage and more concentrates. But for the local pastoral Zebu cattle the reverse proved the case. The Zebu cattle were unable to respond positively to rations rich in concentrates and they outperformed the crossbred cattle when using rations rich in roughage, indicating their superior ability to make use of low-cost, high-forage rations. The improved Borans occupied an intermediate position with their best performance when fed on a 50% roughage, 50% concentrate ration. The reason for the comparative failure of the Zebu cattle on high energy rations and for their comparative superiority on high-forage rations is not exactly known but is possibly related to the following three factors:

1) the higher incidence of digestive disturbance on high-energy rations;

2) high-forage rations appeared more attractive than high-concentrate rations. The percentage of 'hunger strikers' was always higher on the latter than on the former;

3) the alleged ability of Zebu cattle to better digest fibrous feeds.

This was not the first time that it was found that *Bos indicus* under certain conditions can outperform *B. taurus*. Deinum (pers. comm.) in his Ph.D. thesis of 1966 stated, on the basis of an article by Howes et al. (1963), that due to a higher digestive capability of *B. indicus* as compared with *B. taurus* higher animal performances in the tropics can be expected. A possible explanation can be deduced from the study of Hofmann (1973) who classified African ruminant wild life species into concentrate feeders, roughage feeders and intermediate feeders. The number of papillae on the rumen wall was shown to be correlated with digestive capability. Whether Hofmann's classification can also be applied to domestic cattle has never been proven and is therefore purely hypothetical.

Nevertheless the important point is that, unlike the situation in e.g. Western Europe where feeding higher energy levels resulting from less roughage usually leads to better cattle finishing results, in Africa this depends on the type of cattle being fed. As a result of the above it was decided not to draw up rigid energy requirements for alternative forage crops, but to aim for maximum yields of digestible organic matter (d.o.m.) per hectare.

For grain-producing forages there was an additional problem in the measurement of the energy value. When a grain-producing crop is harvested for forage, the crop may be divided into the following morphological components: leaves, stems and grains. It is generally accepted that the grain has the highest energy value of the three. Hence the concept seemed to warrant that one should endeavour to harvest forage crops with a high grain content. This idea is witnessed by the common separation into 'poorly eared' and 'well eared' maize in feeding value tables (e.g. Anon., 1970). The positive correlation between grain content and energy value of the forage was also supported by a number of detailed experiments (Bratzler et al., 1965; Schmid et al., 1976).

By contrast, a number of reports have been published suggesting that grain content is poorly correlated with energy value. This conclusion is either based on animal feeding studies or on plant science trials. Owen (1967) reviewed the animal feeding work, whereas Bunting & Gunn (1973) reviewed the plant dissection and analysis work.

Deinum & Knoppers (1979) have offered a likely explanation for the contradictory findings by suggesting that the level of photosynthesis during the grain filling stage is the key factor in determining the effect of grain content on energy value. If photosynthesis during grain filling is reduced due to low light conditions, foliage diseases or drought, then dry matter translocation from leaves and stems to the grain becomes important and grain content is poorly correlated with the plants' energy value. But if photosynthesis is not too much limited during grain filling, grain content is positively correlated with energy value. There are differences between cultivars in this respect. It should also be realized that the range of the harvest index of maize in the Netherlands (45-55%) is narrow compared with the range of the harvest index of sorghum in Kenya (1-50%).

However, the important point was that at the onset of the Kenyan programme of work, the issue of grain content was still obscured by contradictory findings. Therefore, there was no quick method of ranking grain-producing forages in an order of energy feeding value.

Table 2. Crude protein requirements of beef cattle (percentage of total ration dry matter) (after Anon., 1970).

| Live animal weight | Daily live weight gain (kg) | | |
|---|---|---|---|
| | 0.75 | 1.00 | 1.25 |
| 300 | 11.1 | 11.1 | 11.1 |
| 400 | 8.9 | 10.0 | 11.1 |
| 500 | 8.5 | 9.5 | 11.1 |

This, together with the fact that Zebu and Boran cattle responded differently to varying energy levels in their ration as compared to crossbreds and European cattle breeds, led to the conclusion that actual animal feeding trials would be essential for the valuation of grain producing forages.

*Protein content* The crude protein (c.p.) content of maize forage (7.0% in the d.m.) is too low for the requirements of beef cattle during the finishing stage, which vary between 8.5 and 11.1% c.p. (Table 2). To formulate a ration that is balanced in protein, concentrates with a higher protein content need to be added to the maize forage. This did not present great difficulties during the early life of the project, when good-quality vegetable protein sources were readily available and – in relation to other feed ingredients – cheap.

However, as the project progressed, world prices for high protein cakes increased and local supplies reduced, largely as a result of the Peruvian anchovy shortage. Prices for local cotton seed cake rose six-fold within two years. The levels and sources of protein in the rations thus became increasingly important from an economic point of view, but non-protein nitrogen (n.p.n.) was successfully and increasingly introduced to provide the balance of crude protein. Subsequently, with increasing oil prices, n.p.n. costs also increased.

In the Kenyan highlands more than 50% of the total world production of pyrethrum flowers (*Chrysanthemum cinerariaefolium* (Trev.) Bocc.) is grown. These are locally processed into an insecticide which has a low toxicity for mammals. The dried and ground flower residue, called pyrethrum marc, was largely wasted at the time the project was conceived. But when it appeared that the pyrethrum marc contained about 13% c.p., feeding trials were undertaken to further evaluate it. These trials indicated (Redfern, 1973) that up to 50% of the maize forage could be replaced by pyrethrum marc, without any significant effect on animal performance. This allowed the use of concentrates with a lower c.p. content. However, total demand for the flower residue soon exceeded production and its availability to feedlot farmers became more erratic.

Thus, while the protein content of the forage is not of primary importance when compared to energy, a higher level than that in maize would come as a bonus and increase the flexibility of ration formulation.

### 2.1.5 Climate

The climatic conditions under which forage crops had to be grown were governed by two main factors: altitude and rainfall. Crops had to be adapted to high altitudes (>1500 m) because all feedlots were situated in this area. Early colonization of the 'White Highlands' had left the highlands supplied with a good infrastructure and the boundaries of the 'disease-free zone', more or less, coincided with the 1500 m contour line. The important effect of altitude on plant growth is through temperature, with in Kenya an average reduction on mean diurnal temperature of 6.5°C for every 1000 m increase in altitude. The Kenyan highlands lie mainly around the equator but the average temperatures at Nakuru (altitude 1860 m) (Fig. 5) compare well with the average July temperature in the Netherlands at 52°N.

Annual rainfall in the highlands varies with location from around 500 mm to some 2000 mm. Rainfall at the feedlot farms with maize as the chief forage crop varied from about 875 to 1200 mm annually. The immediate target areas for further feedlot expansion were therefore found in locations with 500-875 mm of rainfall.

The climatic classification of the defined areas is somewhat arbitrary, depending on the classification system chosen. The International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) uses the system proposed by Troll (1958), which calculates the number of months during which rainfall exceeds the potential evapotranspiration. If this is between 2 and 7 an area is considered semi-arid. With this classification most of the 500-875 mm rainfall highland areas, including Lanet (Fig. 6), fall in the semi-arid bracket. Troll's system, however, is perhaps less suitable for use in highland areas because it puts no special weight on temperature as a factor.

The Köppen & Geiger (1936) system, by contrast, takes both temperature and rainfall into account in a simple way. To decide whether a climate is dry or wet, the rainfall index (R) has to be worked out:

$$R = P / (T + C)$$

where P is total annual rainfall (cm), T the average annual temperature (°C) and C an adjustment value which may be set at 14 for Kenyan highland conditions. According to this index the 500-875 mm rainfall areas with average annual temperatures of 17-19°C are classified as either (1) steppe, (2) temperate – warm with a well defined dry season, or (3) tropical savanna.

A complication to correctly classify an area is formed by the different rainfall distributions, which can be separated into two main types: uni-modal and bi-modal. Generally, the uni-modal rainfall distribution is found west of the Rift Valley and the bi-modal distribution is the predominant pattern east of the Rift. The dividing line between the two distributions runs roughly north-south between longitude 36°E and 36°30'E (Fig. 6). In areas where rainfall is received in two distinctly separated seasons, the effective rainfall for crop production may be substantially lower than in areas with an uni-

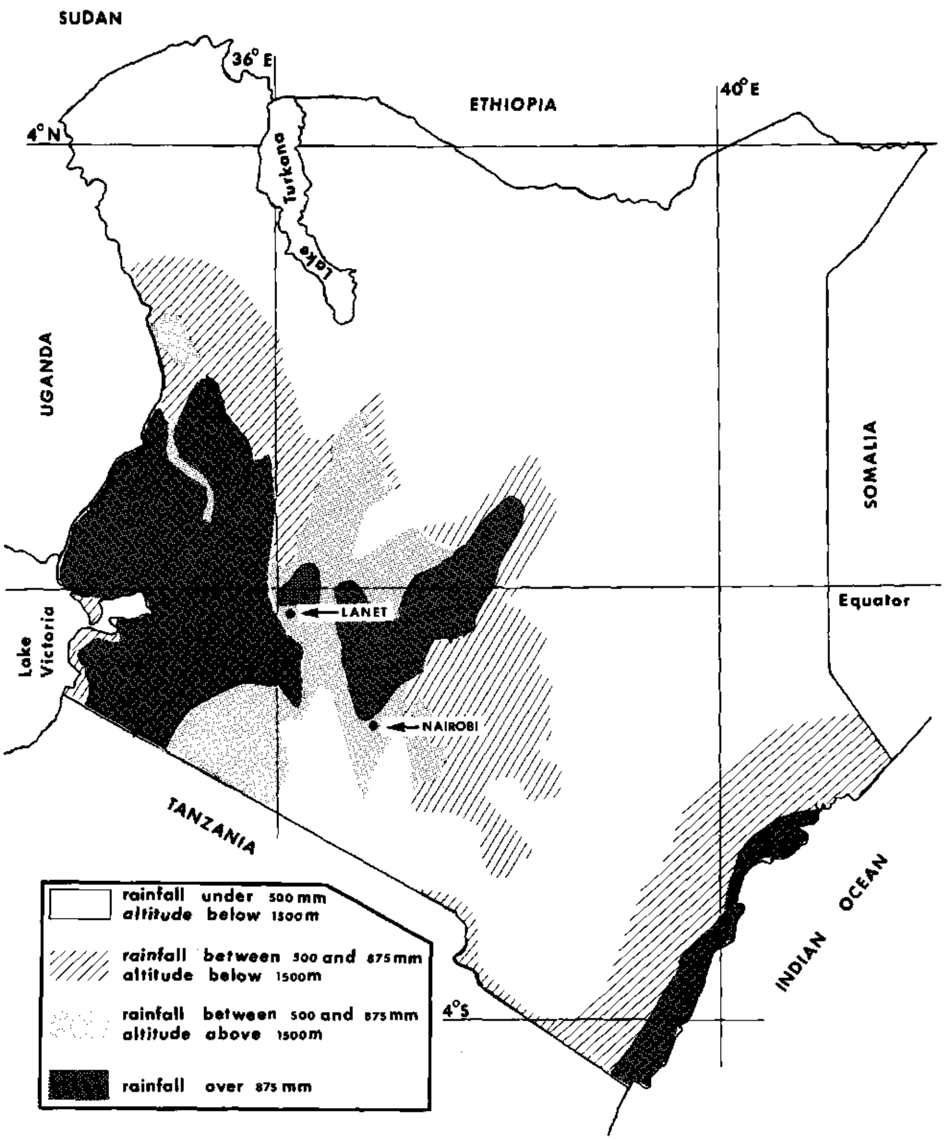


Fig. 6. Map of Kenya showing four different ecological environments based on annual rainfall and altitude.

modal distribution. If total annual rainfall is around 500 mm, only 250 or less may be received during a single cropping cycle.

## 2.2 Miscellaneous aspects

Development efforts in the field of agriculture in the Third World are normally subject to a number of specific (non-agro-technical) conditions, which are different from those in the developed world. It can be expected that these conditions reduce the speed with which project and research objectives are achieved. Nowadays these conditions and their effects on project achievement are well understood, which is witnessed by reports from academic sources (Burke, 1973; Franke & Jansen, 1975; Franke, 1978; Luning, 1978), from aid agency sources (FAO, 1975a) and others (Schumacher, 1973; Goulet, 1977; Galbraith, 1979).

The recognition of the fact that there are often constraints hampering progress in individual Third World countries, has led to the setting up of the large research institutes by the Consultative Group of International Agricultural Research (CGIAR). These international institutes, although located in Third World countries, are not subject to the constraints referred to above, and they are usually better equipped and organized than national research stations. Notwithstanding, national research stations are more dependable than local stations where everything may be erratic. It is therefore well accepted that local stations should not normally be employed for sophisticated research.

The FAO Beef Project was largely a cattle feeding research and pilot project, located at the Kenya Government Beef Research Station (BRS) at Lanet. It was, therefore, only poorly equipped to accommodate a scientific programme of work on plant introduction. Hence it would have been more desirable to have this programme for crop identification and introduction carried out at a larger national research station or international institute. However, this did not prove feasible and as a result the programme had to be conducted at the BRS.

It is not necessary to list all the specific Third World country conditions which may reduce project achievement. The references quoted above give a good cross section of what one might encounter. Notwithstanding, the programme of work discussed in this thesis was carried out under sub-optimal conditions and to enable a better understanding of why certain decisions were taken, the specific conditions that did affect this programme of work will be discussed.

### *2.2.1 Time limitations*

Almost invariably, scientific and other project work is carried out on a contract basis. Extension of contracts, if at all possible, is often tied to results obtained during the previous contract period. While not disagreeing that this time limitation can have a positive influence on achievement, it also puts a pressure on the development worker which may have less beneficial effects. Time limitation also leads to the danger of advising farmers on the basis of too little evaluation. This is particularly so if, after some further work, one has to withdraw earlier statements. Farmers cannot be expected to respond favourably to the whims of researchers and extension men.

Another danger lies in the psychological effect of early commitment. It is a human characteristic to restrain from admitting defeat. Anticipating on research results, therefore, may lead to the tendency to carry on along lines chosen in an earlier stage, even if later results point to a different direction. The experimenter has to be well aware of this danger if he is to resist it.

The terms of reference of the study assignment on which this thesis is based specified that the duration of the study was not to exceed four years with little likelihood of further extension. Results had to be ready for practical use by feedlot farmers within this period. These conditions made it necessary to adopt a practical and direct approach in the study and to avoid, as much as possible, time-consuming research of a more fundamental nature.

The time limitation therefore made it necessary to pre-empt certain issues, to anticipate on experimental results or to take 'an educated guess'. In the first year of the assignment, for instance, already a large proportion of attention was given to detailed crop studies with cold-tolerant (c.t.) sorghum and sunflower cultivars while there was no definite proof at all that either might be a useful crop. Seed multiplication was also started almost immediately.

In 1973, the first plots with c.t. sorghum were sown in Kenya and already in 1976 sufficient experience and research data were available to produce and to circulate to interested growers an extension paper 'Guidelines for success with sorghums' (van Arkel, 1976). In 1977 the total area cultivated to c.t. sorghums on commercial farms was estimated at some 1500 ha.

Anticipation also led to wasted effort in this programme. Detailed plant population, fertilizer and sequential harvesting trials were conducted up to the point of final analysis, when it appeared that the plant material with which the trials were conducted was useless for commercial application. Hundreds of kilogrammes of seed from multiplication plots were eventually fed to livestock because the cultivars later appeared not to stand up to requirements.

### *2.2.2 Integration*

Development work on a section of a production chain of which the other sections are not equally well developed is probably one of the most common reasons for an inadequate effect of the development activity on agricultural production. Nevertheless, such spot development activities are still normal practice and there are two main reasons why they continue: (1) financing the development of the whole production chain is more expensive and aid donors, in general, prefer a wide development distribution pattern above a narrow one; (2) recipient countries prefer a wide spread of foreign aid. This is often the result of 'tugs of war' between different ministries or departments.

To evaluate these reasons is beyond the scope of this paper, but it is important to realize that, against technical judgement, there are – mainly political – forces at work favouring spot development. In the planning and execution of development projects, the development worker should try to recognize the weakness in the whole production chain and, if possible, adjust his course of action accordingly.

The production chain of which the forage crop research was a part looks as follows:

1. Calf production in range areas
2. Marketing range to ranch
3. Backgrounding on ranches
4. Veterinarian control
5. Marketing ranch to feedlot
6. Economic availability of concentrate feeds
7. Forage crop research
8. Extension of crop research to feedlot farmers
9. Feedlot management
10. Marketing feedlot to abattoir
11. Abattoir management
12. Meat marketing and pricing.

This list of activities could be extended substantially if more attention to detail were to be paid, e.g. availability of skilled labour such as tractor drivers or availability of seed production companies.

It is difficult for a development worker to influence any of the above 12 main meat production chain activities. Notwithstanding, if one of the above 12 links malfunctions there will be no absorption for the results of the forage programme, except perhaps in other sectors of agriculture; and this in fact also happened in the case of this programme.

At the time the Kenyan programme was devised, there seemed little reason for fear that the beef production chain and the feedlot sector would not continue to thrive. But it is perhaps common that expatriate development aid staff take a more optimistic view at the start of their assignments than is warranted by subsequent events. Farmers are usually more cautious. The possibility of a less prosperous beef industry remained an active reality in their minds and guided their decision taking. No feedlot farmer, at any stage of the programme, looked favourably upon the prospect of planting Napier grass as a forage. They preferred dual purpose crops as detailed in the section on 'Farmers' requirements'.

It was exactly for this reason, i.e. to avoid being placed in development isolation because of a poorly integrated beef industry, that the programme placed its major emphasis on cereal crops.

### *2.2.3 Agricultural extension*

In most developing countries, the organization of agricultural research is strictly separated from agricultural extension services.

Kenya has a large extension service, and each of the Divisions of the Ministry of Agriculture has provincial and district representations; so there are provincial and district crop production extension officers. It is not the intention to fully evaluate the extension services here, but it is obvious to the casual observer that good extension officers are trying very hard within their possibilities. Nevertheless, the constraints are manifold, causing frustration, and the morale in the extension service is generally quite low. The problem is widely recognized and reported (Heyer et al., 1971, 1976; Leonard, 1974). Among the reasons mentioned for the poor functioning of the extension services are inadequate links between research and extension, a severe lack of transport, excessive administrative duties and committee work and a lack of interest and discipline.

A less effective extension service is by no means unique to Kenya but found in many developing countries. An inadequate extension to farmers appeared as one of the key issues in the 'Draft Declaration of Principles and Programme of Action' prepared by FAO for the World Conference on Agrarian Reform and Rural Development of July 1979.

The important point to be taken from the above observations for this programme is that more than just research had to be done to see recommendations put into practice. In this programme this was achieved by:

1. Writing extension papers
2. Organizing field days for visitors and prospective farmers
3. Planting demonstration fields
4. Laying down experiments on commercial farms. These included some feedlot farms, but also other farms, both large and small, were used.

Activities 1 to 3 could not be carried out before there was anything of interest to be shown. It is also considered important not to start with farmers' trials (activity 4) before the number of interesting crops or methods is sufficiently narrowed down. Farmers usually have little experience with and appreciation of research. A trial with many treatments cannot be expected to be well understood, even if one of those treatments gives twice the yield of the control. A smaller number of treatments is to be preferred.

### *2.2.4 Availability of facilities*

The majority of research stations lack some basic facilities. Basic supplies and spare parts one would like to be available within commuting distance of the station may be available only with great difficulty, if at all. The normal financial structure of cooperative projects, where the national government is made responsible for repair and maintenance of equipment purchased by the aid donor, is no guarantee for the smooth running of a project.

The following may illustrate the effects this had on the execution of this programme.

– A drying oven was not available at the start of the programme and could not be purchased in time. Hence, one with a limited capacity was constructed locally.

– No assistance for the biostatistical analyses of trial data could be obtained, although a large computer installation (without relevant programmes) was available in Nairobi. I had to learn FORTRAN and make programmes for multiple regression, least signification difference, analysis of variance, students t-test, etc. But this took time and slowed down the speed of data analysis.

– Possibilities for laboratory analysis were not available until the beginning of the third year, when the project started proximate analysis. The in-vitro plant digestibility analyses, which were highly desirable for the programme of work, could only be carried out three years after the programme had started when additional, external, funds had become available.

However, these examples may be specific and refer to somewhat sophisticated facilities, but these were by no means the only facilities that were limited in availability during the course of the programme. Petrol, fertilizers and pesticides have all been lacking during some critical stage. Obviously, this has had an adverse effect on the usefulness of certain experiments and some had to be discarded. The important point, therefore, was to keep the planning of experiments down to the most basic elements. It could not be attempted to try anything special, unless the required facilities were clearly in hand.

### *2.2.5 Variability of material*

A research station in a developing country often has to cover a geographically large area, and this usually means that results must be applicable to a wide range of environmental conditions. In an experimental programme test sites should cover a similar wide range of variability. If such trials are conducted, trial supervision is often inadequate, which does not assist uniformity of trial conduct. Distances can be large, which makes delegation of trial control necessary. Trials laid down at other research stations will compete with the stations' own research programmes for farm inputs, labour and control. The alternative is to use farmers' fields, but farmers, however willing to cooperate, have usually little appreciation of the specific requirements of experiments. These effects all result in uneven trial conduct, which leads to a large coefficient of variation.

Trial fields for crop experiments seldom have a well documented description of the soils on which they are laid down. Consequently, variability within an experiment can be large and the coefficient of variation is often high.

This means that it is often difficult to establish biostatistically significant differences of experimental treatments, except when averages of treatments differ by a great margin.

The implication of all these factors contributing to variability is that (1) treatments, sites and materials have to be selected very carefully; (2) the number of treatments should be kept to a minimum; (3) the number of replicants, or more correctly the number of degrees of freedom in the experimental error component, must be as high as feasible.

Similarly, work with cattle, particularly with native Zebus, also often has to deal with – by standards of developed countries – enormous variabilities, and the same three precautions must be taken to reduce the coefficient of variation. For example, the cattle feeding trial evaluating the feeding value of two cold-tolerant sorghum cultivars and maize was conducted with 540 feeder steers. Where, under more controlled conditions, such forage evaluation experiments might be possible with only tens of animals, the great variability of range steers demanded the use of this relatively large number.

In statistically designed experiments, the establishment of a significant difference between treatments depends mainly on two factors: the difference in average value per treatment and the experimental variability. If variability is larger, the difference between treatments must be bigger too, if they are to be statistically significant. If the above paragraphs have argued that in developing countries experimental variability is often larger than in developed countries, the conclusion must be that in developing countries it is more difficult to find statistically significant differences.

However, there does not appear to be any reason why the Cobb-Douglas production function, showing diminishing returns from increased inputs, should not also apply to agricultural research. So, in countries with a long history of intensive agricultural research, production increases are usually only a few per cent per case. But in countries with less previous research efforts, far greater leaps are possible and often obtained. The introduction of maize hybrids (Harrison, 1970), the time of planting trials with maize (Allan, 1972), the crop husbandry research programme to increase seed yield of Rhodes grass (Boonman, 1973) are all Kenyan examples of production increases between 40 and 100%.

So, the fact that relatively large differences are necessary to prove the biostatistical superiority of the higher-yielding treatment, is not always a disadvantage. It means that there is a biostatistical reason for avoiding to accept 'improvements' that give only small yield increases over present farming practices.

### *2.2.6 Appropriate technology*

It is an acknowledged fact that modern technology, on its own, is usually not suitable for application in developing countries. Numerous articles and reports, criticizing the transfer of sophisticated technology to developing countries, have been published e.g. by Schumacher (1974) and by Goulet (1977).

There are also examples of inappropriate technology in the field of plant introduction. For instance, what is the point of trying to prove that hybrids can outyield non-hybrids in countries without a seed-producing industry or adequate distribution system? It is exactly on this point of appropriate technology that the 'green revolution' has received so much criticism. It is claimed that the new cultivars of the green revolution are only able to bring out their full extra yield potential if correct weed control is exercised and fertilizer dressings are adequate. However, such pre-requisites are difficult to meet for a large proportion of the target group of farmers and the potential yield increase is, therefore, not realized. Hence it may be advisable to design a programme of work of which the results are immediately applicable by the agricultural community for which the programme is intended.

The reason that this subject is discussed here is that both the FAO project concept and the forage harvesting methods used in the programme of this study are examples of cases where Western technology, although sophisticated, is not inappropriate. The immediate target group of farmers were well advanced, they had shown that they were able to respond to technical innovations and had access to financial resources. They all had large farms (>100 ha) and were few in number (14 feedlots). This made direct contact between researcher and farmer possible. So, although silage or hay making equipment is also an example of Western technology, it is not considered inappropriate for use by Kenyan feedlots.

# 3 Experimental

## 3.1 Methodology

The actual methods employed for individual trials or experiments are described in the Papers I to V and others in which the experimental results were published. All these trials and experiments were part of an overall systematic programme methodology. This methodology had two aspects. The first one was based on considerations of how and where to plan actual experiments and when to rely on information from elsewhere and how to plan the dissemination of results. This is called here 'Programme approach'. The second aspect was based on the distribution of the experiments over the years and how the planning for further experiments developed with time. This aspect is discussed in more detail in the chapter on 'Phasing' below.

## 3.2 Programme approach

The elements of the programme are shown in Fig. 7. In broad terms, the problem had been identified before I was recruited and this initial identification is given in Section 1. The more detailed picture of the problem transpires from Section 2, in which the problem was further specified.

After the problem identification and specification an investigation of what was known elsewhere in Kenya or Eastern Africa on the subject was carried out. This was supplemented with a study of world literature. With the aid of literature searches and the knowledge from local and regional research stations the designs were prepared for both the initial field trials and the laboratory analyses for plant composition, nutritive value and ensilability of the crops grown. The laboratory analyses and the results of field trials formed the basis for selection of the crops to be grown on a pilot scale. This in turn made possible the production of sufficient forage for carrying out a commercial-scale animal feeding trial. The results of this together with the results of the field trials provided the elements for demonstration and extension to farmers.

Some of the field trials indeed had a double function:

- they provided technical information to the experimenter;
- they provided an immediate demonstration field and extension tool, because they were laid down on farms.

Although each activity imposed a limitation on the speed of progress from 'Problem identification' to 'Cultivation by farmers', for two activities this was most acutely felt: 'Laboratory analyses' and 'Animal feeding trials'.

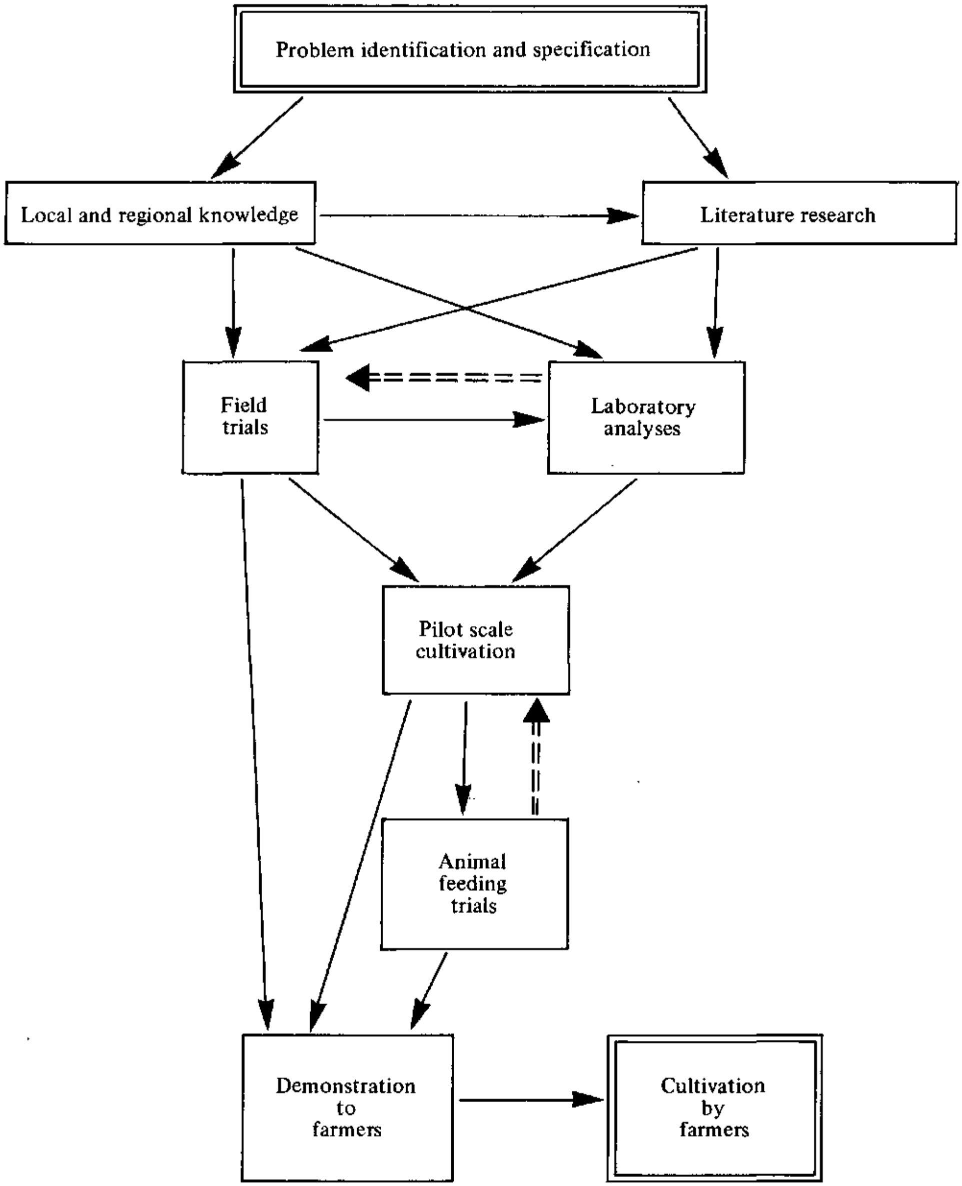


Fig. 7. Activities and their interdependencies of the case study (◀ ==== bottlenecks limiting number of entries and treatments).

The practical implication of this was that the available capacity for laboratory analyses determined the number of field trials that could be analyzed. The capacity for animal feeding trials had a similarly restricting effect on the number of crops that could be grown on a pilot scale.

## 3.3 Objectives of the programme

It was thought convenient to split the main objective (i.e. the identification and introduction of a suitable forage crop other than maize) into five sub-objectives as follows.

### *3.3.1 Identification of potentially suitable crops*

Having listed all the requirements for suitable crops in previous sections, it may seem as if the choice of alternatives to maize was very limited. Indeed, there appeared to be a good case for arguing the need to more lodging-resistant and drought-tolerant maize cultivars, but within the life of the project this could not be realized.

Thus the crops selected for the first identification trials (Paper I) were the result of a compromise and all left something to be desired if compared with maize. Pasture grasses do not allow forage of constant quality to be made. Forage grasses contain too much moisture to be ensiled easily in the absence of high levels of management and their forage quality is usually low. Sorghums do not grow well at high-altitude areas and all previous experience with their cultivation above 1500 m was unfavourable. Highland sorghum was a new source of germplasm and no knowledge regarding its yield, cultivation, multiplication or forage quality was available. Results with sunflower for forage and silage as indicated in the literature were highly variable. Equally, bulrush millet was a 'shot in the dark'. Hence, it became the first objective of the programme to screen entries in respect of their dry matter yield potential in comparison with maize (Paper I).

### *3.3.2 Forage quality determination*

Data for total dry matter yield provide insufficient information, unless the forage quality is known. So, attention to forage quality had to be paid during the early stages of the programme and three methods of forage quality determination were applied, each subsequent method being a refinement of the previous one.

To start with, published data on forage quality were taken to guide the selection of crop entries in the first observation trials and also to assist establishing the best harvesting time. These forage quality data were supplemented with laboratory analyses (i.e. the second method) of crops that were actually grown as part of the programme. With the third method the forage quality of the most promising crops was tested in actual feeding trials, when the forage, in the form of silage, was to be fed to livestock.

### *3.3.3 Crop husbandry*

The objective of establishing correct crop husbandry techniques for selected crops did not stand entirely on its own as there was expected to be an interaction with the establishing of forage quality: detailed forage quality should only be determined on crops that were managed correctly, hence the need for crop husbandry trials. But it can also be argued that detailed crop husbandry trials are only worth conducting with crops of sufficiently high-forage quality. It was also thought possible that crop husbandry may have an effect on the forage quality. Thus most crop husbandry trials were also subjected to forage quality analyses.

The outcome of the crop identification exercise being unknown the objective of establishing correct crop husbandry techniques could, initially, not be very specific with regard to species. Because, if no acceptable alternative to maize could be found, obviously all efforts had to be directed towards improving present cultivation methods of maize. If an alternative crop could be found, however, the main aspect would be to optimize the cultivation methods of that particular crop. In both cases, crop husbandry had to be studied and planning attention was paid to (1) soil moisture conservation; (2) weed control; (3) time of planting; (4) plant population; (5) fertilizer application.

### *3.3.4 Interaction with the environment*

The overall objective of the programme was to identify suitable forages for cultivation in the drier parts of the highlands. The study of the interaction with the environment was devised to qualify this aspect. In other words: what is the relation between rainfall, temperature and altitude on one side and crop yield on the other? To enable this objective to be achieved crop nurseries were planted under as wide a range of environmental conditions as possible.

### *3.3.5 Demonstration and extension*

Unlike the situation in most plant research programmes, it was understood from the onset of the assignment that results, where positive, had to be extended to farmers. The scientific isolation in which many research programmes operate had to be opened and the stated ultimate objective of the programme was the adoption of recommendations by the farming community.

## 3.4 Phasing

The strict limitation of the available time made careful programme planning imperative. In conformity with the rainy season, which roughly runs from March to October (Fig. 5, the programme was planned in four phases, each of one year from 1974 to 1977.

During the preliminary phase from recruitment in September 1973 to March 1974, attention was paid to further specifying the identified problem (Section 2), studying the available local information, surveying literature sources and to planning and discussing the experiments for 1974. Cooperative

*Results* The results of the screening nurseries (Paper I) indicated that h.a. sorghums figured prominently among the other groups of crops, particularly if compared with lowland sorghums (Fig. 8). Sunflower yields varied widely, the yields being closely correlated with tallness (Fig. 9). Maize also appeared amongst the highest yielding entries, but lodging was a common problem (Fig. 10). Other entries produced less interesting yields, with perhaps the exception of Napier grass.

*Review* The most important conclusions to be drawn from the field nurseries of year 1 (Paper I), which affected the direction of future field work, were the following.

1. Maize is not necessarily the highest-yielding forage crop for the defined ecological area. This was thought to warrant further detailed study of other crops, of which the group of h.a. sorghums, in contrast to the common lowland sorghums, seemed most promising.
2. The maize yields in these experiments, however, were considerably above commercially recorded yields. Lodging and its associated harvesting losses,

Fig. 9. A crop of sunflower 'Kenya White'.

Fig. 10. Kenya maize hybrids can grow tall and it is likely that the lodging susceptibility will be reduced if shorter cultivars are developed.

therefore, became an area of interest, which had barely been covered elsewhere.

### *3.4.2 Second year (1975)*

To ensure seed availability for pilot cultivation in an early stage of the programme, the dry season of 1974/1975 (i.e. the period between year 1 and year 2) was used to bulk up seed of six h.a. sorghum cultivars; and several hundreds of kilogrammes were produced before the start of the 1975 rainy season.

*Planning* Among blocks of sunflower and maize, five blocks of about 5 ha each were planned to be sown to five different h.a. sorghum cultivars at the start of the 1975 growing season, using the preliminary information of the 1974 husbandry trials to guide cultivation methods. These crops were sown to gain practical experience with the planting, husbandry and harvesting under commercial conditions and to make silage. The small-scale experimental programme for 1975 was planned as follows.

these experiments unfortunately were not well adapted to Kenyan conditions and their use on a commercial scale could not be recommended.

In using Kenyan maize cultivars the presence of a heavy crop, whether resulting from a productive soil and/or high rainfall, seemed the prime cause of lodging. Yields in excess of 10 to 15 t/ha dry matter led to lodging and harvesting losses. But the forage sorghum 'E 6518' did not suffer from lodging to any appreciable degree when yields were above this level (Fig. 12).

*Review* At the end of 1975 results and programme progress was reviewed and the following points were considered important.
1. The favourable dry matter yields of some of the h.a. sorghum cultivars if compared with maize made an analysis of the nutritive and feeding value of the sorghums more desirable and a strong effort was made to obtain these analyses.
2. The forage type 'E 6518' and the grain type 'E 1291', the two highest-yielding sorghum cultivars, were indigenous collections selected out of a total of only 85 high-altitude collections tested. It was considered likely that:
a) there would become more, perhaps higher-yielding, material available if a fuller search for collections to high-altitude conditions was made, and
b) breeding would produce material of superior genetical potential.
3. A limited approach to farmers, to demonstrate the possible potential of the h.a. sorghums, was considered justified.
4. The response of h.a. sorghums to time of planting and possibilites of obtaining ratoon yields emerged as questions.

### *3.4.3 Third year (1976)*

*Planning* In conformity with the above considerations and with the external programme review of 1975 ('t Hart, 1975), field experiments were planned as follows.
– The regional nurseries were further reduced in size to four entries, two maize cultivars and two h.a. sorghum cultivars, but their number was increased up to 21. Most nurseries were laid down in farmers' fields, to act as demonstration plots. This was in contrast with previous years when nurseries were confined mainly to research stations.
– Time of planting trials and ratoon yield trials with the grain type and the forage type sorghum.
– To extend the search for more productive h.a. sorghum cultivars the following four nurseries were prepared for planting: (1) 210 entries from the world collection originating from areas above 1200 m; (2) 195 entries selected from the sorghum programme in the Ethiopian highlands; (3) 21 experimental hybrids, all of which had 'E 1291' as the female parent; (4) 30 entries (F4 to F6) from the cold-tolerant sorghum programme based at CIMMYT, Mexico.

During 1976 the programme obtained access to laboratory analyses for nutritive value and a selection of dried samples to be tested was made. *

*Results* The laboratory analyses for nutritive value enabled a fuller evaluation of the effects of weed control and fertilizer placement on h.a. sorghums and the results were published (van Arkel, 1979; Paper III).

The laboratory analyses also allowed the completion of the study of the effects of plant population, nitrogen and age on the nutritive value of sunflower (van Arkel, 1978a). It proved that sunflower was not a viable proposition as an alternative to maize under most conditions in Kenya.

The results of the ratoon yield trials were considered conclusive and were summarized (van Arkel, 1978b).

For the time of planting trials, the results were less straight forward and a further year of experimentation proved necessary.

None of 405 newly tried h.a. sorghums produced a yield even near the yields of 'E 6518' and 'E 1291'. Although the trial was only laid down at one location, yields were so much lower that further testing did not seem warranted.

The 21 hybrids all produced vigorously growing plants, which showed promise, but this was negated when it appeared that all were male-sterile. This was probably because all 21 male parents were non-restorer lines. The conclusion was therefore drawn that the hybrids used thus far were of no use but that hybridization could become more important in the future, if suitable restorer lines could be found.

Some of the introductions from CIMMYT, although still strongly segregating, proved well adapted to the Kenyan conditions. They were all short and their dry matter yields were not interesting, but some grain yields were good and the number of days to maturity were lower than from any h.a. sorghum tried thus far.

The feeding trial with a sequential slaughtering design and feeding silages from forage sorghum, grain sorghum and maize to 540 animals was analyzed and published (van Arkel et al., 1977).

The regional nurseries, together with the demonstration fields planted at the project site, triggered an expansion of commercial interest. Therefore, a simple cultivation handbook was compiled and distributed to those interested (van Arkel, 1976).

*Review* A factor that had to be taken into account at this stage was the fact that political support for the beef industry in Kenya had increasingly diminished since 1973. Without going into detail it is probably safe to state that, against economical and technical judgements, governmental price structures

* A laboratory for proximate analysis was set up by the FAO project. The Department of Field Crops and Grassland Husbandry of the Agricultural University of Wageningen agreed to assist in the analysis of 1500 samples for cell wall digestibility. The latter was financed by the Netherlands Ministry of Development Cooperation.

# 4 Evaluation of results

In this section will be discussed: (1) whether or not the feedlot farmer should make use of the new crops made available to him; (2) if and where there are other applications for the new forage crops; (3) whether there are possibilities for applying those findings of the programme which were not the result of the original objectives (i.e. grain yield).

The research questions of the study on which the programme was unable to provide sufficiently satisfying answers and which may require further attention are discussed in Section 5.

## 4.1. Forage yield

### *4.1.1 Feedlots*

The programme of work has fulfilled its objective: it has identified and introduced a (new) forage crop other than maize, that appeared acceptable and useful to farmers under certain conditions. The introduction

Table 3. Crop production (CP), silage yield (SY) in tonnes and silage cost price in K.Shs. per tonne crops at three ecologically different areas.

| Crop | Relative environmental index | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | -56 | | | +13 | | | +78 | | |
| | CP[1] | SY[2] | price[3] | CP[1] | SY[2] | price[3] | CP[1] | SY[2] | price[3] |
| Forage sorghum | 6.2[a] | 5.5 | 580 | 16.0[a] | 14.0 | 303 | 25.0[a] | 22.5 | 243 |
| Grain sorghum | 6.0[ab] | 5.3 | 603 | 11.5[b] | 10.4 | 370 | 16.5[b] | 14.7 | 303 |
| Maize | 5.2[b] | 5.0 | 723 | 15.0[a] | 10.8 | 390 | 25.2[a] | 13.6 | 360 |

[1] Crop production data with the same superscript within the same column do not differ significantly at $P \leqslant 0.05$.

[2] Silage yield = crop production minus harvesting losses minus 10% dry matter losses assumed during ensiling. Where crop production data did not differ significantly, the average of the two crops that were not different is taken as the yield of both crops.

[3] 1.00 US \$ = 7.14 K.Shs. (1973); cost price calculations based on FAO (1970) and unpublished calculations by Squire (pers. comm., 1977).

of cold-tolerant sorghum has given the feedlot farmer in the highlands of Kenya a possibility of planting a forage crop other than maize. Whether he sould plant a grain type or forage type sorghum instead of maize depends on a variety of factors among which risk evasion, expected nett crop yield and expected animal performance appear most important.

The expected dry matter crop production of the three crops can be compared at various values of the 'relative environmental index' (r.e.i.) as shown in Fig. 2 of Paper V. These yield data can then be adjusted for harvesting losses on the basis of Paper II. Subsequently the cost price of the silages can be worked out. Table 3 shows the expected crop production, nett silage yield and silage cost price for three different values of the r.e.i. It can be seen that the cost price of forage sorghum silage is appreciably lower than of the other two crops which is due to its higher yield, its lower cost of establishment and to its lower cost of harvesting (greater speed of operating coupled with lower wear and tear on machinery).

The in-vitro digestibility values (D-value) estimated by the Tilley & Terry method were 41, 47 and 60 for the forage sorghum, the grain sorghum and maize respectively. This gives an indication of the expected animal performance but also allows to transform the silage yield data from Table 3 and compare the crops in terms of digestible silage dry matter yields. The yield advantage of the sorghums then largely disappears and only the forage sorghum, grown under the ecologically favourable conditions of r.e.i. = +78, at 9.2 tonnes/ha outyields the maize by 1.1 tonne/ha. However, the results of the feeding trial with Zebu and crossbred cattle (Tables 4 and 5) allow a more meaningful crop comparison.

It appears from these tables that within each breed, carcasses were approximately of the same weight. The exception was the carcasses of the crossbred cattle fed on forage sorghum silage which were significantly heavier than those fed on maize silage. This was because the latter had a higher fat percentage.

With both breeds of cattle it is evident that the grain sorghum silage had a similar performance to the maize silage, but that the forage sorghum silage was poorer. The difference was less pronounced with Zebu cattle than with crossbreds, which is consistent with previous findings that Zebus outperform crossbreds on low-energy rations (Table 1). The animals fed on forage sorghum silage had a higher daily dry matter intake than the animals fed on maize silage in all comparisons ($P \leqslant 0.05$) and in two of the three comparisons a higher total feed consumption and longer feeding period. The longer feeding period and/or the additional feed required to achieve the same carcass with forage sorghum will adversely affect feedlot turnover, increase the non-feed costs per head and increase the costs for concentrate feeds.

The results of the feeding trials have cast some doubt on the in-vitro D-values of the sorghums. A D-value of 41 comes close to the maintenance level for ruminants and does not leave much energy for animal production. It is therefore advisable to re-establish the D-values of sorghum silage in future experiments.

Table 6. Number of beef steers that can be finished in a feedlot from 1.0 ha of forage crops.[1]

| | Relative environmental index | | | | | |
|---|---|---|---|---|---|---|
| | -56 | | +13 | | +78 | |
| | R3[2] | R4[3] | R3 | R4 | R3 | R4 |
| *Zebu* | | | | | | |
| Forage sorghum | 11.1 | 16.9 | 28.2 | 43.0 | 45.3 | 69.1 |
| Grain sorghum | 12.0 | 18.0 | 24.0 | 35.3 | 33.9 | 49.8 |
| Maize | 12.7 | 16.9 | 27.5 | 36.6 | 34.6 | 46.1 |
| *Crossbred* | | | | | | |
| Forage sorghum | --- | 8.0 | --- | 20.4 | --- | 32.8 |
| Grain Sorghum | --- | 9.7 | --- | 19.1 | --- | 27.0 |
| Maize | --- | 9.2 | --- | 19.8 | --- | 24.9 |

1 Data computed by dividing nett silage yields (Table 3) over feed dry matter intake per steer (Tables 4 and 5), whereby intake figures which did not differ significantly were averaged. For convenience it is assumed that forage quality (and cattle performance) is not affected by the r.e.i.

2 R3 = ration 3, containing 67% silage in the dry matter.

3 R4 = ration 4, containing 50% silage in the dry matter.

Table 7. Total carcass gain of all the animals that can be finished in a feedlot using the silage obtained from 1.0 ha of each of the three forages grown in three different environments (tonnes/ha).

| | Relative environmental index | | | | | |
|---|---|---|---|---|---|---|
| | -56 | | +13 | | +78 | |
| | R3 | R4 | R3 | R4 | R3 | R4 |
| *Zebu* | | | | | | |
| Forage sorghum | 0.42 | 0.63 | 1.06 | 1.61 | 1.70 | 2.59 |
| Grain sorghum | 0.45 | 0.67 | 0.90 | 1.32 | 1.27 | 1.87 |
| Maize | 0.48 | 0.63 | 1.03 | 1.37 | 1.30 | 1.73 |
| *Crossbred* | | | | | | |
| Forage sorghum | --- | 0.64 | --- | 1.64 | --- | 2.64 |
| Grain sorghum | --- | 0.76 | --- | 1.50 | --- | 2.13 |
| Maize | --- | 0.71 | --- | 1.52 | --- | 1.92 |

ming techniques, which would lead us beyond the scope of this thesis. However, in the course of advising farmers a large number of different situations were worked out and there appeared to be situations for all three crops to become the forage of choice.

Thus the conclusion must be that the balance of advantages between the three crops is fine. The choice of the appropriate forage crop for any particular situation will depend on the yardstick used for measuring the relative benefits. If national beef production is the yardstick, the forage sorghum clearly scores highest if environmental conditions are above average. At r.e.i. = +78, with a ration 4, the forage sorghum outproduces maize by 50% (Table 7). If feedlot profitability is the yardstick, there are possibilities for all three crops depending on the farming situation. In anticipation of rapidly changing situations, all feedlots by 1977 had included one or both sorghums, besides maize, in their cropping programme.

The feedlot profitability calculations referred to above also revealed that under environmentally unfavourable conditions crop yields were low and hence feedlot profits became negative, irrespective of crop choice. Thus, although the programme of work was originally set up to identify a more drought resistant forage to enable feedlot expansion into the drier areas this expansion never took place. Further feedlot expansion was also precluded by a changed governmental price policy for the beef industry which reduced feedlot profitability in general.

### *4.1.2 Other farms*

The small-holder mixed farms in Kenya (average 2.7 ha subsistence farming) have, in general, no tradition of planting annual forage crops. Although the possibility of ensiling whole maize plants was successfully demonstrated already in the middle thirties in Kenya, the technique never gained a commercial application on any scale. It is therefore not surprising that sorghums for forage did not present any particular appeal to the small holder.

The residue yield of sorghums harvested for grain, however, appeared attractive to the farmer, because the acceptability of sorghum stover exceeded that of maize stover, if offered to Zebu cattle. The ability of sorghum to produce a ratoon crop (van Arkel, 1978b) should form an attractive characteristic to the small holder.

By contrast, a definite interest for forage sorghums developed from some of the larger dairy farms and cattle ranches during the course of the programme. This interest was often triggered by the conduct of testing nurseries on the farms. A limiting factor for the adoption of these forage crops by this sector of agriculture was the absence of forage harvesters on these farms. It confirmed our thinking (Section 2.1.1) that hardly any farmer in this group was prepared to buy a new forage harvester. As time progressed, second-hand harvesters became available from feedlots and these often found their way to farmers in this category. However, harvesting was also carried out on a and appeared to have yielded 6.1 tonnes/ha of cleaned and dried grain. Its grain yielding potential - under commercial conditions - was reconfirmed when in 1976, which was a dry year with only 561 mm of rain, the average yield of a 5.0 ha field was recorded at 6.0 tonnes/ha. Since then several farmers have planted the grain type sorghum for grain to be fed as a concentrate feed to cattle.

The above yields were considered high for the area. Fig. 2 of Paper V shows that the grain type sorghum increased its grain yield advantage over its competitors if environmental conditions worsened.

This finding, although a by-product of the main study, may have interesting applications in Kenya. Relatively large areas in the highlands receive less than 875 mm annually (Fig. 6). The 875 mm isohyet approximately coincides with r.e.i. = +60 which is the transition point above which maize gives the highest grain yield, but below which the grain type sorghum gives the highest grain yield (Paper V).

The areas in the highlands where annual rainfall is under 876 mm are up to now largely for cattle ranching, but are increasingly used to settle people from areas with a higher rainfall and a higher population density. Plots of up to 4.0 ha are allocated to subsistence farmers with a maize cultivating tradition. However, maize grain yields are often disappointing in the drier highlands (Section 5.2).

# 5 Scope for further work

In fulfilling its objective, the programme has created its own demand for further research. The execution of the programme has also had several spin-off effects, requiring further research. Further, the programme has encountered several problems which it was unable to solve. In the final section of this thesis, a brief indication of those aspects that seem useful for further work will be given.

## 5.1 Forage production

The yield advantage of the sorghums under environmentally favourable growing conditions was largely based on the lodging and harvesting losses of maize. In view of the higher D-value of maize, it seems that breeding for maize cultivars that are more lodging-resistant should have a high priority. It seems likely that lodging is correlated with plant tallness (Fig. 10). It was shown that tallness is also positively correlated with total dry matter yield, but that yield reduction, resulting from shorter plants can be compensated by planting the crop at a higher population (Table 4 of Paper I). However, this will also result in lower grain yields, which may be unacceptable (Tables 4 and 5 of Paper I). This indicates that new sources of germplasm to be used in a breeding programme may be useful to break through these tendencies.

The yield advantage of the forage sorghum was largely negated by its lower D-value. Hence it may be argued that future breeding efforts should concentrate on improving the digestibility of the sorghums. The use of brown midrib ($bm_5$) genes may well have this effect, but experience in the USA showed that the $bm_5$ genes also often increase the lodging susceptibility. The $bm_5$ lines from Purdue University that were tried in Kenya were poorly adapted and showed no signs of cold tolerance, indicating that results may require some time.

The assumption that grain content in the forage is important in determining forage quality (Section 2.1.4) has been challenged in recent years. For the ten c.t. sorghum cultivars which were used in various trials in the programme grain content was positively correlated with the D-value of the whole plant (van Arkel, unpublished). But it is obvious that other factors such as plant density, age at harvest and total yield confounded the correlation and they may also have an influence on D-value.

Deinum & Knoppers (1979) posed the hypothesis that the question of grain content and forage quality hinges around the question of whether the growing conditions during the grain filling stage are favourable or not. If growing conditions are favourable, grain filling results largely from actual photosynthesis and grain content is positively correlated with the digestibility of the forage. If, however, growing conditions are unfavourable – due to insufficient light at higher latitudes – grain filling results from a translocation of carbohydrates from the stem and leaves to the grain. In this case grain content has little or no effect on the digestibility of the forage.

In Kenya there are situations where growing conditions during grain filling are good, but there are also situations where grain filling takes place when the rainy season has stopped and growth is severly curtailed by moisture deficiencies, and when photosynthesis is probably highly reduced.

The long growth cycle of the forage sorghum used in this study causes this cultivar often to mature under conditions of limited moisture availability. Translocation of highly digestible dry matter from the leaves and stems to the grain, coupled with a rapid lignification of the stem may well be responsible for the low D-value of this cultivar.

It seems that a better understanding of the factors responsible for the digestibility of these crops will allow a more useful breeding effort for improved nutritive value of c.t. sorghums for forage.

A high digestibility of the forage does not necessarily result in a high feeding value of the silage. This is examplified by the results of the feeding trial as shown in Tables 4 and 5. The rations based on forage sorghum silage resulted in a consistently higher dry matter (d.m.) intake than maize silage-based rations. It is likely that these differences in d.m. intake were caused by differences in d.m. % and pH of the silages, which are both positively correlated with d.m. intake (Richards & Wolton, 1975). The d.m. % of the maize and forage sorghum silage were 30 and 37% respectively, while the pH was 3.6 and 4.2 respectively. It is possible that the crop with the higher digestibility and higher content of soluble carbohydrates, i.e. maize, fermented better during ensiling and, therefore, reached a lower pH. This in turn may possibly have affected the d.m. intake negatively. Although the above is partly hypothetical, the feeding trials have demonstrated that acceptability can be as important as digestibility.

The conclusion must therefore be that further work aimed at elucidating the plant characteristics controlling silage d.m. intake deserves as important a place as further work aimed at improving digestibility.

## 5.2 Grain yield

The grain yield advantage of the grain sorghum over maize becomes relatively larger as the actual yield level decreases (Fig. 2 of Paper V). Notwithstanding, it is here, under the driest conditions in the highlands, that the greatest proportional yield improvements are considered possible.

This is based on the observation that the specific water use of the grain sorghum, although better than for the maize, was higher than reported in the literature (Paper V). But also the time from sowing to maturity is long, indicating that improvement (through plant breeding) may be possible. Under

Fig. 15. A new experimental short grain type sorghum cultivar was developed in Kenya from material obtained from the high-altitude sorghum breeding programme at CIMMYT. This field of 2.5 ha in Naivasha yielded 6.53 t/ha in 176 days on 460 mm of rain.

the driest conditions in the highlands the rainfall pattern becomes distinctly bi-modal as shown in Fig. 5, but with a very dry period from June to September. This leaves two rainy seasons of about two to three months each. The grain sorghum 'E 1291' requires, depending on where it is grown in the highlands, 4½ to 6 months to mature. Thus grain filling occurs when the plant lives on residual soil moisture only. The time to maturity is probably a function of the degree of cold tolerance (among other factors that control flowering and maturity). As the Kenya programme was one of very first attempts to use c.t. sorghum outside its area of origin, it is likely that future efforts will be able to distinguish different levels of cold tolerance, and that this variability shoud be used to select earlier maturing c.t. cultivars. A first positive indication that this might indeed be possible can be deduced from Fig. 15, where a new experimental, short, earlier maturing, cold-tolerant grain sorghum is shown.

Although the grain yields of sorghum gave rise to an optimistic view of the prospects for food production in the drier highlands, the use of sorghum grain posed a problem. This problem was based on three characteristics of the grain which require improvement. The tanning content of the kernel gave it – besides bird resistance – a bitter, astringent taste and reduced the digestibility.

The soft endosperm coupled with the small grains (1000-kernel weight is about 18 g) made mechanical processing, aimed at removing the tanning containing testa layer, difficult. Breeding aimed at further reducing the time to maturity and at producing lines with hard endosperm and larger grains, should have a high priority in agricultural research in Kenya.

Notwithstanding, the finding that the introduction of c.t. grain sorghums has opened new possibilities of producing grain in areas which were previously considered unsuitable for arable agriculture must be considered highly interesting. It warranted the formulation of an UNDP/FAO-assisted project. This project is addressing itself today to the problems indicated in this sub-section.

## Summary


The American feedlot-system for finishing beef cattle was introduced into Kenya in 1969. In subsequent years the system was adapted to local conditions, concentrating work on two types of cattle, Zebus (*Bos indicus*) and crossbreds (*Bos indicus* × *B. taurus*). The Zebu cattle comprised mainly of surplus animals from the semi-arid and arid regions of the country where their owners led a semi-nomadic life, while the crossbred cattle were mainly obtained from ranches in the medium potential areas of the country. The rations developed were all based on maize silage as the main feed ingredient. The feeding results were considered good, with average daily live weight gain, during the 80-120 days feedlot finishing period, of around one kg per day.

The use of the adapted feedlot system, as a means of producing beef and transferring money into the rural areas of Kenya, was generally considered successful. Notwithstanding, the use of maize as the forage crop was considered less desirable because of its low yield under adverse rainfall conditions and its susceptibility to lodging. Hence, a programme was initiated to search for high-yielding forage crops other than maize to be used as silage for beef cattle finishing rations.

This programme of work had, as a second objective, the aim to introduce the new forage crop(s) into the farming community for which it was intended. Therefore, attention was paid to use the new crops. The results led us to believe that pasture grasses were probably less suitable for the purpose. This was because grass silage would require farmers to buy additional machinery.

The following species were selected, to be tested in the first introduction and screening trials: maize (*Zea mays*), Elephant grass (*Pennisetum purpureum*), bulrush millet (*Pennisetum typhoides*), sunflower (*Helianthus annuus*) and sorghum (*Sorghum bicolor*). Of the latter species, cultivars of two different origins were used:

1. a selection of known forage and grain sorghum cultivars from local and foreign sources (lowland sorghums),
2. a number of accessions from fields in the highlands of Ethiopia and Southwest Uganda (high-altitude sorghums).

The results indicated that the yields of bulrush millet were too low to warrant further research. The lowland sorghums were all heavily affected by one or more foliage and head fungus diseases and generally grew slowly. The yields of sunflower were variable, although good in some places. Work in subsequent years revealed that dry matter yield of sunflower was positively correlated with tallness. Tallness was positively correlated with lodging and

## Samenvatting


Het Amerikaanse 'feedlot'-systeem voor het afmesten van rundvee werd in Kenia in 1969 geïntroduceerd. In de daaropvolgende jaren werd het systeem aangepast aan de plaatselijke omstandigheden, waarbij de nadruk lag op twee soorten vee: zeboes *(Bos indicus)* en kruisingen tussen zeboes en Europese veerassen *(Bos indicus* × *B. taurus)*. Het zeboevee werd voornamelijk in de semi-aride en aride gebieden van het land aangekocht, waar hun eigenaren een semi-nomadisch leven leiden. Het kruisingsvee werd voornamelijk op de 'ranches' in de middelmatig vruchtbare streken van het land gekocht. Maiskuilvoer was het belangrijkste bestanddeel van alle gebruikte rantsoenen. De gemiddelde dagelijkse groei gedurende de 80-120 dagen durende afmestingsperiode was ongeveer 1,0 kg per dag.

Het gebruik van het aangepaste 'feedlot'-systeem werd als een succes beschouwd, zowel voor de vleesproduktie alsook om de inkomsten van de bewoners van de arme, droge gebieden van Kenia te verbeteren. Desondanks werd het gebruik van mais als voedergewas als minder gewenst beschouwd, voornamelijk wegens de droogtegevoeligheid en gevoeligheid voor legering van mais. Daarom ging men over tot het ontwikkelen van andere voedergewassen met een hoge opbrengst die gebruikt zouden kunnen worden als kuilvoer in rundveerantsoenen.

Dit had tevens ten doel om het (de) nieuwe voedergewas(sen) daadwerkelijk te introduceren bij de boeren. Zodoende was het nodig de bijzondere behoeften en wensen van de 'feedlot'-boeren te analyseren. Hieruit bleek o.a. dat weidegrassen minder geschikt waren voor dit speciale doel, omdat voor het maken van graskuilvoer extra machines aangeschaft zouden moeten worden.

De volgende gewassen werden in de eerste introductie- en observatieproeven opgenomen: mais *(Zea mays)*, olifantsgras *(Pennisetum purpureum)*, parelgierst *(Pennisetum typhoides)*, zonnebloem *(Helianthus annuus)* en sorghum *(Sorghum bicolor)*. Van het laatstgenoemde gewas zijn rassen van twee verschillende herkomsten gebruikt:

1. een selectie van bekende voeder- en graansorghumrassen van diverse herkomsten (laagland sorghums);
2. een aantal pas verzamelde inheemse landrassen uit de hooglanden van Ethiopië en het zuid-westen van Oeganda (hoogland sorghums).

De resultaten wezen uit, dat de opbrengst van parelgierst te laag was om een nader onderzoek zinvol te doen zijn. De laagland sorghums waren in de hooglanden van Kenia alle zwaar aangetast door één of meer blad- en aarschimmels en zij groeiden over het algemeen langzaam. De opbrengsten van zonnebloemen waren van plaats tot plaats sterk wisselend. In de daarop-

volgende jaren werd aangetoond, dat de drogestofopbrengsten van zonnebloemen een positieve correlatie hadden met de planthoogte. De planthoogte was echter ook positief gecorreleerd met de legering en negatief met de voederkwaliteit. Bovendien bleken de inkuilproeven slechts een matig succes op te leveren. Als gevolg hiervan werd geconcludeerd, dat zonnebloemen ongeschikt waren voor het specifieke doel. De opbrengsten van de voedergrassen waren in het eerste jaar veelbelovend en zodoende werd gedurende enkele jaren een teeltmethodenproefveld met twee rassen van olifantsgras aangelegd. Het bleek, dat het mogelijk was om hoge drogestofopbrengsten te verkrijgen, maar dat de mogelijkheden om het gewas te oogsten en in te kuilen beperkt waren.

Diverse inheemse hoogland sorghumrassen bleken de hoogste opbrengsten te geven; de planten waren gezond en krachtig en hoewel dit genetische materiaal vóór de aanvang van deze studie nog nooit in enige wereldliteratuur beschreven was, waren de opbrengsten zó hoog dat besloten werd een nader onderzoek in te stellen.

Het werk dat beschreven wordt in dit proefschrift concentreert zich op één aspect van het hierboven genoemde onderzoek: het identificeren en introduceren van koude-tolerante sorghum in de hooglanden. In de eerder gepubliceerde artikelen, die een wezenlijk onderdeel van dit proefschrift vormen, worden sommige proefnemingen met dit type sorghum in vergelijking met mais beschreven. De artikelen bevatten de belangrijkste aspecten van teeltmethodiek en ecologische gewasaanpassing. Het werk betreffende de andere gewassen, evenals het werk ten aanzien van andere aspecten van sorghum, is elders gepubliceerd (zie literatuurlijst).

De maishybriden en -rassen die in Kenia verbouwd worden, kunnen erg hoog worden (stengellengtes van meer dan 3,5 m zijn gemeten). Het bleek, dat hoogte een nauw verband hield met de totale drogestof- en graanopbrengst. Een hoog gewas, al dan niet als gevolg van het gebruikte ras, van de grond, van de teeltmethode of van het voor de groei gunstige weer, bleek de hoofdoorzaak van legering te zijn. Legering in mais leidt tot oogstverliezen die op kunnen lopen tot 50%. Enkele voedersorghumrassen werden even hoog als mais; desondanks kwamen legering en oogstverliezen hoger dan 5% niet voor, zelfs niet als de totale drogestofopbrengst 25 ton per hectare bedroeg.

Het bleek, dat de verschillen in drogestofopbrengst, graanopbrengst en voederkwaliteit als gevolg van diverse kunstmestbehandelingen klein waren. Onkruidbestrijding daarentegen had een grote invloed op de opbrengst. De begingroei van sorghum is minder snel dan die van mais, hetgeen van belang is voor de onkruidbestrijding in het vroege groeistadium. Een bespuiting, vóór opkomst, met atrazine (2,0 kg actieve stof per hectare), bleek een effectieve, veilige en betrouwbare methode van onkruidbestrijding, althans voor de bestudeerde sorghumrassen.

Eén van de belangrijkste aspecten van de maisteelt in Oost-Afrika is de zaaitijd en een aantal experimenten werd ontworpen om enig licht te werpen op dit aspect van de sorghumteelt in vergelijking met de maisteelt. De resultaten tonen aan dat het effect van de zaaitijd afhankelijk is van de regenval. Als er weinig regen valt tijdens de zaaitijd zal een uitstel van enkele weken de uiteindelijke drogestof- en graanopbrengst gunstig beïnvloeden. Als er daarentegen volop regen valt aan het begin van het groeiseizoen zal uitstel van zaaien een lagere opbrengst ten gevolge hebben. Voor iedere week dat er later gezaaid werd, verminderde de opbrengst van het sorghumras 'E 6518' en de maishybride 'H 613' met 1,0 ton drogestof per hectare.

In het vijfde artikel worden de resultaten van alle opbrengstproeven in de hooglanden van Kenia met sorghum en mais samengevat, met de bedoeling om het effect van de natuurlijke omgeving op de drogestof- en graanopbrengst te analyseren. Het bleek, dat regenval de meeste invloed had op de opbrengsten, hoewel slechts de helft van alle opbrengstverschillen hierdoor verklaard werd. De graansorghum gaf de hoogste graanopbrengst in gebieden met een lage en middelmatige regenval; dit was slechts voor een deel het gevolg van een meer efficiënt watergebruik van de sorghum, belangrijker bleek de gunstige drogestofdistributie te zijn.

De voedersorghum produceerde onder de meeste omstandigheden de hoogste drogestofopbrengsten. De maisrassen brachten alleen hogere opbrengsten wanneer de groei-omstandigheden gunstig waren. In gebieden met > 1000 mm regenval waren de drogestofopbrengsten van alle gewassen lager dan daar waar 800-1000 mm regen viel. Vooral de sorghumopbrengsten waren lager in gebieden met een hoge regenval. Maar het was niet duidelijk of deze lagere opbrengsten het gevolg waren van alléén regenval, of ook van verschillen in temperatuur.

Kuilvoer van mais, graansorghum of voedersorghum werd in uitgebalanceerde rantsoenen aan 540 stuks rundvee gevoerd om de vergelijkende voedingswaarde vast te kunnen stellen. Het bleek, dat de drogestofopname van het sorghumkuilvoer hoger was dan die van het maiskuilvoer, hetgeen de lagere verteerbaarheid van sorghum enigszins compenseerde.

De balans tussen voor- en nadelen van sorghum en mais wordt bepaald door tal van omstandigheden, zoals regenval, beschikbaarheid van krachtvoer en de prijzen van de produktiemiddelen. Het blijkt echter dat, onder specifieke omstandigheden, de rundvleesproduktie van één hectare voedersorghum 30-50% hoger kan zijn dan die van één hectare voedermais.

In het eerste gedeelte van dit proefschrift worden de specifieke omstandigheden waaronder dit programma werd uitgevoerd geanalyseerd, waarbij enkele aspecten van het werkzaam zijn in een ontwikkelingsland worden beschreven. Er wordt gesteld, dat de strakke tijdsbegrenzing, die normaliter gehanteerd wordt bij ontwikkelingsprojecten, het soms noodzakelijk maakt om op praktijkervaring gebaseerde, in plaats van berekende en statistisch gerechtvaardigde beslissingen te nemen. Ook wordt erop gewezen, dat de landbouwvoorlichtingsdienst in Kenia minder efficiënt werkt dan die in de westerse wereld. Dit betekent, dat in een onderzoekprogramma, dat de resultaten van het onderzoek door boeren toegepast wil zien (het hier beschreven onderzoekprogramma is daar een voorbeeld van), veel aandacht aan voorlichting moet worden besteed. Evenzo zijn de beschikbaarheid van faciliteiten en de variabiliteit van proefmateriaal anders dan wat men normaliter in de westerse wereld aantreft. De effecten die hiervan werden ondervonden bij de uitvoering van het onderzoekprogramma worden eveneens besproken. In het algemeen moeten onderzoekprogramma's in ontwikkelingslanden veelomvattender zijn om de voetangels naar het succes te vermijden. De vaak snel veranderende omstandigheden maakten het nodig het programma regelmatig kritisch door te lichten. Tijdens de uitvoering van dit programma bleek, dat de Keniaanse landbouwpolitici vrij plotseling minder belangstelling voor de vleesproduktie hadden. De flexibiliteit waarmee dit programma was opgezet, maakte het echter mogelijk om ook aandacht te besteden aan aspecten van de graanproduktie, waarbij bleek dat grote gebieden in de Keniaanse hooglanden welke te droog zijn voor een betrouwbare korrelproduktie van mais potentieel geschikt zijn voor de produktie van sorghumgraan. Dit kan uiteindelijk leiden tot een uitbreiding met ± 25% van het gebied, dat nu in Kenia voor de graanproduktie wordt gebruikt.

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**Paper I**

# New forage crop introductions for the semi-arid highland areas of Kenya as a means to increase beef production

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# New forage crop introductions for the semi-arid highland areas of Kenya as a means to increase beef production

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## Summary

A UNDP/FAO Development Project has initiated and aided the establishment of a commercial beef cattle finishing sector in the Kenya agriculture. The feeding systems developed utilize surplus cattle from rural areas which are fed on rations based on maize silage. The project has now initiated a search for forage crops suitable for cultivation under highland conditions, but more drought-resistant than the presently used maize. It appeared that new introductions of cold-tolerant sorghums from the high-altitude areas of Uganda and Ethiopia produced consistently good yields which were comparable to, or better than, maize.

Some of the high altitude sorghums were completely free from diseases which are typically encountered when 'lowland' sorghums are grown above 1600 m in Kenya. In contrast with maize and sunflower, the new sorghum introductions were highly resistant to lodging. Correlation analysis showed that the unwanted tallness of crops is highly associated with the yield of maize and sunflower, whereas with cold-tolerant sorghums there is scope for selection or breeding of high-yielding material which is shorter. The single highest-yielding entry for cold-tolerant sorghum, sunflower and maize produced 30.5, 29.5 and 26.6 tons DM $ha^{-1}$, respectively.

## Introduction

Agricultural development activities in developing countries, directed towards increasing productivity are usually concerned either with the introduction of distinct agrotechnical innovations or their individual merits. There is, however, a growing recognition that development programmes linking several sectors of a country's economy have an important role to play in rural development. (Taylor, 1974; Anon., 1973). The Kenya Beef Industry Development Project is an example of such an

'Integrated Rural Development Project', although it is unusual in that it is using large-scale farming methods to introduce new technology, while relying on market mechanisms to spread the resulting benefits. Because of its success, the project has created its own research needs which led directly to the necessity for an identification of additional forage crops.

The introduction in 1969 of intensive systems for beef cattle finishing to induce a stratification in the beef cattle industry, was a basic innovation in the Kenya agricultural economy aimed at increasing the productivity of the large numbers of indigenous pastoral Zebu cattle (*Bos indicus*). This feedlot system (Creek, 1971) proved to be successful on a technical level and its economic attraction was confirmed by an extensive commercial interest.

Because of the limited land area available for intensive feeding systems the project was requested to develop alternative forages suited to land of lower agricultural potential. This paper briefly describes the feedlot system against the background of traditional beef cattle raising systems. The results of a species introduction and screening trial to find new forages suitable for silage production are discussed.

## Agricultural potential, cattle distribution and beef supply

A large proportion of the land surface of Kenya receives insufficient rainfall to sustain crop production. A belt along the coast and an area around Lake Victoria has a higher precipitation. Areas with a higher elevation usually receive more rainfall as well.

Altitude effects agricultural potential in two ways, via rainfall and temperature. It has been calculated in Kenya that the mean diurnal temperature decreases by 6.5 °C for every 1000 m increase in height above sea level (Anon., 1970a). Therefore at the higher altitudes where precipitation is relatively plentiful, moisture availability to the plant is further increased by reduced evaporation due to lower temperatures. However, lower temperatures reduce growth rates of some crops and completely preclude the cultivation of others such as sugar-cane which require warm growing conditions.

Various attempts have been made during the past twenty-five years to classify the different zones of climatic conditions according to their agricultural potential. Swynnerton (1955) recognizes two classes, high and low potential, and Brown (1963) adds a class of medium ecological potential. For the purposes of this paper Brown's classification, slightly refined, will suffice.

The uneven distribution of rainfall is also reflected in the human population and cattle distribution; in the drier areas people keep more cattle. The broad boundaries of the agricultural potential classes can be readjusted for a discussion of the potential for supply of beef: (Table 1).

1. The area with *more than 750 mm* annual rainfall. Cattle are kept mainly for dairying, either for subsistence or to supply the market. Male calves are usually killed at birth as they are uneconomic to rear.
2. The area with *between 500 and 750 mm* annual rainfall. Here commercial ranches are mainly found. The cattle breeds used are either 'Improved Boran', a

Table 1. Beef supply potential related to land classification.

| Agricultural potential (Brown, 1963) | Number of ha (% of land area) | Maize production potential | Beef supply class |
|---|---|---|---|
| 'High potential area' with more than 875 mm rainfall p.a. | $6.69 \times 10^6$ ha (11.89%) | a good maize grain crop production is possible every year if altitude is less than 2300 m | 1 |
| 'Medium potential area' with 625–875 mm rainfall p.a. | $3.13 \times 10^6$ ha (5.57%) | 750 to 875 mm: a good to average grain crop production is possible every year | 1 |
| | | 625 to 750 mm: an average to low maize grain crop production is possible every year; excellent rangelands | 2 |
| 'Low potential area' semi-arid to arid lands with rainfall less than 625 mm p.a. | $41.74 \times 10^6$ ha (74.22%) | 500 to 625 mm: maize grain crop failure in three to four years out of five; good to average rangelands | 2 |
| | | less than 500 mm: maize production impossible; poor rangelands; pastoral cattle husbandry is the only way of agricultural production | 3 |
| Remaining area | $4.69 \times 10^6$ ha (8.34%) | | |
| Total area | $56.24 \times 10^6$ ha (100%) | | |

selection from indigenous Zebu, or crosses between these Borans and European breeds. These ranches have traditionally been self-contained units, where the breeding, growing out and finishing of beef cattle are combined in one enterprise.
3. The low potential area with *less than 500 mm* rainfall. Livestock raising is still in its most traditional, semi-nomadic form and there is little production for a market. Instead it is subsistence farming emphasizing female cattle as the most valuable assets on account of their milk production. Male cattle are kept as reserve assets for sale when cash is required. The breed of cattle here is pure Zebu.

In spatial terms 45 % of the national cattle herd is kept in the arid and semi-arid low potential areas. It has been recognized in the national plans that cattle must play an integral role in the agricultural development of the large dry areas of Kenya (Anon., 1973). The need for, and the scope of, livestock development programmes is implied by the low annual off-take of approximately 13 %, and from the large proportion of low-grade, light weight carcasses which are processed by the abattoirs (Daly, 1974; Anon., 1974, 1975). In 1968 the UNDP/FAO/Kenya Beef Industry Development Project was thus initiated to study the possibilities of increasing beef production in Kenya. It was clear from the outset of this project that native Zebu cattle from the low potential area had to play an important role in its investigations. The project was directed to promote stratification of production, separating the breeding, growing out and finishing phases of beef production in different areas. The feedlot finishing phase was given prime attention as a tool to induce the stratification of the whole industry.

## The feedlot system for intensive finishing

The American feedlot system was modified by the project for introduction into Kenya, and it is essentially a short period of intensive feeding to ensure that cattle are brought to their optimal condition prior to slaughter. The project has demonstrated two significant findings: it has proven that pastoral indigenous Zebu cattle, when coming from the range, can respond very well to intensive feeding (Creek, 1971), and it has shown that agro-industrial by-products, e.g. molasses and pyrethrum residue, can successfully be included in the rations (Creek, 1973).

Local Zebu cattle respond well to high levels of roughage in the ration, thus reducing the necessary amounts of the more expensive high-energy components in the ration to a very modest amount (Table 2).

A survey of several feedlot farms showed an average yield of 10.5 tons of DM out of the silage pit per ha of maize forage. This implies (Table 2) that on a feedlot finishing farm 46 Zebus or 57 cross-breed cattle can be fed from 1.0 ha of maize, provided the necessary non-forage ration components are available. 46 Zebu's deliver a carcass weight increase of 2.4 tons while for 57 cross-breed cattle the carcass weight gain is 4.7 tons. Because feeder cattle usually have a fully developed skeleton before entering the feedlot, the above figures represent an almost complete increase in edible meat.

Table 2. Expected performance of two types of cattle during feedlot finishing (Creek and van Arkel, unpublished).

| | Zebu<br>High roughage (66%) | Cross-breed<br>Low roughage (33%) |
|---|---|---|
| Initial live-weight (kg) | 260 | 350 |
| Initial dressing percentage | 47.5 | 48.0 |
| Days on feed | 81 | 95 |
| Final live-weight (kg) | 340 | 478 |
| Final dressing percentage | 51.5 | 52.3 |
| Daily live-weight gain (kg) | 1.0 | 1.3 |
| Total live-weight gain (kg) | 80 | 128 |
| Carcass weight increase (kg) | 52 | 82 |
| Conversion ratio | 7:1 | 7:1 |
| Feed DM used (kg) | | |
| forage (maize silage) | 228 | 183 |
| non-forage (agro-industrial by-products) | | |
| roughage | 152 | 122 |
| concentrate | 190 | 611 |

The feedlot system increases the amount of beef reaching the slaughterhouse in two ways. It increases the beef off-take by producing heavier carcasses by virtue of the additional finishing they receive. Also it offers attractive prices for young unfinished stock which are well above their current slaughter value. The sale of this young stock to the feedlot releases grazing for breeding females, hence offering a chance of increasing their productivity. Thus far, feedlot rations have mainly been based on maize silage as a source of forage. It is, however, quite clear that in areas where maize can be cultivated there is a social pressure to develop smallholder systems of farming with the main product being maize grain for human consumption. Consequently the need was foreseen to develop alternative feeding systems to maize silage. For this reason studies on the use of high levels of molasses (Creek et al., 1974) and of fresh sugar-cane (Creek et al., 1976) were undertaken. Simultaneously, the search was commenced for a suitable forage crop for cattle feeding operations which can be grown in those parts of the high-altitude (HA) areas, i.e. $>1600$ m, where arable agricultural potential is less favourable and where the human population is much lower. Such crops must therefore be more drought-resistant than maize, while they must also have the ability to withstand the relatively low temperatures prevailing in the highlands. The restriction on altitude was made because this area has a well developed infrastructure and is free from foot-and-mouth disease.

## Crop literature review and entry selection

Few studies with silage crops have been conducted under the special climatic conditions of Kenya's highlands where solar radiation and photoperiod are tropical, and temperatures are temperate and rainfall varies from semi-arid to medium-wet. A brief literature survey for the potentially suitable species follows, together with the origin of cultivars to be tested in three introduction and screening trials.

*Sorghum (Sorghum bicolor (L) Moench)*
It is generally accepted that sorghums are more drought-resistant than maize. Martin (1930) showed that sorghums have a more xeromorphic structure than maize, the number of stomata per cm$^2$ of leaf area is higher, while the individual size is smaller. The leaf stalk surface is covered with a waxy cutinized epidermis, also osmotic concentration of leaf juice is higher and evaporation during periods of moisture stress is lower. Glover (1959) proved that sorghum, after a period of moisture stress, re-commences photosynthesis immediately, whereas maize, although it regains turgidity when the water supply is restored, does not recover its normal photosynthetic behaviour. Despite its drought resistance sorghum is seldom grown in the dry areas of the Kenya Highlands nowadays. Various attempts to introduce grain sorghums here have failed completely in the past, which is – most likely – due to the fact that the germplasm used was not adapted to the relatively low air temperatures.

Quinby et al. (1958) states that minimum temperature for germination of sorghum seed is 7 to 10 °C and that for subsequent growth is about 15 °C. They also report that the optimum mean temperature for the growth of sorghum is about 27 °C.

Ross & Webster (1960) in the USA recommended that sorghum should not be planted where soil temperatures are below 21 °C.

Another limiting factor for sorghum cultivation in the highlands, where low temperatures are coupled with seasonally heavy rainfall, is that honeydew disease (*Sphacelia sorghi* (McRae)) can be serious. This fungus invades the ovary when pollination is delayed due to cold conditions. Fertilization does not take place and the disease is often followed by a black fruiting fungus (*Cerebellum* spp.)

Clearly, the above-mentioned problems have contributed to the lack of popularity of sorghum in the Kenya Highlands. Therefore, at the start of the programme, a selection was made from a series of typical high-altitude (HA) sorghums which might be adapted to the prevailing climatic conditions. A great number of sorghums naturally occurring in the high-altitude areas of Ethiopia and Uganda were collected during the 1960's by the East African Agricultural and Forestry Research Organization (EAAFRO) at Serere in Uganda. From this collection the author selected, on a visual basis, a number of lines, which are reported under an 'E' or a 'Hirna' number.

In addition a small selection of 'lowland' sorghum cultivars and hybrids was made by the US Department of Agriculture, by various commercial American seed companies and by Israelian and Kenyan sources for inclusion in the trial.

Some other sorghums which are sometimes cultivated in Kenya highlands (Boonman, 1969) such as Columbus grass (*Sorghum almum*), velvet sorghum (*S. halepense* × *S. bicolor*), two sorghum × Sudan grass hybrids (*S. bicolor* × *S. sudanense* (Piper) Stapf) and two Sudan grass cultivars (*S. sudanense*) were also entered in the trial. This group of sorghums is reported under 'Miscellaneous sorghums'.

*Sunflower (Helianthus annuus (L))*

Sunflower is widely cultivated for seed, but its productivity and quality as a cattle feed has also been tested under widely differing conditions. Cotte (1957) in France, Bengtsson (1958) in Sweden, Sivokonev (1959) in Russia, Warren Wilson (1966) in Australia, and Henning (1949) in the Republic of South Africa, showed the relatively high drought resistance of sunflower. Several reports indicate that under marginal conditions sunflower may outyield maize in terms of DM ha$^{-1}$ (Putt, 1963 (Canada); Henning, 1949 (South Africa); Hagsand, 1956 (Sweden); Schuster, 1954 (Germany)). Little experience of sunflower for silage is available on the continent of Africa. Henning (1949) in South Africa values the crop highly while Miller et al. (1963) in Nigeria states that, due to the low digestability of the various plant components, no further research with sunflower is warranted. Eijnatten (1971) in Kenya recorded a production of approximately 28 tons DM ha$^{-1}$ and, in a later study (Eijnatten, 1973), reasonably good proximate analysis figures for sunflower are shown. A number of locally available sunflowers, some locally adapted and some imported cultivars, were included in the trial.

*Bulrush millet (Pennisetum typhoides (Burm) Stapf & C. E. Hubb)*

This species is known to be remarkably drought-resistant. This is partly on account of its ability to start heading extremely soon when moisture conditions become adverse. The term 'drought-escaping' is therefore often used. The composites used in this study were all selected from EAAFRO Uganda. Apart from their drought resistance they have been included for their quick development and their ability to produce regrowth when rainfall is adequate. The species is usually grown for grain production.

*Grasses*
Little experience with the agronomy of grass as a forage was available in Kenya at the start of the project, whereas maize agronomy was well developed. The recurrent costs of ploughing and planting involved in the cultivation of annual forage crops make up 32 –45 % of the total growing costs. (Anon., 1970b). This certainly makes perennial grasses economically attractive if they can compete in productivity with maize. Rhodes grass (*Chloris gayana* Kunth cv. Mbarara), and Bana grass (*Pennisetum purpureum* Schumach.), a newly introduced selection out of Napier grass, were used as test material in the trials.

*Maize (Zea mays (L.)*
The four maize cultivars were included in the trials as the controls. 'H 613' and 'H 512' are the most widely used Kenya hybrids, particularly suited to the more productive soils. 'Katumani' is a Kenya composite, selected for drier, semi-arid conditions. 'Local yellow' is a Kenyan adapted selection which is locally said to be able to outyield the hybrids if growing conditions are drier.

## Materials and methods

The trial was planted at three different locations:
*Lanet 1.* Elevation 1920 m; has a deep sandy loam soil with excellent waterholding capacity, total rainfall during the growing season (March-November) of the year of experimentation (1974) was 810 mm. The trial site is situated approximately 35 km south of the equator.
*Lanet 2.* 5 km to the south with an elevation of 1860 m; has a soil of recent volcanic origin with a very shallow topsoil, overlaying ash, pumice and lava material. The waterholding capacity of the soil is very limited and total rainfall for the season was 720 mm.
*Naivasha.* Elevation 1850 m, approximately 77 km south of the equator; shows a soil of recent geological origin composed of lake deposits with a clearly developed morphology. The soil is deep, well drained, and has an excellent waterholding capacity. Sowing was delayed for five weeks and this trial was laid down as one completely randomized design. On sowing 70 mm irrigation was given. The rainfall during the growing season was 420 mm.

A total of 72 different entries were chosen and sown at the beginning of the main growing season at the end of March in a randomized block experiment. Each plot was sown to three rows, 70 cm apart, 5.0 m long, except for Rhodes grass which was broadcast overall.

Harvests were taken at the optimal harvesting stage for each crop as specified in

the literature. This was determined as follows:
- maize, sorghum and bulrush millet at physiological maturity, i.e. at the hard-dough stage of the grain;
- haygrazer, velvet sorghum, Sudan grass and Columbus grass at 50 % flowering;
- sunflower when 50 % of the florets of 50 % of the heads could be removed by gentle rubbing; this occurs approximately two weeks after the onset of flowering;
- Rhodes grass at the onset of heading;
- Bana grass, when the crop reached a height of 150 cm.

At the predetermined harvesting stage for each plot, one row 4.0 m long (leaving 0.5 m at each end of the row), was cut and taken to the laboratory for further plant component analysis. The harvested plants were counted, tiller numbers recorded, individual stem lengths measured and the plants dissected into leaf, stem, grain and, where applicable, petiole (sunflower), husk and empty cob (maize). Dry matter percentage of each component was determined by exposing a subsample for 24 to 48 hours to 90 °C in a large drying oven.

## Results

The performance data of fifteen entries is shown in Table 3. Each group of crops is represented by one or more of those entries which gave, on the average, the highest DM or grain yields. The mean DM yield was 17.7, 13.3 and 20.2 tons $ha^{-1}$ for Lanet 1, Lanet 2 and Naivasha, respectively. It is striking that the mean DM yield at Naivasha was the highest one ($P < 0.05$) although the rainfall there was lower than at the other two sites. This higher mean DM yield went in conjunction with the longest mean growing period.

Although maize, the control, did not reach a top yield anywhere, the yields obtained were good and comparable to those reported by Sheldrick (1974) in the Trans-Nzoia typical maize growing area. The relatively high maize yields set a high standard for the other groups. These maize DM figures obtained here are considerably higher than those commonly recorded in large-scale maize farming in the area. Lodging in maize was observed in all three trials.

The lowland sorghums were all heavily affected by one or more foliage and head fungus diseases, such as leaf blight (*Helminthosporium turcicum* (Pass.)), bacterial stripe (*Pseudomonas andropogonis* (E.F.Sm.) Stapp.), antracnose (*Colletotrichum graminicolum* (Ces.) C. W. Wils), rust (*Puccinia purpurea* Cke.), and honeydew disease (*Sphacelia sorghi*).

Several of the sorghums of HA origin appeared among the top yielding entries at each trial site, although none of those sorghums outproduced maize consistently. The DM yield of the entries in the other groups was highly variable with trial location (sunflower) or consistently lower than maize (lowland sorghums, miscellaneous sorghums, grasses and bulrush millet).

## Discussion

### *Suitability for silage making*

To the feedlot farmer the stock-piling of feed supplies, which eliminates seasonality

Table 3. Performance data of the highest DM yielding entries out of each group of crops.

| Entry | Lanet 1 | | | | Lanet 2 | | | | Naivasha | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | DM yield (tons ha$^{-1}$) | | days till harvest | misc.[1] | DM yield (tons ha$^{-1}$) | | days till harvest | misc.[1] | DM yield (tons ha$^{-1}$) | | days till harvest | misc.[1] |
| | total | grain | | | total | grain | | | total | grain | | |
| Maize cv. 'H 613' | 23.6 | 7.0 | 174 | L3 | 17.6 | 5.8 | 196 | L1 | 26.6 | 5.6 | 176 | L4 |
| cv. 'Local Yellow' | 18.4 | 5.8 | 169 | L3 | 17.4 | 3.8 | 183 | L1 | 23.1 | 3.8 | 172 | L2 |
| Lowland sorghum cv. 'FS 4' | 8.3 | 2.3 | 155 | F4, T2 | 7.9 | 2.2 | 163 | F34, T1 | 14.9 | 6.5 | 192 | F34, T1 |
| Misc. Sorghum cv. Velvet | 13.6 | | 144 | F1 | 10.1 | | 179 | 0 | 15.2 | | 187 | F1 |
| Grass: Bana grass | 18.6 | | 3 cuts | 0 | 10.3 | | 3 cuts | 0 | 15.2 | | 2 cuts | 0 |
| Rhodes grass | 17.2 | | 3 cuts | 0 | 8.9 | | 3 cuts | 0 | 15.2 | | 3 cuts | 0 |
| Sunflower cv. 'Kenya White' | 8.9 | 1.9 | 124 | L4 | 5.8 | 1.0 | 126 | F2 | 29.5 | 1.8 | 148 | L5 |
| cv. 'Grey Stripe' | 8.5 | 1.2 | 127 | L4 | 5.8 | 1.0 | 126 | F2 | 29.4 | 1.8 | 147 | L5 |
| Bulrush millet cv. 'Serere 14' | 13.7 | | 132 | T5 | 13.1 | 0.05 | 145 | T5 | 9.3 | | 169 | F2, T3 |
| Ha sorghum cv. 'E 1291' | 17.2 | 7.3 | 166 | 0 | 11.1 | 4.8 | 175 | 0 | 15.8 | 7.0 | 192 | 0 |
| cv. 'E 5766' | 19.8 | 4.9 | 169 | 0 | 13.2 | 4.4 | 175 | 0 | 24.9 | 7.9 | 192 | 0 |
| cv. 'Hirna 547' | 30.5 | 1.7 | 209 | F3, T2 | 20.9 | 0.8 | 224 | F4, T4 | 18.7 | 0.2 | 224 | F3, T4 |
| cv. 'E 6518' | 25.8 | 3.7 | 220 | 0 | 19.5 | 4.0 | 209 | 0 | 20.5 | 4.5 | 224 | 0 |
| cv. 'E 1429' | 19.9 | | 160 | casualty | 20.2 | 3.7 | 224 | 0 | 26.5 | 0.9 | 224 | 0 |
| cv. 'E 6250' | 21.8 | 3.6 | 195 | F2, L1 | 17.1 | 2.7 | 196 | F1 | 18.4 | 2.2 | 224 | 0 |
| Mean | 17.7 | | 165 | | 13.3 | | 179 | | 20.2 | | 190 | |
| LSD ($P < 0.05$)[2] | 3.3 | | | | 3.0 | | | | 4.4 | | | |
| C.V. %[2] | 17.9 | | | | 18.7 | | | | 19.9 | | | |

[1] L = Lodging; F = foliage diseases; T = limited seed formation due to slow plant development or absence of cold tolerance; 0 = no disease
Scale 1–5; 1 = trace; 5 = heavily affected.

[2] All statistical analyses are based on all entries at each trial site and not only on the 15 which are presented here.

in beef production, is central to the concept of feedlot finishing. Silage making is the conservation technique of choice, and the crops studied were chosen with this in mind. However, sunflower, and Rhodes grass and Bana grass with average DM figures of 18.9 %, 22.0 % and 17.5 %, respectively, are too wet for easy silage making, although it is possible by using a period of wilting prior to ensiling. But as well as complicating the harvest, it also makes it difficult to obtain silage of uniform quality and DM %. The need for grasses to be cut several times in one year also reduces the chances of obtaining feed of even quality.

*Suitability for mechanical harvesting*
Mechanical forage harvesting is essential for silage production and the actual forage yields obtained are, therefore, a function of crop productivity and harvesting losses. Field experience shows that the latter is closely correlated with lodging. The heavy lodging in maize and sunflower (Table 3) is therefore a distinct disadvantage, and the lodging-resistant HA sorghums compare favourably since they can be mechanically harvested with little loss. Work is in progress to study the harvesting losses resulting from lodging in more detail, and loss figures of 30 % for lodged maize have been measured whereas sorghum losses generally remain under 5 %.

*Performance by trial site and by group*
The highest average DM yield at Naivasha, where rainfall (+ irrigation) was only 490 mm, is probably associated with the superior water-holding capacity of the soil at this trial site, which ensured a high utilization of the precipitation. Wilting was observed only very rarely whereas this was a common phenomenon at the Lanet 2 site where rainfall was more abundant, but the soil very shallow, and the average yield much lower. Therefore Lanet 2 seems to be the best site of all 3 to represent the semi-arid highlands. Indeed it is only here where three HA sorghum cultivars (cvs) outyielded the two best maize cvs by an average 15 %. The better moisture availability to the plant at Naivasha as compared with Lanet 2 is also confirmed by the 24 days longer period needed by bulrush millet cv. Serere 14 to reach the hard-dough stage (Table 3), because days from planting till heading in bulrush millet is known to be negatively correlated with moisture availability.

The low DM yields which were recorded for the *lowland sorghums* are partly due to the diseases which invaded the crops in the later stages of growth and partly due to the slow growth rates which were observed immediately after emergence. The latter is probably related to the relatively low air temperatures, and this seems to explain previous failures to introduce lowland sorghums in the highlands. Mean daily air temperatures during the growing period for Lanet 1, Lanet 2 and Naivasha were 18.1, 18.3 and 19.5 °C, respectively, which are all well below the reported optimum for sorghum. The American hybrid 'FS 4', which gave the best yield performance in this group, has apparently responded favourably to the increased temperature at Naivasha. The grain yield obtained here ranked No 3 which was significantly better than maize cv. 'H 613' ($P < 0.05$). The presence of severe mould on the grain rendered the produce useless however.

The *miscellaneous sorghums,* containing cultivars which have found a limited place in the agriculture of the Kenya highlands as grazing forages, failed to attain a yield level to qualify for the highest ranks. Since their success was under regimes of frequent defoliation, it is hardly surprising that they performed poorly as a long season crop with a single harvest date. In this group velvet sorghum scored highest, which agrees well with earlier work on these sorghums (Boonman, 1969).

The *grasses* proved unable to rank consistently among the highest producing entries, on account of the potential DM production which was lost during the relatively long-lasting establishment phase. At the Lanet 1 trial site, where rainfall during the first month after sowing was higher than at the other two sites, the grasses established much faster and were able to rank 10th and 13th for Bana and Rhodes grass, respectively. It is clear, however, that no full evaluation of any grass can be given if productivity during the establishment year only is taken into account.

The *sunflowers* demonstrated the largest interaction between trial site and crops. Some sunflower entries at Naivasha qualify for the very highest DM yield level reached in a relatively short period of time, bringing the growth rate at 199 kg DM $day^{-1}$ $ha^{-1}$. In contrast, at the Lanet 2 trial site the two best cultivars 'Grey Stripe' and 'Kenya White', only reached a mean growth rate of 46 kg DM $day^{-1}$ $ha^{-1}$. However, it should be noted that the high yield levels were associated with a severe lodging problem. It seems that sunflower is most sensitive to soil depth and that its reported drought resistance is mainly due to an extensive root system rather than due to xeromorphic characteristics. If physical soil properties prohibit the development of such an extensive root system sunflower becomes a vulnerable crop if rainfall is erratic. This is confirmed by Warren Wilson (1966) who studied sunflower under arid conditions in Australia.

*Bulrush millet* is essentially not a cold-tolerant species, and this was reflected in the almost complete absence of seed formation at all three trial sites. Nevertheless, at Lanet 2, where growing conditions were poorest, the composite 'Serere 14' yielded 13.1 DM tons $ha^{-1}$ in 145 days. Its growth rate of 90 kg DM $day^{-1}$ $ha^{-1}$ compares well with the growth rate of the highest-yielding entry 'Hirna 547', i.e. 93 kg DM $day^{-1}$ $ha^{-1}$. The growth rate only has a limited value in the interpretation of our trial data since the available growing season was only partially used as none of the entries produced any appreciable regrowth.

The high DM yield of some of the *HA sorghums* is partly explained by the long growing period required to reach the hard-dough stage (Table 3). Within the group of HA sorghums there is a large variability in grain yield. 'E 1291' and to a lesser extent 'E 5766' produced consistently the highest grain yield at a relatively lower total DM level. It seems therefore appropriate to classify them as grain types, whereas the other cultivars displayed a more forage-type performance with higher DM yields and lower grain yields. Within the latter sub-group grain formation is almost absent in some entries. This was caused by a slow plant development whereby plant heading took place too late in the season to allow successful grain formation.

'E 1291', 'E 5766', 'E 6518' and 'E 1429' were completely free from lodging or any other serious 'set-back'. A small infection of bacterial stripe was recorded in all four cultivars, but this disease is reported to have little effect on crop productivity

(Edmunds et al., 1970). All four lines were also infected, though very slightly only, with rust, which invaded the older leaves in the later stages of growth. Rust inoculum was also present during the early stages of growth (some lowland sorghums were heavily affected in that stage), and this demonstrates some form of resistance of the four HA lines. Horizontal resistance is not present however and the lines under discussion must be kept under close observation since new, potentially dangerous, rust races may develop.

It appears from the yield figures that the more xeromorphic character of the HA sorghums did not result in a consistently higher DM yield than maize. Three possible explanations offer themselves. The infection with foliage diseases may have affected the production of certain HA sorghum lines to an unpredictable and variable degree. This could explain the interaction between trial site and yield of 'Hirna 547'. The maize entries used in this study are lines resulting from intensive breeding and selection work, and are therefore well adapted to the local ecological conditions. The HA sorghums, by contrast, are new introductions and it is likely that by breeding and selection they will relatively easily produce lines of superior productivity. Thirdly, it may well be that the HA sorghums, of which very little is known about their optimal crop husbandry, would have benefited from different plant spacings. The latter two aspects are examined in the next paragraph.

*The scope for obtaining yield increases*

A problem when commencing a screening trial of this nature, is that of identifying the optimal management practice for each crop. Thus although the planting densities chosen were within the accepted range of good husbandry practices for each species, it is possible that individual groups would have benefited by the use of higher or lower populations. To investigate this subject further, and also to examine the prospects for improvement by selection and breeding, the original data for Table 3 have been subjected to correlation analysis.

In view of the importance attached to lodging as a factor which reduces the net yield of a forage crop when it is made into silage, particular attention has been paid to the importance of stem length and tiller population as they affect forage yield (Table 4).

The question of whether the correlation between two variables is statistically significant, is different from that of how much the variability of one character explains the variation in another. This is clearly demonstrated if one compares the combined effects of stem length and tiller population on the total yield of sunflower and HA sorghum (Table 4). In both cases the correlation is highly significant ($P < 0.001$) but the explanatory value (D%) varies from over 90 % for sunflower to only just one third for sorghum.

Stem length can be varied according to the choice of cultivar planted, and tiller population is a function both of cultivar and seeding rate; guide as to the relative importance of these two factors can be obtained from a study of the standard partial correlation coefficients shown in the table. For example, the coefficients for stem length and tiller population for HA sorghums are 0.51 and 0.24, respectively. This implies that the statistical chance of obtaining a higher yield is equal whether one

Table 4. Multiple correlation calculated for the correlation between stem length and tiller population, and the yield of the various groups of crops for all three trial sites.

| Crop | Degrees of freedom | Total DM yield[1] | | | | Grain yield[1] | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | r | D% | b1 | b2 | r | D% | b1 | b2 |
| Maize | 25 | 0.80*** | 64.0 | 0.68*** | 0.35** | 0.63*** | 39.9 | 0.63*** | —0.17 |
| Lowland sorghum | 138 | 0.57*** | 32.0 | 0.58*** | 0.09 | 0.45*** | 19.8 | 0.42*** | —0.09 |
| Miscellaneous sorghum | 42 | 0.82*** | 66.4 | 0.82*** | 0.02 | 0.62 *** | 37.9 | 0.62*** | 0.04 |
| Sunflower[2] | 65 | 0.95*** | 90.1 | 0.76*** | 0.28*** | 0.88*** | 77.4 | 0.41*** | 0.57*** |
| Bulrush millet[2] | 40 | 0.09 | 0.8 | 0.07 | 0.04 | 0.80*** | 63.3 | 0.56*** | 0.51*** |
| High altitude sorghum | 90 | 0.58*** | 33.7 | 0.51*** | 0.24*** | 0.22 | 4.8 | —0.22* | 0.02 |

[1] r multiple correlation coefficient; D% factor of determination; b1 standard partial correlation coefficient for stem length; b2 standard partial correlation coefficient for tiller population; * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.
[2] Grain yield and grain % for sunflower is based on the unthreshed heads.

Table 5. Multiple correlation calculations for the correlation between stem length and tiller population, and the dry matter distribution of maize, sunflower and HA sorghum.

| Crop | Degrees of freedom | Leaf % | | | | Stem % | | | | Grain % | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | r | D% | b1 | b2 | r | D% | b1 | b2 | r | D% | b1 | b2 |
| Maize | 25 | 0.46 | 20.9 | —0.19 | 0.44* | 0.71*** | 50.0 | 0.28 | 0.62*** | 0.59** | 34.5 | 0.01 | —0.59** |
| Sunflower | 65 | 0.82*** | 66.6 | —0.48*** | —0.43*** | 0.90*** | 80.8 | 0.97*** | —0.13 | 0.71*** | 50.9 | —0.87 *** | 0.38** |
| HA Sorghum | 90 | 0.06 | 0.4 | —0.03 | 0.05 | 0.58*** | 33.4 | 0.57*** | 0.04 | 0.46*** | 20.7 | —0.45*** | —0.06 |

chooses a 10 % taller variety or a 21% higher tiller population.

The problem posed by these findings hinges around the fact that stem length, and to a lesser extent tiller population, are also positively correlated with the susceptibility to lodging. From the point of view of mechanical forage harvesting shorter crops than the presently used maize cultivars would be advantageous. It is, therefore, of particular importance to know about the possibilities of achieving higher yields without increasing stem length or population. This is indicated by the differences not accounted for by the multiple regression (i.e. 9.9 % for sunflower, 36.0 % for maize and 66.3 % for sorghum). The disadvantage of sunflower can further be seen from a simple linear regression calculation which revealed that 85.2 % of total plant yield differences can significantly ($P < 0.001$) be explained by plant length differences only. The fact that eight different sunflower cultivars, varying in average height from 94 to 385 cm, were planted at three ecologically different trial sites and that such a large proportion of the yield variance was correlated with plant length differences, indicates that there is little scope left for exploring the variability towards finding high DM yielding varieties of reduced length and thus reducing lodging susceptibility.

Grain yield is also positively correlated with stem length and tiller population except for HA sorghums. This implies that whereas for maize tallness is an apparent necessity for high grain yields, there is a small but significant indication that shorter crops produce higher grain yields for HA sorghum.

The implication of this correlation analysis is that there appears to be scope for choosing HA sorghum lines with high yields of DM and grain within the range of variability used. For the other group of crops the scope for such a choice is far more limited. Presumably, further improvement by selection and breeding can be achieved more easily with the HA sorghums as parent material than with the maize or sunflower lines which were studied. It should be noted, however, that the analysis is valid only over the range of the relatively narrow genetic base available for this study.

The analysis in Table 5 shows the correlation between stem length and population and the plant components. It has been assumed that leaf % and grain % will have a positive influence on the nutritive value of the forage. Once again it appears that the situation is most favourable in the HA sorghums group, since a reduction in stem length is accompanied by a lower stem % and increased grain %. If shorter varieties are then planted more densely, there will be no noticeable effect on DM distribution, within the range considered. For sunflower the combined effect of plant size reduction and increased population has a similar effect on DM distribution to HA sorghums. Maize, by contrast, does not have a changed plant composition where shortened, but when planted at higher population its stem proportion and leaf proportion is increased at the expense of grain formation.

## Conclusions

In plant introduction work, the results of a single year are an insufficient base for definite conclusions. However, it is clear from the data presented that cold-tolerant sorghums look to be the most promising of the groups studied and, therefore, warrant further investigations. Some of these sorghums produced yields equal to, or more than maize. An important factor in favour of sorghum proved to be its lodging resistance. This ensures that the nett yield under commercial systems of cultivation will be close to the yields measured in these trials. Maize, by contrast, will, under such large-scale cultivation systems, produce a lower yield because of its harvesting losses. The observation on lodging combined with the correlation calculations presented above suggest that sorghum yields can be improved further by planting higher populations, whereas maize yields will be reduced owing to the necessity of lower plant populations. It is further argued that the scope for obtaining yield increases by selection and breeding is greater for sorghum than for maize. The HA sorghum cultivars 'E 6518' and 'E 1429' for total DM yield, and 'E 1291' for grain yield, appeared as the most promising lines. A clear disadvantage of the HA sorghums proved to be their comparatively slow initial growth, which increased the problems with weed control.

As a result of the above analysis, work was put in hand to enable a further evaluation of the place of HA sorghums in feedlot farming, and to investigate how their productivity can be improved upon. Specific areas of field experimentation include the following.

1. Given the difference in lodging susceptability between maize and sorghum and the mechanical harvesting losses resulting from it, studies were undertaken to establish the relation between experimental plot yields and yields obtained in large-scale mechanical harvesting systems.
2. Studying the effect of different methods of weed control on sorghum production.
3. Investigating the influence of fertilizer application on yield and quality of sorghum grown under different rainfall regimes.
4. Establishing the growth curves of sorghum as affected by environment and plant population in relation to those of maize.
5. Examining the feeding value of sorghum as affected by agronomic practices, grain content and time of harvest in relation to maize.
6. Studying the yield stability of HA sorghum under different ecological conditions.

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**Paper II**

# The forage and grain yield of sorghum and maize as affected by soil moisture conservation, lodging and harvesting losses

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# The forage and grain yield of sorghum and maize as affected by soil moisture conservation, lodging and harvesting losses

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*Key words:* forage crops, sorghum, maize, lodging, harvesting losses, soil moisture conservation, cold tolerance, drought resistance

**Summary**

The effects of early ploughing (before the start of the dry season) and late ploughing on the yields of a forage maize, and cold-tolerant forage and grain sorghum crops are reported. It appeared that on a shallow soil no significant effects on crop producton could be shown. But on a deep soil with good water-holding capacity, crop yields were increased considerably by reducing soil moisture evaporation in the dry period prior to the growing season.

The forage sorghum outyielded the maize, a difference which was accentuated when mechanized harvesting systems were used in lodged crops. The forage sorghum proved to be more lodging-resistant than maize but, even when lodged, was harvestable without too much difficulty. The use of small-plot maize yield trials is considered to have limited applicability to mechanized harvesting systems when presently available Kenyan maize hybrids are used. Lodging was the major limiting field factor for the harvesting of heavy maize crops.

The highest net yields recorded for maize and sorghum were 12.0 and 23.7 tons DM $ha^{-1}$, respectively. The higher yield of sorghum was probably not due to better drought resistance but to a lower lodging susceptibility and a longer growing period.

## Introduction

In an earlier paper (van Arkel, 1977) the introduction of new sorghums, (*Sorghum bicolor* (L.) Moench), originating from the highlands of Ethiopia and Uganda, into the highlands of Kenya was discussed. It appeared that some sorghums equalled or outyielded maize (*Zea mays* L.) in terms of total dry matter (DM) production or grain yield. All yields reported were based on carefully hand-harvested small experimental plots and the observation was made that most maize plants had lodged severely. Hence the question was posed whether sorghums would have a greater advantage over maize if large-scale mechanical harvesting systems were used because of the expected harvesting losses in lodged maize crops.

Cultivation methods to conserve soil moisture are of prime importance in many dryland farming systems. A comprehensive discussion of these methods is given by Arnon (1972). In Kenya, however, little attention has been paid to this aspect of crop yield improvement as yet. No reports with regard to soil moisture conservation for forage crops are available. However, a study on wheat *(Triticum* spp.) (Poulsen, 1974) showed that under a 739-807 mm unimodally distributed annual rainfall and at 2135 m elevation, ploughing at the very beginning of the dry season conserved up to 125 mm of additional soil moisture, as compared with ploughing later in the same season. This early ploughing resulted in up to a 50 % increase in subsequent grain yield.

The newly introduced, promising, cold-tolerant, high-altitude sorghums were grown in an area which is ecologically similar to the area which Poulsen had used. Hence the question arose whether sorghum yields could be increased by early ploughing to a similar extent.

The present paper describes two experiments designed to evaluate the effect of ploughing date on the yield of sorghum. At the same time the experiments were designed to study the difference between the yield obtained by careful hand-harvesting and mechanical harvesting, thus estimating the harvesting losses. In each of the two experiments two of the newly introduced cold-tolerant sorghums were compared with maize, which is currently the crop of choice in feedlot farming, to give a comparative baseline. Experimental observations on the incidence of lodging, and how lodging effects harvesting losses are discussed.

## Materials and methods

### *Trial sites*

Both experiments were conducted on the farm of the Kenya Government Beef Research Station near Nakuru. The study conducted formed part of the activities of the UNDP/FAO-sponsored Kenya Beef Industry Development Project.

*Experiment 1* was laid down on a sandy loam with a shallow (approx. 30 cm) topsoil overlaying a murram-pumice-lava mixture with a small water-holding capacity. In the previous year (1974) the trial area of the experiment had been used for nine strips (35 m $\times$ 400 m) each of a different crop of either maize, sorghum or sunflower *(Helianthus annuus* L.). The trial site was located 40 km south of the equator at an elevation of 1860 m. The average rainfall of the last 8 years was 786 mm. The rainfall distribution for 1974 and 1975 is shown in Fig. 1.

*Experiment 2* was laid down on a deep well-drained sandy loam, with excellent water-holding capacity. In the previous year (1974) the trial area of the experiment had been planted to a crop of forage maize. The trial site was located 35 km south of the equator at an elevation of 1920 m. The average rainfall

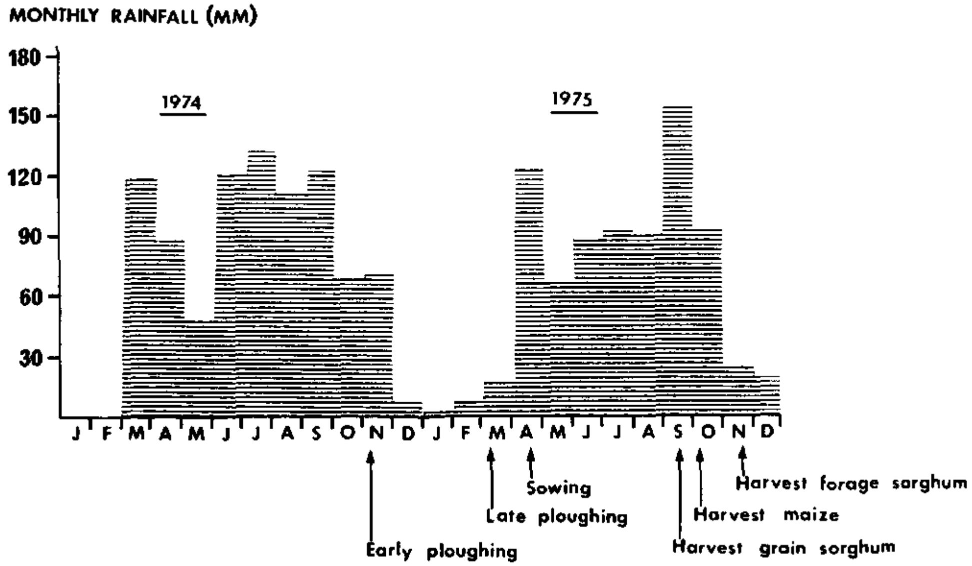


Fig. 1. Monthly rainfall during 1974 and 1975 and timing of operations in Experiment 1.

during the last 8 years was 960 mm. The rainfall distribution for 1974 and 1975 is shown in Fig. 2.

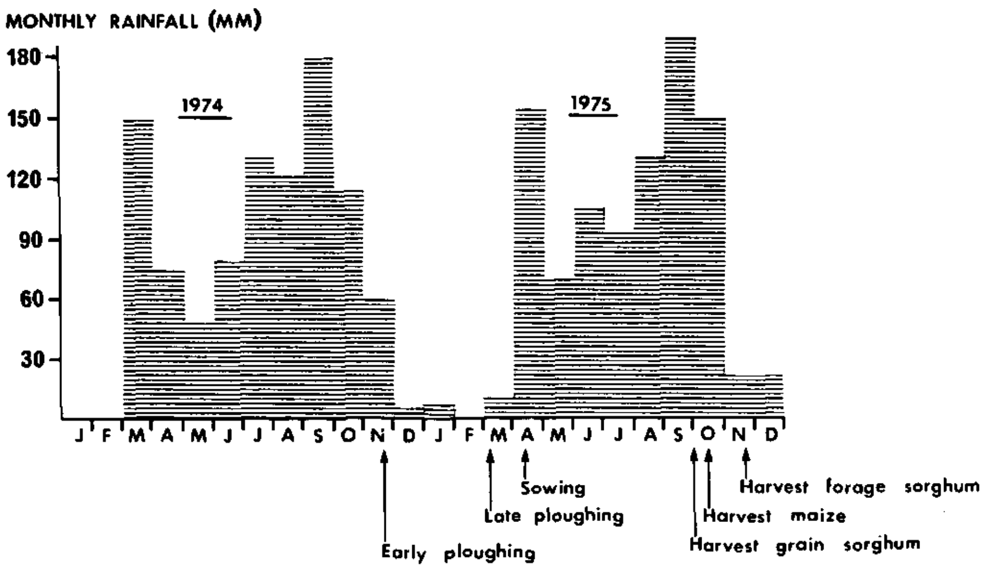


Fig. 2. Monthly rainfall during 1974 and 1975 and timing of operations in Experiment 2.

*Crops*

The four crops studied were:
1) maize cv. 'H 613', a tall relatively late-maturing Kenya hybrid;
2) sorghum cv. 'E 1291', a relatively short, non-tillering cold-tolerant grain type;
3) sorghum cv. 'E 5766', a medium tall non-tillering, cold-tolerant type;
4) sorghum cv. 'E 6518', a tall multi-tillering, cold-tolerant forage type.
A more detailed description of the production characteristics and origin of the cultivars is given by van Arkel (1977).

*Ploughing date and experimental design*

In preparation for Experiment 1, the nine crop strips from 1974 were treated in the following manner. After harvesting the crops in 1974, each strip was divided into two halves; one was randomly selected to be ploughed immediately and kept bare until the planting season of 1975; the other received a soil moisture depletion treatment by not ploughing until just before the rains started in 1975.

In April the field was sown to maize and grain sorghum 'E 1291' and forage sorghum in three strips 350 m long by 130 m wide, so that the strips were at right angles to the 1974 strips.

In preparation for Experiment 2, the trial area which was sown to forage maize in 1974 was divided into 4 sections after harvest. Two of those sections, randomly selected, were ploughed immediately and kept bare by cultivating twice during the dry season. The other two sections were ploughed just before the rains of 1975. Each of the four sections was then sub-divided into three strips of 25 m $\times$ 120 m to which maize and grain sorghum 'E 5766' and forage sorghum were allocated at random.

In both experiments the whole field was sprayed pre-emergence with atrazine at 2.5 kg $ha^{-1}$ active ingredient (a.i.) two days after sowing. The atrazine was very effective against most broadleaved weeds, but not very effective against grasses, mainly *Cyperus esculentus* (L.) and annual *Setaria* spp. In both experiments the plant density for the forage sorghum was 11 plants per $m^2$. The plant density for the grain type sorghums in both experiments was around 18 plants per $m^2$. The plant density of maize was purposely kept under the recommended density of 4.8 plants per $m^2$ to reduce the risk of lodging. After plant establishment the average density was 3.6 plants per $m^2$.

Both experiments were fertilized with 20 kg N $ha^{-1}$ and 60 kg $P_2O_5$ $ha^{-1}$ in bands of compound fertilizer 15 - 45 - 0 at the rate of 133 kg $ha^{-1}$ applied at sowing. All crops received a top dressing of 39 kg N $ha^{-1}$ by broadcasting calcium ammonium nitrate at the rate of 150 kg $ha^{-1}$ when the crops had reached a height of 70 cm.

In both experiments the crops were harvested with a forage harvester at the hard-dough stage of the grain. For the maize and forage sorghum, which had been sown in rows 85 cm apart, a row attachment was used on the harvester. The non-tillering grain type sorghums had been sown in 45 cm wide rows which were first cut with a reciprocating cutter bar, after which the crop was immediately picked up with the forage harvester fitted with a pick-up reel. The trailer loads were weighed on a weigh-bridge and samples were taken for DM analysis.

The exact time of ploughing, sowing and harvesting in relation to the actual rainfall can be seen from Fig. 1 and 2.

One day before mechanical harvesting, from each plot were taken one (Exp. 1) or five (Exp. 2) handcut samples, each from 4.25 $m^2$. These samples were taken to the laboratory for further plant component dissection and DM analysis.

It was assumed that the yields computed from the handcut samples gave the best estimate of the true yield because care was taken not to loose any plant material. From the comparison between this yield figure and the yield obtained by using the forage harvester, the harvesting losses were calculated.

*Lodging*

In Experiment 1 no lodging was observed, but the lodging in Experiment 2 was measured by two different techniques. For maize, where individual plants had fallen surrounded by unlodged plants, a few sample rows were taken and the number of lodged (angle of stem $<60°$) plants were counted against the number of standing plants. For sorghum, which showed scattered patches in which all plants had lodged, an aerial grid estimation of the lodged proportion was made.

During the course of the experiments it was thought useful to obtain additional information on lodged versus unlodged forage sorghums. From each of eight different commercial sorghum fields, five lodged and five non-lodged adjacent patches, selected at random, were sample harvested (4.25 $m^2$ each) and taken to the forage laboratory for component analysis.

## Results

*Experiment 1*

Table 1 shows that ploughing date did not have a significant effect on either total DM yield or on grain yield. Thus the amount of soil moisture which was preserved in the soil by early ploughing was probably too little to ensure better growth in the following crop. The observation that the weeds left in the un-

Table 1. Effect of ploughing date on the total DM yield and grain yield of maize cv. 'H 613', grain sorghum cv. 'E 1291' and forage sorghum cv. 'E 6518' in Experiment 1 (tons $ha^{-1}$). (All yields obtained from hand-cut samples.)

| Ploughing time | Maize 'H 613' | | Grain sorghum 'E 1291' | | Forage sorghum 'E 6518' | | Average | |
|---|---|---|---|---|---|---|---|---|
| | total DM | grain | total DM | grain | total DM | grain | total DM | grain |
| early | 9.3 | 3.2 | 6.3 | 1.9 | 10.2 | 2.9 | 8.6 | 2.7 |
| late | 9.2 | 3.3 | 6.1 | 1.8 | 10.4 | 2.6 | 8.6 | 2.6 |

SE total DM yield = 1.32 tons $ha^{-1}$; SE grain yield = 0.73 tons $ha^{-1}$.

Table 2. Harvested and grown DM yields for the three crops studied in Experiment 1.

| | Total field[1] DM yield (tons $ha^{-1}$) | Mean sample[2] DM yield (tons $ha^{-1}$) | Harvesting losses (tons $ha^{-1}$) | Harvesting losses (%) |
|---|---|---|---|---|
| Maize 'H 613' | 10.0 | 9.3 | 0.7 | −7.5 |
| Grain sorghum 'E 1291' | 5.9 | 6.2 | 0.3 | + 4.8 |
| Forage sorghum 'E 6518' | 11.1 | 10.3 | −0.8 | −7.8 |

SE of sample yields = 555 kg $ha^{-1}$.
[1] Yields obtained by using a tractor-driven forage harvester.
[2] Yields obtained by careful hand harvesting.

ploughed sections started wilting soon after the dry season of 1974/75 had started supports this finding.

Table 2 shows that there were no significant differences between the sample yields and the actual yields. This indicates that at the relatively low yields of Experiment 1, harvesting losses did not occur.

*Experiment 2*

The amounts of DM grown after early and late ploughing were consistently higher after the former for each crop (Table 3a). The increase varied from 12.3 % for maize to 24.6 % for grain and 10.8 % for forage sorghum. Maize and forage sorghum showed heavy lodging in the early ploughed plots, and this is probably the reason why the grain sorghum benefited relatively much more from early ploughing. The yield differences between the three crops studied are so large that they tend to overshadow the effects of ploughing date. Table 3b, however, shows clearly that the ploughing date effect on DM production is statistically significant ($P<0.01$).

In all three crops, harvesting losses were higher after early ploughing. Despite the increased harvesting losses in the heavier crops, early ploughing resulted in higher final yield for the two sorghums. By contrast, for the heavier maize crop the final net yield was not appreciably different from the lighter, late ploughed maize. This was because the extra harvesting losses due to lodging in the early ploughed treatment exceeded the increased DM production.

## Discussion

*Ploughing date*

Early ploughing as a means of preserving soil moisture apparently only results in increased crop production on soils with a sufficiently high water-holding capacity. Visual observations in Experiments 1 and 2 showed that late ploughing allowed many weeds to produce viable seeds. In both experiments most of the resulting weeds were successfully killed by the herbicide. It must be assumed that if weed control would not have been so successful, the yield reduction from late ploughing would have been larger.

On soils with a good water-holding capacity the beneficial effects of early ploughing are partly reduced by increased harvesting losses. Statistically there is no significant crop × ploughing date interaction for the harvesting losses. This means that the extra percentage of harvesting losses due to early ploughing is not necessarily different for the three crops studied. However, there is a tremendous interaction for the practising farmer because, for both sorghums, the extra harvesting losses due to early ploughing, are a small insignificant proportion of the total forage yield. For maize, by contrast, the extra amount of unharvested forage is a relatively important quantity and a significant proportion of the amount which is brought to the silage pits (16.9 %).

*Crop comparison*
In a previous paper (Arkel, 1977) the need for a forage crop more drought-resistant than maize has been argued. Cold-tolerant sorghum was presented as a possible source of promising material. Now the question again arises as to whether these sorghums indeed fulfil this need. The yield data presented in the present study fail to demonstrate the more drought-resistant nature of the sorghums. The productivity of the forage sorghum was 10.1 % higher than the

ble 3a. The effect of ploughing date on the performance of maize and two sorghums in experiment 2.

| | Early ploughing | | | Late ploughing | | |
|---|---|---|---|---|---|---|
| | maize 'H 613' | grain sorghum 'E 5766' | forage sorghum 'E 6518' | maize 'H 613' | grain sorghum 'E 5766' | forage sorghum 'E 6518' |
| 1 production (tons ha$^{-1}$) | 16.4 | 19.2 | 24.7 | 14.6 | 15.4 | 22.3 |
| t DM yield harvested (tons ha$^{-1}$) | 11.8 | 18.2 | 23.7 | 12.0 | 14.8 | 22.1 |
| rvesting losses (tons ha$^{-1}$) | 4.6 | 1.0 | 1.0 | 2.6 | 0.6 | 0.2 |
| rvesting losses (%) | 28.3 | 5.3 | 4.1 | 17.8 | 3.9 | 0.9 |
| ain (%) | 29.3 | 23.4 | 19.4 | 34.9 | 26.6 | 24.7 |
| ain yield (tons ha$^{-1}$) | 4.8 | 4.5 | 4.8 | 5.1 | 4.1 | 5.5 |
| dging (%) | 33.2 | 2.0 | 76.7 | 18.7 | 0.0 | 8.3 |

ble 3b. Analysis of variance on production data from Experiment 2, as shown in Table 3a.

| | Ploughing date | | Crops | | Ploughing date × crops interaction | |
|---|---|---|---|---|---|---|
| | SS (%)[1] | P | SS (%)[1] | P | SS (%)[1] | P |
| 1 production (tons ha$^{-1}$) | 12.2 | ** | 81.6 | *** | 1.8 | n.s. |
| t DM yield harvested (tons ha$^{-1}$) | 2.8 | * | 92.8 | *** | 2.6 | n.s. |
| rvesting losses (tons ha$^{-1}$) | 6.2 | * | 84.5 | *** | 3.3 | n.s. |
| rvesting losses (%) | 7.1 | * | 82.8 | *** | 3.6 | n.s. |
| ain yield (tons ha$^{-1}$) | 5.1 | n.s. | 51.2 | * | 19.4 | n.s. |
| dging (%) | 26.9 | *** | 44.1 | *** | 28.6 | n.s. |

SS % = percentage of total sum of squares due to the level of significance.
P < 0.05; ** P < 0.01; *** P < 0.001; n.s. = not significant.

lodging is the result of a heavier crop, because lodging-causing diseases or pests were not present. The yield figures in Table 4, however, significantly suggest that the lodged sorghum had a lower yield at harvest. This must mean that during the period from lodging till harvest, i.e. the last 2½ months of growth, the unlodged crop had a faster growth rate than the lodged crop. Also, crop development in the lodged crops was significantly retarded, resulting in a lower grain percentage ($P<0.001$). This shows that lodging, also in sorghum, is disadvantageous and should be prevented where possible.

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Paper III

# Fertilizer response of cold-tolerant sorghums under semi-arid high-altitude conditions

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# Fertilizer response of cold-tolerant sorghums under semi-arid high-altitude conditions

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*Key words:* Sorghum, cold tolerance, fertilizer, nitrogen, phosphorus, potash, magnesium, forage yield, grain yield, forage quality, digestibility, protein content

**Summary**

Five fertilizer trials were carried out over 1974 and 1975 at three different high-altitude locations in Kenya. In three of the five trials the yield response of a grain type sorghum cultivar was compared to the response of a forage type sorghum to nitrogen (N) and to phosphorus (P). In the other two trials the yield response of a grain type sorghum to N, P, potash (K) and magnesium plus zinc, boron and copper (M) was studied. Rainfall during the field period of the crop varied from 225 mm to 811 mm. There was no interaction with years, but the responses varied greatly with trial site.

Although DM yields obtained from the grain type in the driest trials were considered good, (4.9 tons DM $ha^{-1}$ on 255 mm and 7.2 tons DM $ha^{-1}$ on 294 mm), no response to N or P was observed.

Under wetter conditions it appeared that N increased the total DM yield of the forage type cultivar and the grain yield of the grain type cultivar: the type was accentuated. P increased the grain yield and total DM yield of the grain type cultivar. Both N and P increased the protein content of the forage sorghum, but with the grain sorghum only N increased protein % whereas P decreased protein %.

K and M had a positive influence on yield in two experiments, but more work is needed to evaluate this effect in detail.

Yield and forage quality differences resulting from different fertilizer applications were small. One possible reason for this is nitrogen-fixation in the soil, but more research is needed to substantiate this.

In the trials with the lowest rainfall, the earlier maturing grain type outyielded the forage type, but if rainfall was less limited the forage type had a clear advantage over the grain type.

## Introduction

Considerable work has been done on the relationship between fertilizer input and growth response of sorghum *(Sorghum bicolor* (L) Moench). A worldwide review of recommendations is published by de Geus (1973) while Kramer & Ross (1970) discuss the accumulated knowledge on fertilizer response in America. Recommendations are low and growth response to nitrogen (N) shows more in stover than in grain production, whereas with phosphorus (P) the reverse holds true.

Sorghum can be a relatively heavy user of the major fertilizer elements and can be similar to maize in total uptake. In spite of this the crop is often grown without added nutrients. Even in America where sophisticated husbandry practices dominate, in 1964 only 50 % of the total area under sorghum was fertilized. Sorghum is often grown under marginal conditions, resulting in relatively low yields. The low usage of fertilizer is therefore due to the fact that yields are usually not high enough to be seriously limited by nutrient supply.

In highland locations of Kenya, new cold-tolerant sorghum introductions from Ethiopia and Uganda have given promising forage and grain yields (van Arkel, 1977a, 1978) and information upon the response of these sorghums to fertilizer input was required. Existing information for maize in the wetter parts of the Kenya highlands showed a good response to P, but no consistent response from N could be recorded (Sheldrick, 1974). Another study with maize under drier high-altitude conditions showed a variable response to N and concluded that increased N rates soon lead to precocious lodging, thus precluding a positive N response (Anon., 1970).

The present study was undertaken in 1974 and 1975 to examine the response of cold-tolerant sorghums to N and P fertilizer applications under semi-arid highland conditions. In 1975 an additional trial was sown to investigate a possible response interaction with applied potash (K) and magnesium plus trace elements (M).

## Materials and methods

The experiments were conducted in Kenya during 1974 and 1975 at two locations of the Kenya Governments Beef Research Station (BRS) near Nakuru and at the experimental farm of the East African Agriculture and Forestry Research Organization (EAAFRO) near Athi River. A brief description of the soil at each trial site is given in Table 1.

The design for Experiment 1 was a $2 \times 3^2$ factorial replicated twice. This experiment was conducted at the BRS at site 1 in 1974 and at EAAFRO during 1974 and 1975. Two cultivars were used, a tall forage type cultivar, 'E 1372' at BRS and 'E 6518' at EAAFRO, and a shorter grain type cultivar, 'E 5766' at the BRS and 'E 1291' at EAAFRO. There were nine fertilizer treatment combinations (39, 91 and 143 kg $ha^{-1}$ of N, each at 0, 52 and 104 kg $ha^{-1}$ of $P_2O_5$). The N was applied as calcium ammonium nitrate (26 % N) of which half was incor-

Table 1. Brief characteristics of the three experimental sites.

| Site | Altitude (m) | Distance south of the Equator (km) | Chemical analysis of the soils | | | | Descriptive characteristics of the soils |
|---|---|---|---|---|---|---|---|
| | | | pH ($H_2O$) | K (meq) | P (mg/kg) | N (%) | |
| BRS (1) | 1860 | 40 | 5.5 | 1.0 | 19 | 0.10 | Soil of recent volcanic origin. Thin (20-30 cm), sandy loam topsoil overlaying murram, pumice lava mixture. Little water-holding capacity. |
| BRS (2) | 1920 | 35 | 5.5 | 1.6 | 30 | 0.23 | Deep sandy loam soil with good water-holding capacity. |
| EAAFRO | 1580 | 157 | 5.5 | 5.5 | 20 | 0.12 | Brown sandy loam topsoil, overlaying deep sandy clay subsoil. Good water-holding capacity, but subsoil has a low water permeability. |

Table 2. Monthly rainfall data for the three experimental sites and two years of experimentation.

| Month | Rainfall (mm) at site | | | | |
|---|---|---|---|---|---|
| | BRS (1) | | BRS (2) | EAAFRO | |
| | 1974 | 1975 | 1975 | 1974 | 1975 |
| January | 0 | 4 | 8 | 6 | 2 |
| February | 0 | 10 | 0 | 9 | 4 |
| March | 121 | 19 | 10 | 114 | 63 |
| April | 88 | 123 | 156 | 119 | 78 |
| May | 48 | 66 | 70 | 30 | 128 |
| June | 120 | 88 | 103 | 42 | 0 |
| July | 133 | 95 | 92 | 35 | 19 |
| August | 111 | 89 | 129 | 12 | 0 |
| September | 124 | 153 | 190 | 1 | 8 |
| October | 68 | 94 | 151 | 8 | n.d. |
| November | 72 | 23 | 20 | 0 | n.d. |
| December | 10 | 17 | 23 | 0 | n.d. |

porated in the seedbed and half was broadcast as a top dressing. The P was given as single superphosphate (21 % $P_2O_5$) which was applied at sowing in a band 5 cm to one side of the seed.

In view of the small response obtained at the BRS in 1974, a second experiment different from the above, was designed as a $2^4$ factorial. This experiment was conducted in 1975 at trial sites 1 and 2 of the BRS. The following factors and levels were used:

Nitrogen: 0 and 80 kg $ha^{-1}$ of N
Phosphorus: 0 and 100 kg $ha^{-1}$ of $P_2O_5$
Potash: 0 and 150 kg $ha^{-1}$ of $K_2O$
Mineral mix (M): 0 and 300 kg $ha^{-1}$ of the mix.[1]

N was applied as in the first experiment. P was applied as triple superphosphate (44 % $P_2O_5$) and banded at sowing. K (muriate of potash) and M were broadcast and incorporated into the seedbed on the day of sowing. Four plots were combined in a block and the following interactions were confounded with blocks: N×P×K and K×M. The experiment was replicated twice and the grain type sorghum 'E 5766' was used as the test cultivar.

The rainfall distribution for the five trials is given in Table 2. The trials were sown as soon as possible after the top 15 cm of the soil became wet at the start of the rainy season. This varied from between 1 April and 22 April. A plant population of 14.3 $m^{-2}$ (70 cm × 10 cm) was attained by thinning a thickly sown stand 14 and 28 days after sowing. The plot size for all trials was 4.9 m × 5.0 m with 7 rows 70 cm apart.

For both the grain and the forage type sorghums, harvests were taken at the

[1] The 300 kg mixture contained 75 kg MgO as $MgSO_4$, 3 kg Cu as $CuSO_4.10H_sO$, 2 kg B as $Na_2B_2O_7$ and 4 kg Zn as $ZnSO_4$.

hard-dough stage of the grain. This resulted in the grain type cultivar to be harvested 33 days earlier than the forage type in Experiment 1 at the BRS (1) site. At the EAAFRO site the grain type was harvested 22 days earlier than the forage type in both years.

In all five trials, out of each plot the central 3.0 m of the middle three rows were clipped. The plants were removed as close to the ground as possible. The samples obtained were separated into morphological component parts, i.e. stem (stem plus leaf sheaths), leaves (leaf blades), and head (panicle). Of each component a sample was taken and dried in a forced air oven at 90 °C to constant weight. Dried samples were ground over a 1.0 mm screen and analysed for nutritive value. Nitrogen content was determined by the macro-Kjeldahl method. Cell wall constituents (% CWC) were determined by the Neutral Detergent Fiber method described by Van Soest & Wine (1967). The percentage of cell contents (% CC) was obtained by substracting the % CWC from 100. In vitro true organic matter digestibility (TOMD) was established by the method published by Van Soest et al. (1966). From these data the digestibility of the cell walls was computed according to: $\mathrm{Dig}_{\mathrm{cell\ walls}} = 100 - 100\ (100 - \mathrm{TOMD})\ /\ \%\ \mathrm{CWC}$. Apparent digestibility was calculated with the regression established from the true digestibility in vitro of samples of known digestibility in vivo. Multiplication of the apparent digestibility with the organic matter content of the sample gives an estimate of the amount of digestible organic matter in the dry matter (D value).

The determination of TOMD in vitro, organic matter content and the calculation of apparent digestibility and D value was carried out by the forage quality laboratory of the Department of Crop Science and Grassland Husbandry of the Agricultural University at Wageningen. All other analyses were carried out by the forage quality laboratory of this project.

## Results

### *BRS 1974*

The total DM yield and the grain yield of the N×P experiment at the BRS (1974) are shown in Fig. 1. No significant N×P interaction was computed and N effects and P effects may therefore be considered independently. It appears from the data that N significantly increased the total DM yield of the forage type cultivar ($r = 0.65^{***}$) and the grain yield of the grain type cultivar ($r = 0.42^{*}$). Grain yield of the forage type and the total DM yield of the grain type were not affected by N fertilization. P significantly increased the grain yield of the grain type cultivar ($r = 0.42^{*}$) and also the total DM yield of the same cultivar ($r = 0.76^{***}$), but the forage type cultivar was unaffected.

The DM distribution within the plant was not altered by N or P in the forage cultivar but there was a clear and negative N×P interaction in the grain cultivar for grain % and stem % (Table 3). The leaf % was unaffected and averaged 11.2 for the grain type and 12.1 for the forage type. Hence at a low input level of one fertilizer, an increase in the other fertilizer tends to become more visible in stem growth rather than in grain formation. If the crop index is to be main-

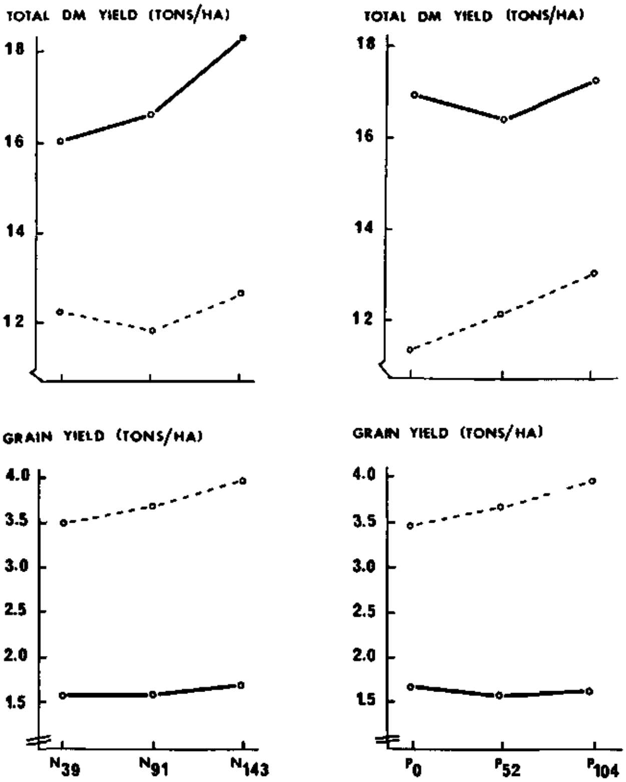


Fig. 1. Yield response of a grain type sorghum ('E 5766') and a forage type sorghum ('E 1372') to N and P fertilizer applications at the BRS in 1974. o———o forage type; o— — —o grain type.

tained or slightly increased, then N and P must be increased simultaneously.

The average protein % and the total protein yield of the total DM is given separately by cultivar and N and P level in Fig. 2. The positive correlation

Table 3. Grain % and stem % of the grain type cultivar (' E 5766') as affected by N and P.

| | Grain (%) | | | Stem (%) | | |
|---|---|---|---|---|---|---|
| | $N_{39}$ | $N_{91}$ | $N_{143}$ | $N_{39}$ | $N_{91}$ | $N_{143}$ |
| $P_0$ | 32.6 | 30.2 | 29.6 | 56.8 | 58.8 | 59.7 |
| $P_{52}$ | 26.8 | 32.7 | 31.2 | 62.1 | 56.3 | 56.7 |
| $P_{104}$ | 27.4 | 30.2 | 33.4 | 61.2 | 57.9 | 55.8 |
| *Source of variation:* | | | | | | |
| $N^*$; $P_{ns}$; $N \times P^{***}$; CV = 14.8% | | | | $N^*$; $P_{ns}$; $N \times P^{***}$; CV = 4.6% | | |

$^*$ $P < 0.05$; $^{***}P < 0.001$; ns = non-significant.

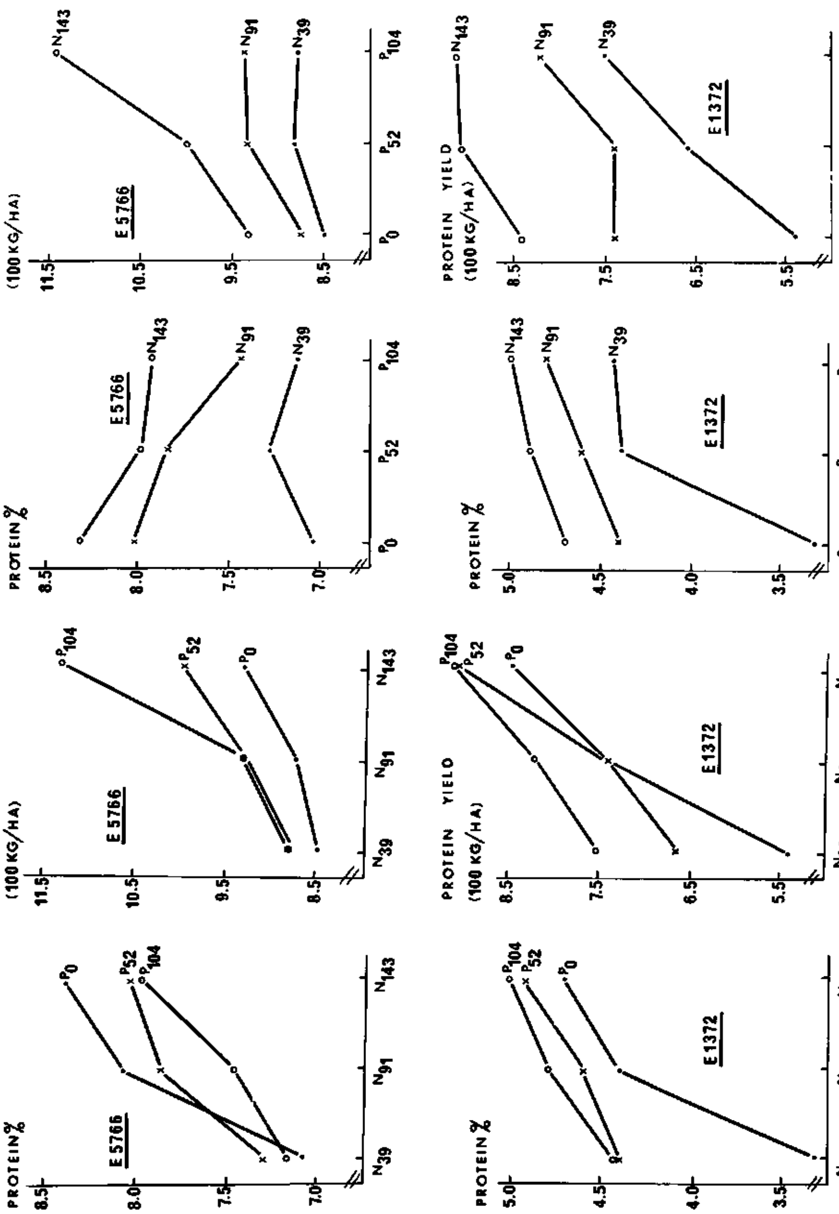


Fig. 2. Protein % and protein yield as affected by N and P for a grain type sorghum ('E 5766') and a forage sorghum ('E 1372') at the BRS in 1974.

Tabel 7. Interaction between P and M for total DM yield and grain yield at trial site 1, BRS 1975.

| | Total DM yield (tons $ha^{-1}$) | | Grain yield (tons $ha^{-1}$) | |
|---|---|---|---|---|
| | $P_0$ | $P_{100}$ | $P_0$ | $P_{100}$ |
| $M_0$ | 6.5 | 7.5 | 1.29 | 1.66 |
| M+ | 8.1 | 7.3 | 2.04 | 1.78 |

Table 8. Interaction between P and M for total DM yield and grain yield at trial site 2, BRS 1975.

| | Total DM yield (tons $ha^{-1}$) | | Grain yield (tons $ha^{-1}$) | |
|---|---|---|---|---|
| | $P_0$ | $P_{100}$ | $P_0$ | $P_{100}$ |
| $M_0$ | 19.4 | 20.1 | 4.73 | 5.13 |
| M+ | 20.4 | 19.0 | 5.28 | 4.10 |

negative interaction $M \times P$ ($P<0.01$) (Table 7). It is difficult to detect which element of the mixture was responsible for the antagonism with P.

The same experiment carried out at trial site 2 resulted in very much higher average yields (Table 8). Despite this no effects of N or K could be demonstrated. The main effects of P and M were curtailed by their significant interaction ($P<0.05$), thus confirming the $M \times P$ negative interaction observed in the trial at site 1.

## Discussion

*Fertilizer effects on yield*

The yield increase resulting from the application of nitrogeneous fertilizer was small in two trials and completely absent in the other three.

The average DM yields obtained at the relatively dry EAAFRO trial sites were high if compared with the yield one may expect to obtain from the natural rangeland vegetation (Le Houerou & Hoste, 1977), and they rank among the very highest forage yields ever obtained at this trial site under these rainfall conditions (Annual EAAFRO reports, 1963-1973). However, the severely limited moisture availability probably accounted for the lack of response and precluded a possible fertilizer effect. But another study with sorghum under similarly dry conditions in Kenya (Anon., 1965) indicated that low applications of N were beneficial, but quantities greater than 33 kg N $ha^{-1}$ decreased yield.

At the much wetter BRS sites, DM yields were considerably higher and comparable to those recorded in other trials (van Arkel, 1977a, 1978). However, yield responses to N were also limited. In one trial, yields were totally unaffected by N and in the other two trials DM yields were increased from 7.5 –

14.6 %. The highest N recovery percentage computed was 31.

Although the low response to N fertilization has also been reported by other workers (e.g. Berra et al., 1971), usually DM yields of forage crops are increased more substantially if the N content in the soil is low and if annual rainfall is between 500 and 1000 mm (Engelstad & Russel, 1973; de Geus, 1973). Singh (1971) working with forage sorghums reported DM yield increases of up to 32 % from 67 kg N $ha^{-1}$. Roy & Wright (1973, 1974) working with grain sorghums under similar conditions found DM and grain yield increases of 39 and 60 %, respectively. N recovery percentages were computed to be around 61. No reports on the response of sorghum to N fertilizer, applied under similar high-altitude conditions were available for comparison. However in a study with forage grasses (*Pennisetum* spp.) at the same BRS sites, van Arkel (unpublished data) measured N recovery percentages of up to 64, which is about twice as high as the N recovery percentage measured in the present sorghum trial.

The exact explanation of the limited response to N is difficult. The possibility of other nutrients being limited in supply thus preventing N effects was disproved by the subsequent experiments in 1975. Other possible explanations such as a high organic matter content in the soil (Keogh & Maples, 1959) or increased insect and pest attacks (Martin, 1963; Rosenow, 1963) did not withstand investigation. Leaching or volatilization is not likely to have played a major role under our conditions (Engelstad & Russel, 1973).

It appears attractive to consider the possibilities of nitrogen fixation under a crop of sorghum. It has been suggested that sorghum can benefit from non-symbiotic nitrogen fixation (Dart, 1977, pers. comm.), but it is clear that more research is needed to substantiate this claim.

In the trials where N did have an influence on yield, it appeared that the forage yield of the forage type cultivar and the grain yield of the grain type cultivar were increased most: the type of the cultivar was accentuated (Fig. 1). The general inference from the results of the three experiments at the BRS is that P was the principal factor which limited the yield of the grain type sorghum. In all three experiments this element led to an increase in grain yield and total DM yield, the only exception being when magnesium and the trace element mixture was added.

*Effects on digestibility*

No significant effect of N or P on the digestibility of the crops was shown. This is in contrast with some work carried out on grasses elsewhere, whereby a clear positive correlation between fertilizer rate and digestibility was demonstrated (Fribourg et al., 1971).

The average D values recorded for the two cultivars (54.2 and 62.6) were well within the range of D values published by Sheldrick (1974). Working with maize grown under high-altitude conditions in Kenya, and in a comparison of different cultivars grown over several years, he found D values from 46.0 to 66.0. Wedin (1970) working with several forage type sorghums in America found D values from 52.0 to 59.1. It must be noted that maize and sorghum grown at higher latitudes in Europe tend to achieve higher D values (Sheldrick, 1971). However, the D values recorded in this study are not exceptional for sorghum grown in the tropics and also the values for component %, ash % and CC % are within the range of exceptability (McDowell et al., 1974). Particularly noteworthy is the high ash % in the leaves of sorghum (Table 4).

Despite the above, the differences in digestibility between the two types of sorghum were conspicuous. This was probably associated with differences in the ages of the crops and with differences in morphological plant composition. The forage type cultivar was 33 days older than the grain type cultivar when harvested. In grasses ageing is associated with a decreasing digestibility. This is not necessarily so with cereals with a good grain yield. Bunting & Gunn (1973) and Sheldrick (1974) have shown that in maize digestibility changes markedly little over time. The quality of the stover decreases during the grain filling period but this is compensated for by the formation of the highly digestible grain. Grasses do not have the ability of producing so much seed and therefore they cannot compensate for the loss of digestibility in the stover. It seems logical to assume that the grain type sorghum (crop index = 30.5 %) was little affected in its digestibility by age (Table 4). The forage type sorghum with a much lower crop index of 9.8 % has probably decreased its digestibility somewhat due to ageing.

In both cultivars, the head components had a substantially higher D value than the leaves and stems. It therefore seems logical to assume that this was also part of the reason that the cultivar with the higher crop index also had the higher overall D value. However, the positive correlation between crop index and crop digestibility has been questioned (Bunting & Gunn, 1973). At present work is in progress to evaluate this correlation in more detail for Kenyan conditions.

*Fertilizer application as a husbandry factor*

It is clear from these experiments that accurate fertilizer applications played a relatively minor role in determining yield and DM quality. More important factors appeared to include rainfall and physical soil characteristics, or weed control (van Arkel, 1977b). Differences between cultivars were also large, although there was a clear interaction between the yield difference of the grain type and forage type sorghums with rainfall (Table 5). Under the drier conditions the earlier maturing grain type had a distinct advantage over the forage type ($P<0.05$). But under more favourable growing conditions the forage type produced more DM ($P<0.001$).

The relatively unimportant role of fertilizer for obtaining good yields seems to contribute an advantage to this crop. Fertilizer is a relatively expensive commodity and the limited demand reduces the capital risk and makes sorghum an attractive crop.

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**Paper IV**

# 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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# 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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*Key words:* sorghum, cold tolerance, highlands, maize, time of planting, forage yield, grain yield, soil temperature, air temperature, yield stability analysis.

**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 $\times$ 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 |

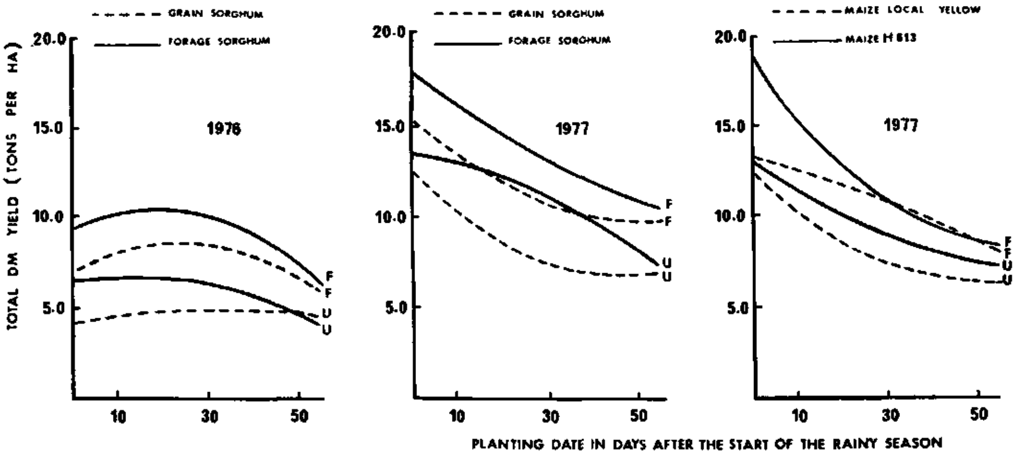


Fig. 1. Relation between total dry matter yield and planting date (data fitted to a quadratic model). F = Fertile soil (site 1); U = Unfertile soil (site 2).

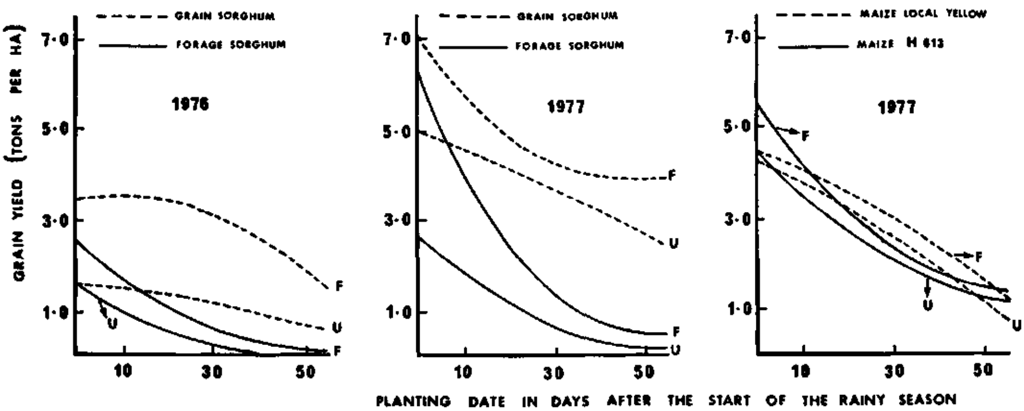


Fig. 2. Relation between grain yield and planting date (data fitted to a quadratic model) F = Fertile soil (site 1); U = Unfertile soil (site 2).

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

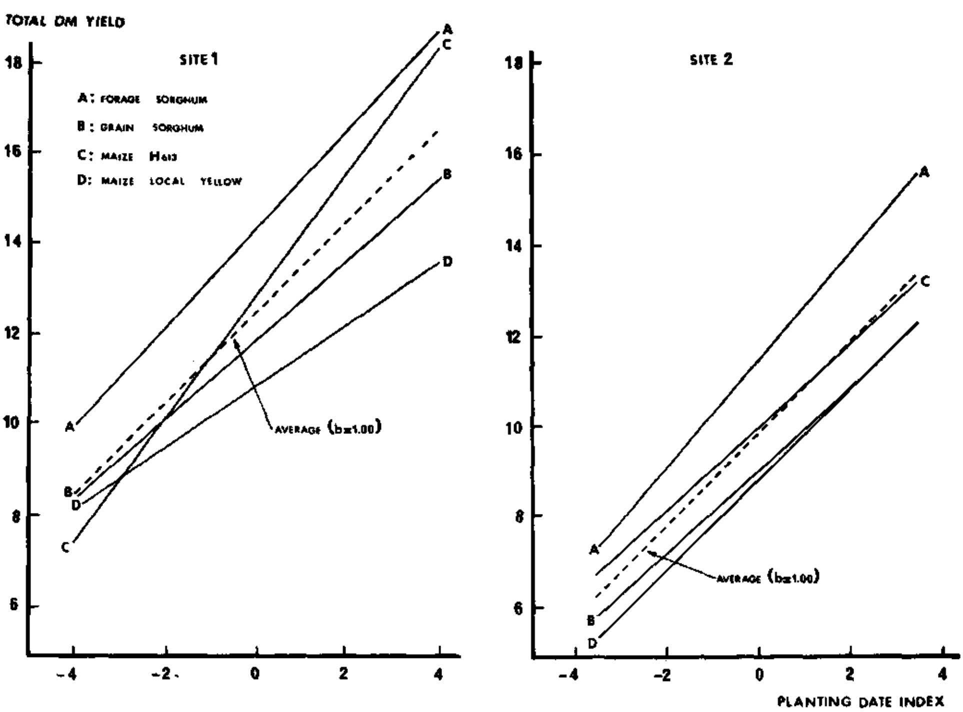


Fig. 3. The total dry matter yield response of two sorghum and two maize cultivars to different planting date conditions in 1977.

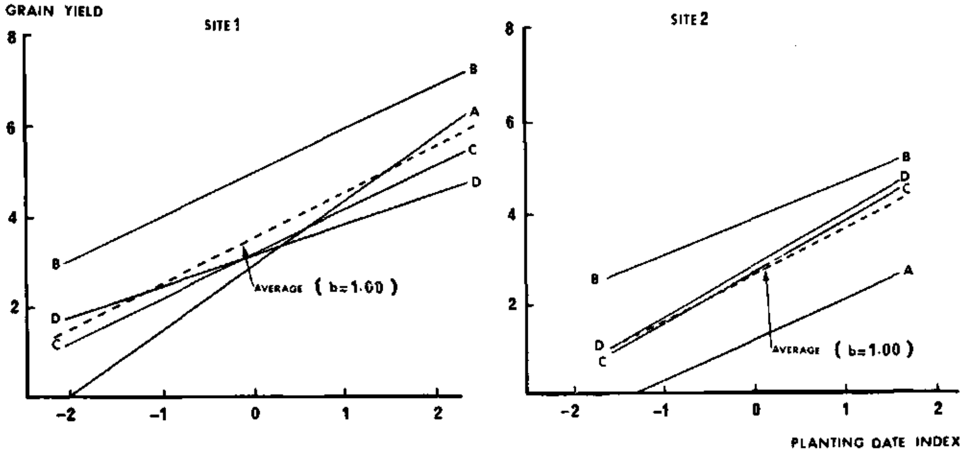


Fig. 4. The grain yield response of two sorghum and two maize cultivars to different planting date conditions in 1977.

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*** |

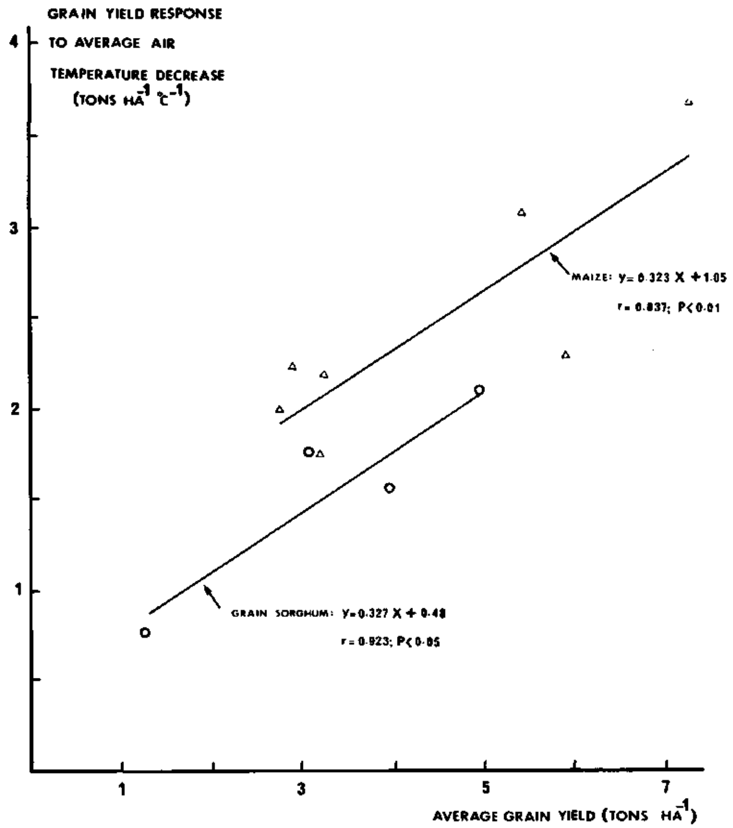


Fig. 5. The grain yield response of grain sorghum and maize to average mean air temperature differences during the first 35 days post-emergence as a function of the average yield level of the trial.

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

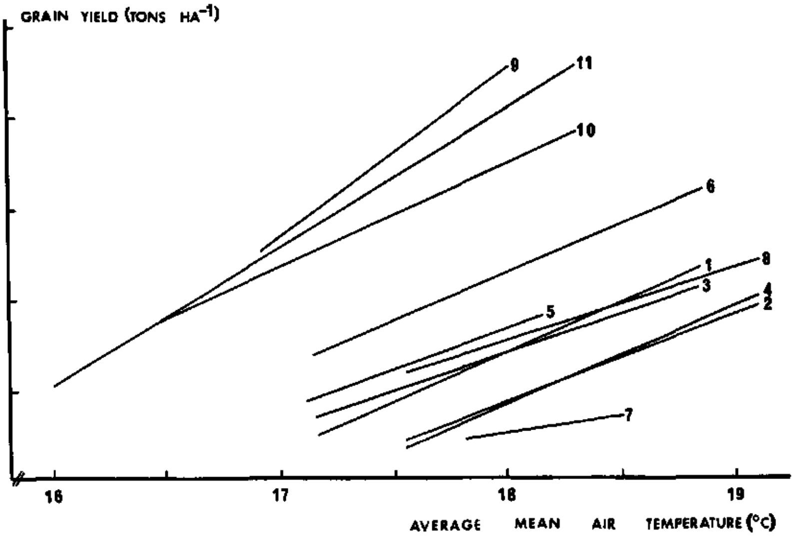


Fig. 6. Relation between grain yield of sorghum and maize as affected by average mean air temperature of the first five weeks post-emergence. (Numbers refer to the reference in Tables 4 and 6.)

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.

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**Paper V**

# The adaptation of cold-tolerant sorghum and maize to different environments in the highlands of Kenya

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# The adaptation of cold-tolerant sorghum and maize to different environments in the highlands of Kenya

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*Key words:* sorghum, cold tolerance, highlands, maize, forage yield, grain yield. yield stability, time of planting, altitude, rainfall, temperature, environmental index

## Summary

Two new introductions of high altitude sorghum, one a grain type and the other a forage type and two maize cultivars were tested in a number of trials during 1974, 1975, 1976 and 1977 in the highlands of Kenya. Yield data were regressed on altitude, rainfall and some data on temperature. Altitude had no significant effect on either grain or forage yield of any crop over the range tested which varied from 1525 to 2593 m. Yields were positively correlated with rainfall and negatively with temperature. The grain sorghum benefited less from increased rainfall and also suffered less from reduced rainfall than any other entry. There were indications that the same grain type sorghum was more sensitive to temperature than any other entry.

The interaction between genotypes and environments was considered more important than the crop yield averages. For an accurate estimate of this interaction the yield stability analysis, whereby yields are regressed on the environmental index, proved essential. Although rainfall was the most important factor affecting crop yields, it only explained about 50% of the yield differences, whereas the index accounted for 90% or more of the yield differences.

The grain sorghum was the highest yielding grain crop at low and medium rainfall levels, but this was only partly due to its superior water use efficiency and mainly to a more favourable dry matter (DM) distribution. The forage sorghum was the highest DM yielding entry under most conditions. The maize cultivars out-yielded the sorghums only if growing conditions were good. Where rainfall was high (> 1000 mm) DM yields of all crops were lower than where rainfall was from 800 to 1000 mm. Particularly sorghum yields were reduced at high rainfall

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giving the maize a distinct advantage. But it was not clear whether this yield effect was due to rainfall per se or to temperature differences.

## Introduction

The search for forage crops suitable for cultivation in the relatively drier areas above 1500 m elevation in Kenya formed part of a project jointly sponsored by the Kenya Government, UNDP and FAO (who all provided funds or facilities). A number of species and varieties were tested in 1974 (van Arkel, 1977), among which were some sorghum collections from the highlands of Southwest Uganda and Central Ethiopia. In the first screening nurseries some of these high altitude sorghums outyielded maize. Essentially, it was immediately apparent that whereas sorghums originating from lowland areas were slow growing and susceptible to leaf and panicle diseases, the high altitude cultivars were relatively free from disease and were vigorous in their growth. No information regarding optimum crop husbandry or response to different environments using this newly identified germplasm was available, and an agronomy programme was mounted to gain a deeper understanding of the specific requirements for a successful cultivation of the crop (van Arkel, 1978a, b, c, 1979, 1980). At the same time a number of new sorghum lines were selected for further regional testing in subsequent years.

In the highlands of Kenya considerable differences in average annual rainfall and temperature and in soil conditions occur over short distances. Furthermore, total annual rainfall usually varies widely around the long term average. This leads to a wide range of environmental conditions in the highlands and it is desirable to know the relative expected yield performance of various crops. This will facilitate agricultural planning and enable farmers to minimize their cropping risks. To evaluate these aspects, this paper examines the yield potential of two of the high altitude sorghum cvs and two maize cvs by analysing the yield data of four years of crop testing nurseries. Special attention is paid to the relative reaction of the sorghum and maize cultivars to altitude, rainfall and temperature differences; and to the causes of grain yield differences.

## Materials and methods

### *Nurseries and trials*

The yield data used in this study were taken from the regional sorghum test nurseries in 1974, 1975 and 1976 and from a 'time of planting' experiment in 1977. The experimental procedures and results of the 1974 trials were reported by van Arkel (1977) and for the 1975 trials by Enserink (1976). All regional trials were laid down as completely randomised block designs with three replications, which were all planted immediately after the onset of the rains. The only exception was the trial at Kitale in 1975 which was planted on 15 May, about six weeks after the rainy season had started. The total number of genotypes in the trials was progressively reduced from 216 in 1974 to 21 in 1975 and to 4 in 1976. But the number of test sites was increased from 3 in 1974 to 9 in 1975 and 21 in

1976. For reasons of resource availability it had to be decided to discontinue the regional trials in 1977. Instead a 'time of planting' experiment with the same four genotypes as in the 1976 regional trial and with six planting dates was carried out at two distinctly different trial sites. This provided 12 additional environments and the details of this experiment were reported by van Arkel (1980).

The results of eight regional trials were excluded from the analysis because the yield data were mistrusted. This was due to either excessive bird or game damage, to inadequate germination, to severe sorghum shootfly damage or to uncontrolled irrigation.

Consequently, 37 test environments remained for analysis. The elevation of the sites ranged from 1525 to 2593 m above sea level. The rainfall ranged from 155 mm to 1305 mm during the field period of the test crops which compared with a range of 255 mm to 1850 mm of total annual rainfall.

*Genotypes*

Out of the 85 high altitude sorghum collections which were brought to Kenya in 1973, 25 were selected to be included in the 1974 nurseries. The following year this was reduced to nine lines. With the performance data of three years it then became clear that there was one line to be preferred above all others for total dry matter (DM) yield potential and one for grain yield potential. The code number for the former is 'E 6518' which will be referred to as the forage sorghum and the code number of the latter is 'E 1291' which will be referred to as the grain sorghum. The forage sorghum — when grown in the Lanet area under good conditions — matures in approximately 215 days and can grow up to a height of about 3.5 m. The grain sorghum grown in the same area will mature in about 165 days and reaches a height of about 1.6 m.

The two maize cultivars 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. A more detailed description of the pedigree and yield performance potential of 'H 613' can be obtained from Darrah & Penny (1974) and Darrah (1976). 'H 613' appeared as one of the highest maize grain yielding entries in East Africa when grown above 1600 m. But also in maize trials for total forage production 'H 613' regularly ranked as one of the highest total DM yielding entries (Sheldrick, 1974).

*Statistical analysis*

The genotype environment interaction was studied by means of a yield stability analysis, where the yield data of each genotype were regressed in a linear model on the 'environmental index'. The latter was obtained by subtracting the grand mean yield of all genotypes over all environments from the mean yield of all genotypes at any one environment. This method was first introduced by Yates & Cochran (1938), later used by Finlay & Wilkinson (1963) and refined by Eberhart & Russell (1966). For the examination of significant differences between the regression lines the above method was modified again, as proposed by Freeman &

Perkins (1971). The modification was made by taking a different set of yield data to constitute the independent variable in the regression model. The 'environmental index' was computed as above, but only the yield data of one replicate were used. The average yield of the other two replicates was then regressed on to the environmental index. This modification was needed to satisfy the statistical requirement of regression analysis models. To analyse the probability levels for differences between regression lines, the Newman-Keuls test as published by Zar (1974) was used.

To visualize the genotype environment interaction, the regression lines were shown in a diagram with one section for total DM yield and one section for grain yield. To allow a comparison between the total DM yield and grain yield reaction of a genotype to environmental differences, the total DM yields and grain yields were regressed on a common base: the 'relative environmental index'. The difference between this and the conventional environmental index is that the relative index is expressed in percentage yield deviation from the mean instead of a deviation expressed in weight per ha.

## Results

*Effects of altitude, rainfall and environmental index*

The yield data (Table 1) were grouped into three categories as follows: (I) Environments where rainfall was under 1000 mm and where the crops were planted early. (II) The time of planting trials where crops were planted at progressively longer intervals after the start of the wet season, but where rainfall was always under 1000 mm. (III) Environments where rainfall was above 1000 mm.

Crop yields were not significantly correlated with altitude (data not shown) regardless of whether data were analysed separately in group I and III or whether they were pooled. However, altitude had a significant effect on rainfall ($P < 0.01$) and explained 38% of all rainfall differences of all sites in group I and III. Data from group II were excluded from the above analyses because they were obtained from only two different sites and rainfall differences and yield differences could therefore not be related to altitude.

The yield data of group I and II were separately regressed on rainfall (Fig. 1), which showed that there was a linear yield increase with increased rainfall for all crops. For total DM yield in group I, the grain sorghum was the top yielding entry under the very driest conditions. But under all other conditions the forage sorghum was the highest yielding entry, although the difference with maize 'H 613' became smaller and smaller as rainfall increased. For grain yield in group I, the grain sorghum was the top yielder if rainfall was under 640 mm and maize 'H 613' outyielded all other entries if rainfall exceeded 640 mm.

The yield levels in group II were lower than in group I at comparable rainfall levels. This was possibly due to below average soil conditions or to a less favourable rainfall distribution. However, the more interesting difference between group I and II was the slope of the regression lines, which can more easily be seen ıble 1. Total DM yield and grain yield for two sorghum and two maize cultivars grown at 37 different ıvironments where rainfall was recorded.

| :ar | Location | Total DM yield (1000 kg/ha) | | | | Grain yield (1000 kg/ha) | | | | Rain-fall (mm) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 'E 6518' | 'E 1291' | 'H 613' | 'Local Yellow' | 'E 6518' | 'E 1291' | 'H 613' | 'Local Yellow' | |
| 74 | Lanet 1 | 25.8 | 17.2 | 23.6 | 18.4 | 3.7 | 7.3 | 7.0 | 5.8 | 810 |
| 74 | Lanet 2 | 19.5 | 11.1 | 17.6 | 17.4 | 4.0 | 4.8 | 5.8 | 3.8 | 720 |
| 75 | Katumani | 1.2 | 2.9 | 0.9 | 1.6 | 0.0 | 0.4 | 0.0 | 0.2 | 170 |
| 75 | Naivasha | 17.5 | 10.8 | 18.3 | 14.0 | 2.8 | 5.0 | 5.9 | 5.0 | 420 |
| 75 | Lanet 1 | 29.0 | 17.3 | 30.1 | 24.2 | 7.0 | 7.2 | 9.0 | 6.4 | 783 |
| 75 | Lanet 2 | 17.4 | 8.1 | 17.1 | 17.5 | 5.0 | 3.3 | 5.2 | 5.7 | 645 |
| 75 | Kitale | 11.7 | 6.6 | 21.6 | 18.5 | 1.3 | 1.9 | 7.8 | 7.4 | 1050 |
| 75 | Baraton | 9.9 | 7.2 | 17.3 | 14.8 | 3.0 | 1.6 | 7.3 | 7.4 | 1200 |
| 76 | T. Falls | 6.4 | 6.4 | 4.0 | 4.4 | 0.0 | 2.5 | 0.4 | 0.8 | 250 |
| 76 | Njoro | 17.0 | 11.8 | 16.0 | 13.0 | 3.6 | 5.1 | 4.8 | 4.1 | 500 |
| 76 | Katumani | 4.2 | 5.1 | 2.4 | 3.3 | 0.0 | 1.6 | 0.0 | 0.3 | 190 |
| 76 | Lanet 1 | 15.5 | 11.2 | 14.4 | 11.8 | 3.0 | 4.7 | 4.1 | 3.7 | 489 |
| 76 | Lanet 2 | 8.5 | 7.5 | 6.4 | 6.0 | 0.4 | 2.9 | 1.1 | 1.6 | 433 |
| 76 | Rumuruti | 8.1 | 7.3 | 6.0 | 5.8 | 0.1 | 2.3 | 0.7 | 1.4 | 250 |
| 76 | Elmenteita | 12.8 | 9.7 | 11.2 | 9.5 | 1.0 | 4.0 | 2.9 | 2.9 | 455 |
| 76 | Embu | 23.1 | 15.1 | 23.1 | 18.1 | 5.0 | 6.0 | 6.5 | 5.4 | 805 |
| 76 | Rongai | 16.4 | 12.1 | 17.4 | 13.4 | 3.5 | 5.1 | 4.8 | 4.2 | 505 |
| 76 | Thika | 24.2 | 15.7 | 24.5 | 19.0 | 5.5 | 6.4 | 6.8 | 5.6 | 825 |
| 76 | Kiambu | 22.0 | 14.5 | 21.6 | 17.2 | 4.8 | 6.1 | 6.4 | 5.2 | 695 |
| 76 | Solai | 25.1 | 16.5 | 25.5 | 19.5 | 5.5 | 6.5 | 7.2 | 5.9 | 845 |
| 76 | Gilgil | 3.5 | 4.8 | 0.9 | 1.9 | 0.0 | 1.2 | 0.0 | 0.0 | 155 |
| 76 | Naivasha | 10.5 | 8.7 | 8.7 | 7.7 | 0.9 | 3.0 | 1.4 | 1.9 | 355 |
| 76 | Nyeri | 8.2 | 7.4 | 6.0 | 5.8 | 0.0 | 2.4 | 0.3 | 1.1 | 305 |
| 76 | Molo | 17.0 | 12.0 | 22.5 | 18.0 | 3.6 | 2.2 | 6.6 | 5.9 | 1110 |
| 76 | Ol Joro Orok | 9.8 | 5.3 | 13.1 | 11.9 | 1.0 | 0.4 | 2.9 | 3.2 | 1305 |
| 77 | Lanet 1 P1* | 18.6 | 15.8 | 18.1 | 13.6 | 6.1 | 6.9 | 5.7 | 4.9 | 911 |
| 77 | Lanet 1 P2* | 17.0 | 13.8 | 17.0 | 11.7 | 5.6 | 6.3 | 4.3 | 3.4 | 851 |
| 77 | Lanet 1 P3* | 15.5 | 12.7 | 13.9 | 12.3 | 2.4 | 5.0 | 3.1 | 3.6 | 831 |
| 77 | Lanet 1 P4* | 13.1 | 11.1 | 10.9 | 10.9 | 1.4 | 4.6 | 2.7 | 3.6 | 760 |
| 77 | Lanet 1 P5* | 12.0 | 10.0 | 9.6 | 8.9 | 1.3 | 3.9 | 2.1 | 2.3 | 625 |
| 77 | Lanet 1 P6* | 10.0 | 8.5 | 8.0 | 8.0 | 0.3 | 3.0 | 1.2 | 1.2 | 615 |
| 77 | Lanet 2 P1* | 14.9 | 12.9 | 13.0 | 12.4 | 2.6 | 4.9 | 4.9 | 4.3 | 825 |
| 77 | Lanet 2 P2* | 13.2 | 10.7 | 11.5 | 11.4 | 2.1 | 4.9 | 3.0 | 4.3 | 810 |
| 77 | Lanet 2 P3* | 13.9 | 8.7 | 11.1 | 8.5 | 1.7 | 4.1 | 3.2 | 3.0 | 740 |
| 77 | Lanet 2 P4* | 10.5 | 7.8 | 9.5 | 7.6 | 0.8 | 3.0 | 2.3 | 2.7 | 700 |
| 77 | Lanet 2 P5* | 9.2 | 7.7 | 7.5 | 7.2 | 0.1 | 3.0 | 1.5 | 2.2 | 670 |
| 77 | Lanet 2 P6* | 7.2 | 6.6 | 7.3 | 6.1 | 0.1 | 2.5 | 1.0 | 0.6 | 640 |
| :an of 37 locations | | 14.04 | 10.23 | 13.72 | 11.66 | 2.41 | 3.95 | 3.84 | 3.54 | 655 |
| :an of 33 locations [1] | | 14.27 | 10.53 | 13.12 | 11.15 | 2.43 | 4.24 | 3.49 | 3.25 | 593 |

?1 stands for first planting date, P2 for second, etc.

ıxcluded are the 4 locations where rainfall exceeded 1000 mm.

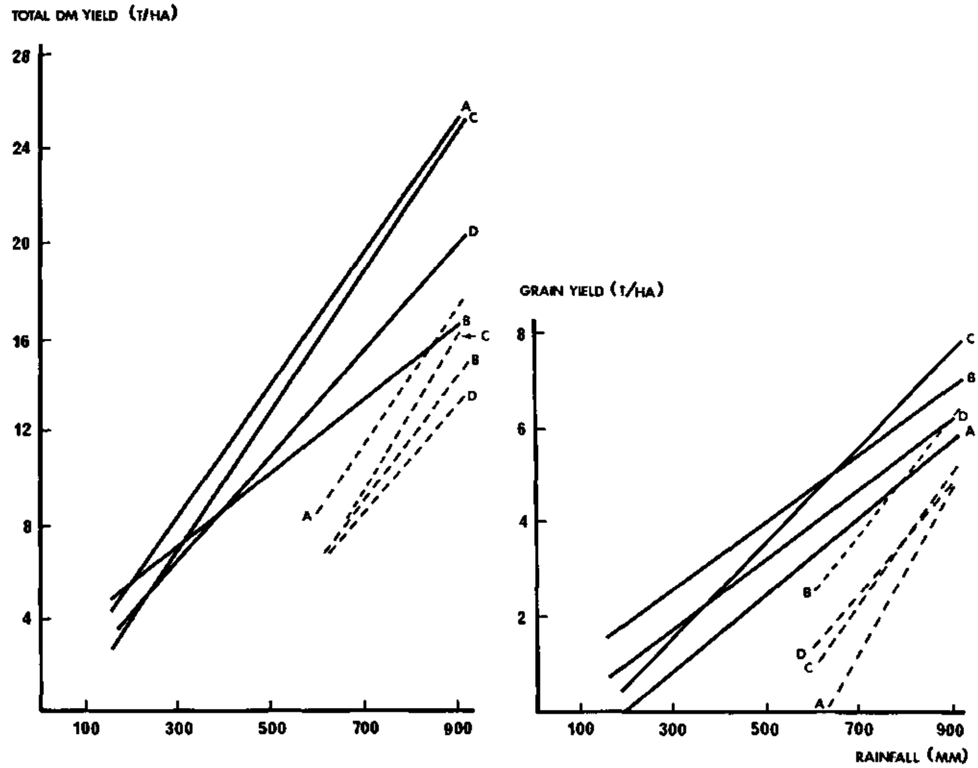


Fig. 1. Relation between rainfall and crop yields. Solid lines = environments in group I; intermittent lines = environments in group II; A = forage sorghum, B = grain sorghum, C = maize 'H 613', and D = maize 'Local Yellow'.

from Table 2. The yield reaction to rainfall variation was, on average, more pronounced in group II as compared to group I. This was particularly so for grain yield and less so for total DM yield. Apparently yields were more reduced if lower rainfall was combined with late planting than if only rainfall was lower, but planting was carried out at the start of the growing season.

Combining the data of group I and II in a single set of yield-rainfall regression lines would have provided a more useful and realistic model for yield predictions under practical farming conditions, because delayed planting is a normal phenomenon under such conditions. But such a model is not shown here because correlation coefficients were low, deviations from regressions high and, consequently, accuracy of prediction too low. Yield stability analysis where all the combined effects of the environment are taken into account partly compensates for this low accuracy, however.

The visual display of the yield stability analysis for environments with less than 1000 mm rainfall (i.e. group I and II) is shown in Fig. 2. For total DM yield it appeared that the forage sorghum was the highest yielding entry under

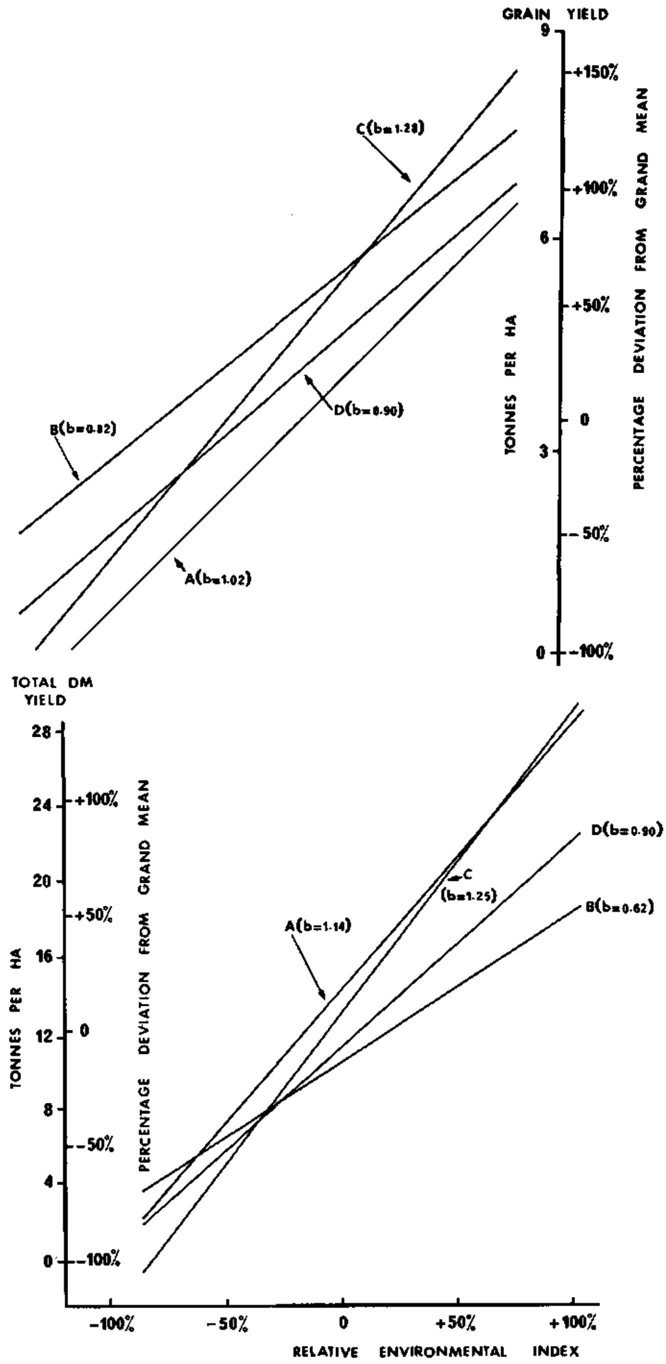


Fig. 2. Yield response to varying environments in the Kenya highlands. b = regression coefficient; A = forage sorghum, B = grain sorghum, C = maize 'H 613', and D = maize 'Local Yellow'.

Table 2. Regression coefficients for the relations yield on rainfall 1000 $kg.ha^{-1}$. $cm^{-1}$ for early planted trials at locations with less than 1000 mm rainfall (Group I) and for the time of planting experiments (Group II).

| | Total DM yield | | | Grain yield | | |
|---|---|---|---|---|---|---|
| | I | II | increase of II over I (%) | I | II | increase of II over I (%) |
| Forage sorghum | 0.28 | 0.30 | 9 | 0.08 | 0.17 | 110 |
| Grain sorghum | 0.16 | 0.25 | 61 | 0.07 | 0.13 | 73 |
| Maize 'H 613' | 0.30 | 0.33 | 9 | 0.10 | 0.14 | 35 |
| Maize 'Local Yellow' | 0.23 | 0.23 | 0 | 0.07 | 0.12 | 57 |

Regression coefficients are rounded to two decimal places; this may result in small discrepancies with the figures for 'increase of II over I (%)'.

most conditions. But if conditions became favourable there was a tendency for the maize hybrid to outyield the forage sorghum. Under very unfavourable conditions the grain sorghum became the highest yielding entry. For grain yield, the grain sorghum was the highest yielding entry under most conditions but maize 'H 613' was the better yielding entry under favourable conditions.

The patterns of lines in Fig. 2 are similar to those in Fig. 1, indicating that rainfall had a relatively large influence on the environmental index compared with other environmental influences. The difference between the two Figs. is mainly in the accuracy of the lines. Where in Fig. 1 the unexplained part of variation is large (approx. 50%), in Fig. 2 less than 10% of yield variation remained unexplained. This allowed significant differences between the four crops to be computed (Table 3). However, if the yield stability analyses were computed including the four yield data of group III, the unexplained variation sharply increased again mainly due to the reversed relation between rainfall and crop yields (analyses not shown). The similarity and difference between Figs. 1 and 2 and the reasoning for excluding group III from the yield stability analyses will be discussed in more detail below.

Table 3. Regression coefficients for genotype × environment interaction and mean yields of two sorghum and two maize cultivars. (b = regression coefficient; $s_b$ = standard error; y = mean yield).

| | Total DM yield | | | Grain yield | | |
|---|---|---|---|---|---|---|
| | b | $s_b$ | y | b | $s_b$ | y |
| Forage sorghum | $1.14^a$ | 0.029 | $14.27^a$ | $1.02^a$ | 0.054 | $2.43^a$ |
| Grain sorghum | $0.62^b$ | 0.045 | $10.53^b$ | $0.82^b$ | 0.020 | $4.24^b$ |
| Maize 'H 613' | $1.25^c$ | 0.031 | $13.12^c$ | $1.28^c$ | 0.047 | $3.49^c$ |
| Maize 'Local Yellow' | $0.90^d$ | 0.043 | $11.15^b$ | $0.90^a$ | 0.049 | $3.25^d$ |

Regression coefficients and mean yields with the same superscript within one column are not significantly different at P = 0.05.

*Interaction between genotypes and environments*

The difference between the reaction of the four genotypes in total DM yield and grain yield production resulting from environmental differences can be seen from two aspects of Fig. 2. Firstly, from the range of the scale of the 'relative environmental index' which is covered; for total DM yield this varied from —85% to +105%, whereas for grain yield, the index varied from —95% to +120%. This shows that, in general, grain yields were more sensitive to environmental influences than total DM yields. Secondly, the regression coefficients can be compared (Table 3). It then appeared that both maize cultivars reacted similarly in total DM yield and grain yield on changes of the 'relative environmental index'. But the two sorghums reacted very differently. The forage sorghum with b = 1.14 for total DM yield reacted favourably on increased values of the index, but this sorghum was not able to react equally favourable on improved conditions with regard to grain production (b = 1.02). The grain sorghum with b = 0.62 for total DM yield reacted less favourably on improved environmental conditions than this sorghum did with regard to grain yield (b = 0.82). Maize 'H 613' and the grain sorghum were the most unstable and most stable crop respectively, both for grain and for total DM yield. But the yield crossing point for these two cultivars occurred for grain yield under more favourable environmental conditions than for total DM yield (Fig. 2). This was because maize 'H 613' required an increasingly higher stover production compared with the grain sorghum to produce one extra unit of grain (Fig. 3).

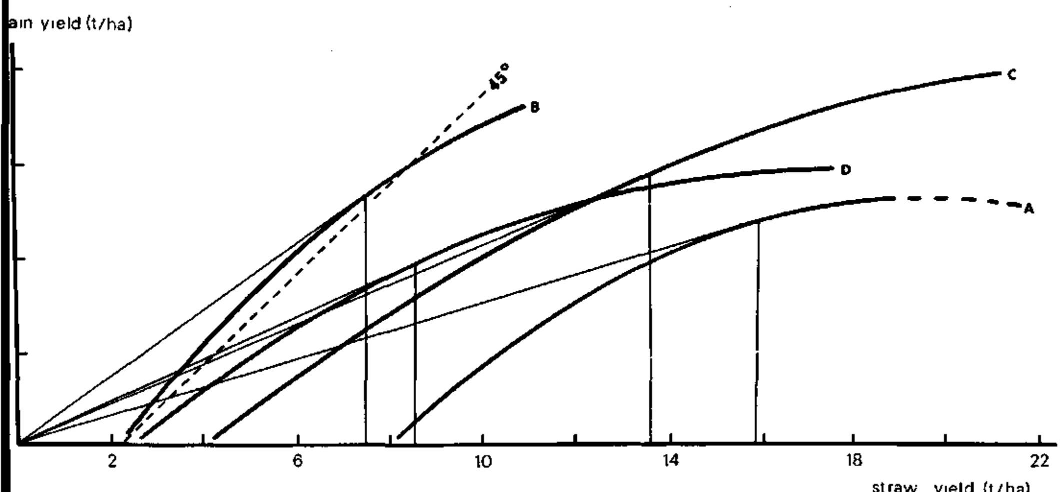


Fig. 3. Relation between straw yield and grain yield in group I. A = forage sorghum, r = 0.79; B = grain sorghum, r = 0.97; C = maize 'H 613', r = 0.96; D = maize 'Local Yellow', r = 0.95.

*Grain production efficiency*

The grain production efficiency is here expressed as a function of the specific water use for DM production and as a function of the DM distribution in the plant. The specific water use for DM production can be deduced from Fig. 1. This was done by dividing the x- co-ordinate over the y- co-ordinate of any point on a regression line, and some of the resulting values are shown in Table 4. Not entirely unexpectedly, the most efficient sorghum had a lower specific water use than either maize cv. The specific water use of the forage sorghum and maize 'Local Yellow' was fairly stable around 350 and 450 litres $kg^{-1}$ DM respectively. But for the two crops most interesting for grain production, i.e. the grain sorghum and maize ' H 613' the situation was different. The grain sorghum had a lower specific water use than the maize if rainfall was low. If rainfall increased the maize improved its specific use but the grain sorghum made less efficient use of the available water. The point where the specific water use of the two crops was the same was at about 300 mm rainfall. This indicates that the noted drought resistance of sorghum, in general, only led to a superior water use efficiency of the grain sorghum used here if rainfall was very low.

The superior grain yielding ability of the grain sorghum, over much of the range of conditions studied, appeared mainly due to the DM distribution. Fig. 3 shows that at any given level of straw production, which could be reached by all crops, the grain sorghum produced the highest amount of grain. The tangent from the origin to any point of the curves gives the grain/straw ratio of a crop. The grain sorghum had its maximum grain/straw ratio of 0.70 at a straw yield of 7800 kg $ha^{-1}$ and at higher straw yield levels the ratio hardly declined. All other crops had the highest grain/straw ratio, which was always lower than of the grain sorghum, only at higher straw yields. If straw yields were higher than where the grain/straw ratio maximized, the ratios decreased more than with the grain sorghum. But some of the decrease may be due to the selection of the regression formula. The curves were forced in a quadratic model in such a way that the total squared deviations from regression were minimized. A questionable result of the selection of the formula, for instance, is the absolute decrease of grain yield at straw yields in excess of 19000 kg $ha^{-1}$ for the forage sorghum. It can also be seen that maize 'Local Yellow' had its maximum grain/straw ratio (0.47) at a lower straw yield

Table 4. Average specific water use for early planted crops (group I) in litres $kg^{-1}$ DM at different amounts of rainfall received during the growing season (derived by regression analyses).

| | Rainfall (mm) | | | | | |
|---|---|---|---|---|---|---|
| | 200 | 300 | 400 | 500 | 700 | 900 |
| Forage sorghum | 347 | 350 | 352 | 353 | 354 | 355 |
| Grain sorghum | 358 | 419 | 458 | 485 | 521 | 543 |
| Maize 'H 613' | 491 | 424 | 396 | 381 | 365 | 357 |
| Maize 'Local Yellow' | 466 | 456 | 452 | 448 | 445 | 443 |

level than maize 'H 613' (0.42). This explains why the yield crossing point for these two maizes in Fig. 2 is at a higher yield level for grain yield than it is for total DM yield.'Local Yellow' only outyielded 'H 613' in DM production under very severe environmental conditions. But, if harvested for grain there was a wider range of — unfavourable — conditions under which 'Local Yellow' outproduced 'H 613'. This finding was in agreement with the widespread farmers opinion in Kenya.

With all four crops a higher grain yield was combined with a higher straw yield. From a comparison of the curves with the 45° line in Fig. 3 it can be seen that, with the exception of the grain sorghum, all crops produced an increasingly higher amount of straw to achieve a certain grain yield increase. From the same figure it can also be estimated at what straw yield grain yield started. For the grain sorghum this was 2500 kg $ha^{-1}$ whereas this was 8000 kg $ha^{-1}$ for the forage sorghum. The maizes with 2600 and 4000 kg $ha^{-1}$ occupied an intermediate position.

The relation between rainfall and grain/straw ratio is also a measure of the grain production efficiency (Fig. 4), although it incorporates much of what has been detailed on this subject above. All ratios initially increased with increasing rainfall and their maximum was estimated to be between 625 mm for the grain sorghum to 850 mm for the forage sorghum. At higher rainfall figures the ratios tended to decline, indicating that additional rainfall increased the straw yield relatively more than grain yield.

## Discussion

*Rainfall and temperature effects*

Separating the yield data into three groups on the basis of time of planting and rainfall has been useful because within each group the rainfall-yield relation was

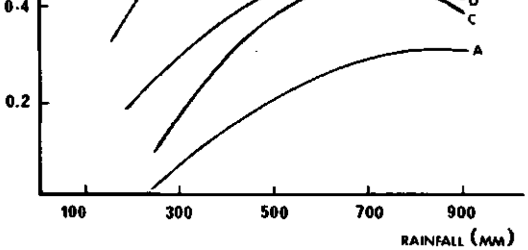


Fig. 4. Relation between rainfall and grain/straw ratio in group 1. A = forage sorghum, B = grain sorghum, C = maize 'H 613', D = maize 'Local Yellow'.

different. It was shown that if rainfall was under 1000 mm the yield-rainfall regression was larger for late planted crops as compared to early planted crops. Furthermore, the positive yield-rainfall correlations as shown in Fig. 1 did not apply to environments where rainfall was above 1000 mm (Table 5). This table shows that yields were generally depressed if rainfall exceeded 1000 mm. But particularly the yields of the sorghum were depressed, thus reversing the yield ranking order for sorghum and maize. It is questionable why the yields in group III were so different from what was to be expected on the basis of rainfall or average crop yield. Since there were only four trial sites in group III and since the environmental data collected were limited to rainfall, altitude and a few temperature data only, these yield reactions cannot be explained satisfactorily. Nevertheless, there are indications that differences between the reactions of sorghum and maize to temperature differences played a role.

Unpublished results of a preliminary trial carried out by the 'Department of field crops and grassland husbandry' in Wageningen support this theory. In a laboratory controlled experiment the growth of maize, the cold tolerant grain sorghum 'E 1291' and a normal lowland sorghum 'Serena' was followed under different temperature regimes from sowing up to the eight leaf stage. Although not conclusive in all aspects there was a clear tendency for maize to have a lower minimum temperature for germination than the cold tolerant grain sorghum. But the latter had a lower minimum germination temperature than the lowland sorghum. The speed of plant development after germination showed the same ranking order.

Increased rainfall reduces soil temperature through increased evaporation (Cooper, 1974). Therefore in group I higher rainfall was associated with lower temperatures. But in group II a lower rainfall i.e. later planting, was associated with lower temperatures. It is likely that these lower temperatures caused the crops in group II to show a stronger relation between rainfall and yield than the crops in group I (van Arkel, 1980). The theory that the sorghums are more sensitive to lower temperatures (i.e. late planting in group II) than maize is not disproved by the experiments reported here (Table 2). But the data in Table 2 do not convincingly suggest the existence of such a difference in temperature sensitivity, which is due to the wide variation of results.

The theory of different temperature sensitivities of sorghum and maize would

Table 5. Average DM yield and grain yield for environments with 800-1000 mm and above 1000 mm rainfall.

| | Total DM yield (1000 kg ha$^{-1}$) | | | | Grain yield (1000 kg ha$^{-1}$) | | | |
|---|---|---|---|---|---|---|---|---|
| | forage sorghum | grain sorghum | maize 'H 613' | maize 'Local Yellow' | forage sorghum | grain sorghum | maize 'H 613' | maize 'Local Yellow' |
| 800-1000 mm | 22.0 | 15.5 | 21.3 | 16.8 | 4.7 | 6.3 | 6.3 | 5.3 |
| > 1000 mm | 12.1 | 7.8 | 18.6 | 15.8 | 2.2 | 1.5 | 6.2 | 6.0 |

explain or is supported by the deviating yields of the four environments in group III. Moisture deficiencies are unlikely to have played an important role here and consequently temperature is thought to have become relatively more important. During the first 35 days after emergence temperatures were 16.3, 15.4 and 15.0 °C for Kitale, Molo and Ol Joro Orok respectively (no data for Baraton were available). This compares with 18.6 °C for Lanet (average of Lanet 1 and 2, 1976, 1977). At Kitale the lower temperature was due to late planting associated with high rainfall and at Molo and Ol Joro Orok the low temperatures were the result of a higher altitude (2593 m and 2410 m) associated with more rain. It was not possible to find significant correlations between these temperatures and yields, but the trend agrees with what was found before. Temperatures at all four stations were lower than at Lanet and crop yields were lower than what would be expected on the basis of rainfall. This can be seen from Table 5 which compares the yields of crops grown under 800-1000 mm rainfall with the yields of crops grown under rainfall above 1000 mm and shows that most yields were lower at high rainfall. Fig. 5 shows that under high rainfall sorghum suffered relatively higher yield losses than maize. The yield reduction of the grain sorghum under colder conditions was even more pronounced if planted late under colder

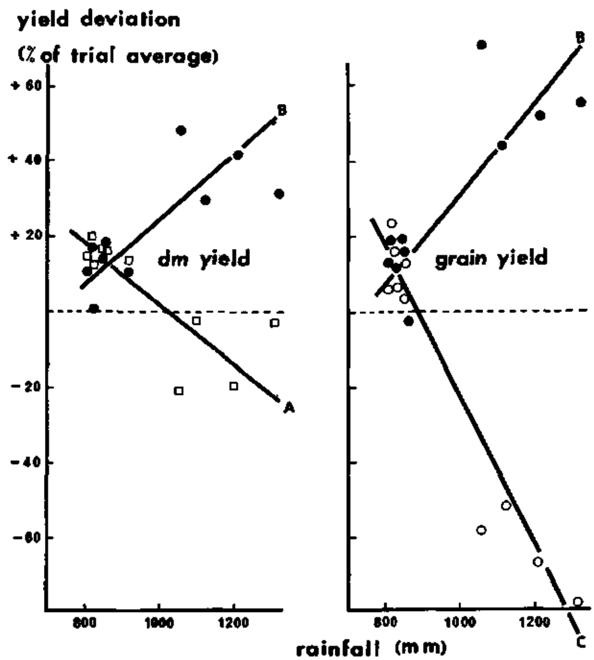


Fig. 5. Yield deviation of the highest yielding sorghum and maize from the trial yield average as affected by rainfall. A = □ = forage sorghum, B = • = maize 'H 613', C = O = grain sorghum.

conditions (at Kitale). Presumably because now also the soil in which the sorghum was planted had cooled down (van Arkel, 1980).

Although the yield of the grain sorghum was severely depressed at Kitale, it is striking that the grain sorghum suffered relatively less, if planted late under the more limited moisture conditions in the time of planting trials. It seems likely that the relatively higher temperature sensitivity of the grain sorghum as compared with the maizes was outweighed by its higher drought resistance. This conclusion changes the interpretation of the results of a previous study where the yield reduction due to late planting was correlated with temperature decreases only (van Arkel, 1980).

The fact that the poor performance of the sorghums under high rainfall conditions should not be attributed to rainfall per se is confirmed by a personal observation which showed that the same grain sorghum and forage sorghum cv. grown with abundant irrigation under warm lowland conditions, performed very well.

There is internationally little known about the relation between temperature and plant development and growth of cold-tolerant sorghum. This is partly because high altitude cold-tolerant sorghums have been only recently identified as such. Standard textbooks still classify sorghum as a crop of hot and warm countries (e.g. Purseglove, 1972). But without fundamental temperature-growth data available it became clear a few years ago that high altitude sorghums were more cold-tolerant than lowland sorghums (van Arkel, 1977; Singh, 1978). These first findings triggered some more detailed work. Besides the above quoted work in Wageningen some interest arose in the USA where it is believed that a higher degree of cold tolerance may allow the cultivation of sorghum at higher latitudes. Eastin et al. (1976) found in growth chamber study that cold-tolerant cvs. had a 6 to 10 °C lower optimum temperature for maximum growth and a 20 to 25% higher respiration rate than cold susceptible sorghums. These results appear to warrant the term cold-tolerant. Some of the results from the experiments reported here indicate that the sorghums were not as cold-tolerant as maize. However, it is likely that there are cv. differences. A further identification and exploration of these differences is likely to produce material with a better cold-tolerance than the cvs. used here.

*Oxygen deficiencies and altitude effects*

The yield differences in this study have been related to rainfall and temperature and one may question the likelihood of oxygen deficiencies in the soil having played an important role. Allan (1972), without measuring soil air composition, indeed suggested that poor soil aeration was responsible for the lower yields of late planted maize. Giesler (1969) showed that the growth of both roots and shoots of maize was positively correlated with the $O_2$ concentration in the soil air atmosphere up to 21% $O_2$. However, Cooper (1975) and Cooper & Law (1977) found in a number of detailed growth studies under field conditions that there was no measurable decline in maize growth rates, even when $O_2$ deficits went up as high as 6%. They also showed this to be an unusually high oxygen deficiency level. Sorghum is known to withstand poor soil aeration better than maize (Purseglove, 1972). In Western Kenya sorghum is often planted in soils with inadequate drainage just for this reason. It is therefore concluded that at high rainfall environments the lower sorghum yields were not due to inadequate soil aeration.

Altitude was not related to crop yields either. This finding is in agreement with other work with maize in Kenya (Darrah & Penny, 1974; Darrah, 1976). These authors reported no significant correlations between altitude and yield within the range of altitudes used here. But if all their data from sites ranging from sea level to 2700 in elevation were regressed on altitude the correlation was significant.

*The measure of the environment*

Yield differences in multi-locational crop testing are always due to a number of factors, e.g. genetic potential, rainfall, altitude, temperature, radiation, soil conditions and others. With the limited information available in this study it was not possible to adequately qualify the effects of each of those factors. It proved that rainfall alone already explained about 50% of the DM yield differences, and between 22 and 57% of the grain yield differences if all 37 sites were combined (Table 6). Subsequently the data from group III were excluded for reasons explained above and group I and II were regressed on rainfall both in a pooled and in two separate analyses. In the pooled analysis the explanatory value of rainfall did not consistently exceed the values obtained in the analyses with all 37 sites. But the regressions had become linear instead of quadratic.

Table 6. Percentages of total DM or grain yield variations explained by rainfall or environmental index if different sets of test environments were pooled. Group I = trials planted early and rainfall under 1000 mm; Group II = time of planting experiment, rainfall under 1000 mm.

| | Rainfall | | | | Environmental index |
|---|---|---|---|---|---|
| | all sites | group I and II | group I | group II | group I and II |
| *Total DM yield* | | | | | |
| Forage sorghum | 50.1* | 52.9 | 80.2 | 80.7 | 99.5 |
| Grain sorghum | 49.0* | 59.7 | 83.6 | 87.4 | 90.8 |
| Maize 'H 613' | 51.9* | 49.8 | 77.2 | 92.1 | 99.1 |
| Maize 'Local Yellow' | 53.9* | 50.3 | 78.5 | 82.1 | 96.6 |
| *Grain yield* | | | | | |
| Forage sorghum | 22.0* | 30.0 | 66.8 | 87.3 | 92.2 |
| Grain sorghum | 57.1* | 63.0 | 81.8 | 83.8 | 89.6 |
| Maize 'H 613' | 38.0* | 35.0 | 72.5 | 85.1 | 96.9 |
| Maize 'Local Yellow' | 52.2* | 48.8 | 78.2 | 80.8 | 93.2 |

* In these instances the quadratic regression component is significant.

By separating the yield data from early planted crops and late planted crops, the explanatory value of rainfall for the prediction of yields was higher around 75% because this excluded the temperature-rainfall interaction. This shows that within group I and II rainfall explained more of the yield variation than any other environmental factor could have done. Indeed there is a great similarity in the patterns of the regression lines of Fig. 1 and those of Fig. 2, where all environmental factors have been taken into account. The difference between Figs. 1 and 2 is the accuracy of the regression lines. The environmental index in most cases explained well over 90% of the yield variation. But based on rainfall alone the 'factors of determination' were too low to be of practical value, in the sense of being able to accurately predict yield and, more important, cross-over points as shown in Fig. 1. To allow for all the combined environmental factors the 'environmental index' method proved a good tool.

Darrah (1976), who also used the yield stability analysis method for his regional maize yield trials, remarked that the method was very precise and allowed the yield of any genotype to be predicted quite accurately. This agrees with the work reported here, where correlation coefficients for genotype yield on environmental index (Fig. 2) were never below 0.95, indicating that at least 90% of all genotype yield variability was accounted for (Table 6). But the prediction is based on the value of the environmental index, which merely means that the yield of one genotype can be predicted accurately if the yields of all genotypes are known. But how can the yield be predicted before planting? This is particularly important around the cross-over point, where maize and sorghum reverse the yield ranking order. This cross-over point is not location specific and varies from year to year, depending on the weather and time of planting. Rainfall, however, was shown to account for only about half the variability of crop yield.

The few temperature data available indicated that temperature is also an important factor to be considered for the adaptation of sorghum and maize to different environments in the highlands. The data available did not allow precise yield-temperature regressions to be drawn. It must therefore be concluded that the best measure of the combined effects of all the relevant factors operating in the environments was provided by the genotypes themselves. This means that in areas where the yield potentials are not clear, some critical experiments will be needed to measure all the combined environmental influences.

*Yield differences between sorghum and maize*

The yields reported in this paper were all based on small plot trials which were carefully hand-harvested. It was shown (van Arkel, 1978a) that with mechanical harvesting, the forage sorghum had a considerable additional DM yield advantage over maize because the former can be harvested with only small losses, whereas the harvesting losses for maize are usually high. This proved particularly so if yield levels were high and when maize had lodged. This effect will result in a yield crossing point which occurs under more favourable conditions and therefore the sorghum would have a larger yield advantage over a larger range of environmental conditions.

Further, the DM yields of the sorghums obtained at the Lanet 1 trial site (Table 1) agreed with those published earlier (van Arkel et al., 1977; van Arkel, 1978a). But the maize yields in those earlier papers were considerably lower than the maize yields reported here. This was partly due to heavy lodging in maize and with its associated harvesting losses. In anticipation of this lodging, plant populations for maize were kept at a sub-optimum level, whereas the plant populations in the small plot trials reported here were kept at a level where yields were expected to maximize. However, the lodging susceptibility of the maize is probably cultivar specific and it must be assumed that this can be improved through plant breeding efforts.

The superiority of the grain sorghum as compared with maize as a grain producer under drier conditions is based on its higher grain production efficiency. This was based, firstly, on a more favourable DM distribution in the plant at low and medium rainfall conditions and, secondly, on a higher water use efficiency of the sorghum under low rainfall conditions. Although superior to maize, the level of specific water use of the grain sorghum must be considered high (Arnon, 1972). This implies that there are likely possibilities of improving rainfall efficiency by improving rainfall penetration into the soil or by breeding for better adapted cultivars.

*Statistical analysis of yield differences*

The average yield differences between the four genotypes in group 1 plus 2 were small. Maize 'H 613' produced, on average, only 8% less DM than the forage sorghum, while the same maize hybrid under-produced the grain sorghum by 17% in terms of grain yield. However, the average yields of the four genotypes are not important for this study, because they depend largely on the distribution of test environments. If a relatively larger number of trial sites had been chosen in environmentally unfavourable areas, the yield advantages of the sorghums over the maizes would have been larger. By contrast, if more trial sites had been laid down in favourable growing areas, the maizes would have produced higher yield averages than the sorghums. The objective of this paper, however, was not to study actual yields but yield potentials. This is indepent of the distribution of trial sites over the various environmental conditions. It is therefore the interaction between genotypes and environments that is important (Fig. 2).

The differences between the regression coefficients (Table 3) were, in majority, only barely significant at the 5% probability level, despite their low variation coefficients. The probability levels for the differences between regression coefficients could have been increased by using the yield data of all three replicates to compute the environmental index, as proposed by Eberhart & Russell (1966). Their method has been used frequently for the purpose of analysing regional crop trials, e.g. Majisu & Doggett (1972), Darrah & Penny (1974), Darrah (1976), Kofoid et al., (1977), and Francis et al., (1978). Unfortunately, the fundamental statistical assumptions do not appear to have been satisfied in any of this work, because the same yield data have been used to determine both the environmental index (independent variable) and the yields (dependent variables). The lines that have been drawn account for the observed results, but it is not valid to regard them as regression lines or to compare their slopes statistically (Freeman & Perkins, 1971).

At the expense of precision it was, therefore, necessary to follow the method used in this paper. Another possibility would have been to use the yield data of all three replicates of one genotype as the base for the environmental index and to regress the average of the three replicates of each of the other three genotypes on it. This method which can be useful (van Arkel, 1980) did not prove satisfactory in the analysis of the data reported here.

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