Deutscher Tropentag 1999 in Berlin
Session: Sustainable Technology Development in Animal Agriculture

Crossbreeding for dairy production in Kenya: Parameter estimates for defining optimal crossbreeding systems

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Abstract

Data from a crossbred herd in the lowland tropics of Kenya were used to estimate crossbreeding parameters for milk production and reproductive traits and for cow live weight (LW). An individual animal model was fitted to these data to estimate breed cross means for a total of 25 genotypes having different proportions of Ayrshire (A), Brown Swiss (B), Friesian (F) and Sahiwal (S) genes. These means were then regressed on gene proportion of breeds and on the coefficients of heterosis and recombination loss. Per lactation, the F contributed 1802 kg and 18.4 kg more milk and milk per unit of metabolic weight (MW), respectively, than the S. The performances of the A and B were intermediate. The contribution of the F breed for most traits was superior to that of the other *Bos taurus* breeds. The heterosis effect between B and S large for lactation milk yield (MY) (296 kg) and calving interval (CI) (-36 days). The heterosis between A and B for most traits was small, which is consistent with other studies in the literature. The estimates of recombination loss were negative in the crosses A x B and B x S for MY, daily milk yield (DMY) and MY expressed per unit MW. Modelling of alternative crossbreeding systems for MY indicated that the performance of the F x S cross for MY was not significantly different from that of the three-breed rotation and the synthetic breeds. It was estimated that the two-breed rotation involving A and S would attain 81 % of the MY of the F x S cross. Among the synthetic breeds themselves, differences in MY were small. Each crossbreeding strategy should be considered in relation to the ecological and socio-economic characteristics of is production system which vary markedly. This study showed that F x S cows were closely rivalled by the three-breed rotation and the synthetics. It is concluded that the first cross is not generally the best suited for dairying in the tropics. There is the need to promote greater awareness of the potential of synthetic breeds and to formulate strategies for developing and exploiting them.

Keywords: Crossbreeding parameters, Crossbreeding strategy, Dairy cattle, Synthetic breeds, Tropics

Introduction

The Sahiwal (S) breed has been the *B. indicus* breed most frequently used in tropical dairy crossbreeding because it is considered unequalled in additive genetic effects for milk production (Cunningham and Syrstad, 1987). Trail and Gregory (1981) reported excellent purebred and crossbred performances of the S breed in a range of tropical production systems and environments. The *B. taurus* breeds that have been used in crossbreeding with the S include Ayrshire (A), Brown Swiss (B), Friesian (F) and Jersey (Cunningham and Syrstad, 1987). The choice of *B. taurus* breeds has been determined by several factors. For example, in production systems in which milk volume has a higher monetary value than milk fat yield (as is the case in Kenya), then A, B and F cattle are most suitable. However, Ahlborn-Breier and Hohenboken (1991) reported small breed differences between the F and Jersey breeds for first lactation milk fat yield in pastoral systems in New Zealand. Because of its large mature size, crossbreeding with the F breed would be expected to result in high cow live weights (LW) of its crosses, which might have a direct influence on food costs and hence profit. Therefore assessment of the suitability of the F breed for crossbreeding to improve milk production is not complete without considering its effect on the LW of its crossbreds.

In order to design efficient breeding systems, information on LW and on milk production expressed per unit of LW and of metabolic weight (MW) is required. Predicted performances of untested genotypes and breeding systems are also required because crossbreeding experiments for dairy and beef cattle are long term and expensive (Dickerson, 1969). This paper gives estimates for additive breed genetic and heterotic effects on milk production and LW of crosses of A, B, F and S cattle. The MY of various breeding systems is predicted.

Material and methods

Data source, herd description and management

Data were made available by a private dairy ranch (Kilifi Plantations) in Coast Province, Kenya. The ranch is located in Kilifi District and is situated 60 km north of Mombasa. The herd, which was established in 1939 from a continuous two-breed rotational crossbreeding system involving the S and A breeds, was transferred to Kilifi in 1963. The A bulls were mated to cows with breed content of 67% S 33% A and S bulls were mated to 67% A 33% S cows. These cows were sometimes mated back to bulls of the same breed as their sires to produce genotypes of 83% S 17% A or 83% A 17% S. In the mid 1970s, B was introduced to the rotation and first mated to the rotation cows to produce genotypes with breed compositions of 50% B 33% S 17% A or 50% B 33% A 17% S. In accordance with the rotation, these were usually mated to A and S bulls, respectively, though sometimes they were mated to B bulls or S or A. That is, the rotation was not followed strictly and several genotypes were generated with a minimum of 8% and maximum of 83% of any one breed. In the early 1990s a fourth breed, the F, was introduced and mated to the above genotypes with the aim of replacing the A breed in the crosses. In the present analysis only the first generation crosses of F are included.

Generally the matings were by artificial insemination (AI); they were not influenced by relative body size of the breed. The A, F (the European strain) and S semen was from the Kenya National AI service, while B semen was imported from the USA. In cases where the cows did not conceive after two AI services, they were grazed together with crossbred bulls for at least two natural services. These bulls were bred in the Kilifi herd and belonged to any of the above genotypes apart from the F crosses.

The cows were grazed rotationally on natural pastures in one of nine milking herds. The predominant grass species was *Panicum infesticum.* During the dry period (generally January-March), approximately 20 kg fresh weight natural pasture silage was offered per cow per day. Mineral licks were always on offer. Milking was by hand twice daily; milk yield was recorded at each milking. During each milking, concentrate feed for *ad libitum* intake (about 3 kg) was offered. Cows were sprayed weekly with acaricide and given prophylactic treatment for trypanosomosis during pregancy. At 7 months of pregnancy, the cows were dried off and taken to ‘pre-calving down paddocks’. Cows were weighed for the purpose of determining the exact dosage of a drug to be used in the event of sickness. The frequency and the reasons of culling in the different age-classes before the introduction of the F breed were described by Thorpe et al. (1994).

Statistical methods

Live weight (LW; kg) and five milk production and reproduction traits were analysed: lactation milk yield (MY; kg); lactation length (LL; days); calving interval (CI; days); annual milk yield (AMY; kg); and daily milk yield (DMY; kg). The AMY was calculated as (MY/CI) x 365, while DMY was defined as MY/LL. A two-step method was used to estimate crossbreeding parameters. In the first step, an individual animal model that accounted for all additive genetic relationships between animals was used to estimate the breed cross means using the DFREML program (Meyer, 1991). For the analysis of the milk production traits, the following fixed effects were fitted: genotype (breed cross) of the cow which consisted of 25 classes with different sire and dam combinations and hence different breed and heterosis contributions; lactation number (1, 2, 3, 4 or >4) and year-season of calving where each year from 1975 to 1997 has four seasons: January to March for the first dry season; April to June for the main wet season; July to September and October to December as the secondary dry and wet seasons, respectively. For the analysis of LW, year-season of calving included each year from 1995 to 1997, each with four seasons; physiological status of the cow at time of weighing consisted of four classes: empty; first trimester of pregnancy; second trimester; and third trimester. The number of days from birth to weighing date was fitted as a linear covariable to adjust for the effect of age of the cow at the time of weighing.

The second step involved regressing the breed cross means on covariables for additive breed and non-additive effects in a weighted least squares (WLS) model. Thus, the model included coefficients for additive breed effect for B, F and S and heterosis and recombination loss effects in the crosses A x B, A x S and B x S. The reciprocals of the variances of means were used as weights. Additive breed effects represented groupings according to the proportion of B, F and S genes in the animals. This implies that additive breed effects (g_i) were expressed as a deviation from the A breed. The coefficients of heterosis and recombination were calculated as $p_i^f p_j^m + p_i^m p_j^f$ and $p_i^f p_j^f + p_i^m p_j^m$, respectively, where p_i^f and p_i^m denote the gene proportion of breed *i* in the sire and dam, respectively (Akbas et al., 1993). To predict performance of alternative crossbreeding system, the A mean, the additive breed, heterosis and recombination effects estimated and the coefficients for a particular crossbreeding system were substituted in the genetic model as described by Kahi et al. (1999). In the data set used, the number of crosses with F genes was insufficient to allow estimation of dominance and additive x additive interaction effects that are due A x F, B x F or F x S crossing.

Results

The mean reproductive and lactational performance was good. The mean LW was 435 kg (SD 70) (Table 1) and the mean CI was 402 days (SD 64), while the mean LL was 326 days (SD 72) with a mean MY of 3446 (SD 1112). This resulted in mean AMY and DMY of 3124 kg (SD 833) and 10.8 kg (SD 2.57), respectively.

Table 1. Estimates (Est.) and standard errors (SE) of individual crossbreeding effects for milk production traits and cow live weight.

Parameter[b]	Milk production traits[a]													
		MY (kg)		AMY (kg)		CI (days)		LL (days)		DMY (kg)			LW (kg)[a]	
Phenotype	n	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	n	Mean	SD
	10213	3446	1112	3124	833	402	64	326	72	10.76	2.57	1178	435	70
Effects		Est.	SE	Est.	SE	Est.	SE	Est	SE	Est	SE		Est.	SE
m		3493	172	2961	127	438	9	349	12	10.01	0.33		413	19
g_B		269	179	240†	132	-10	10	5	13	0.72	0.34		20	19
g_F		1034***	355	1210***	261	-45*	19	-1	25	3.27**	0.68		31†	20
g_S		-768***	149	-554***	109	-23**	8	-43**	11	-1.09†	0.29		-2	24
h_{AB}		-114	129	-47	95	-13†	7	-13	9	-0.02	0.24		8	13
h_{AS}		-74	228	186	167	-15†	7	-24	16	0.58	0.43		1	22
h_{BS}		296†	146	382**	106	-36**	12	-8	10	1.06*	0.28		23	17
r_{AB}		-168	371	-51	272	-28	20	-1	26	-0.39	0.70		16	34
r_{AS}		530†	270	499*	198	-16	15	26	19	0.98	0.51		-7	23
r_{BS}		-99	378	274	277	-39†	21	-31	26	-0.68	0.72		34	31
R^2		0.932		0.921		0.814		0.866		0.914			0.477	

[a]MY = Lactation milk yield; AMY = Annual milk yield; CI = Calving interval; LL = Lactation lenght; DMY = Daily milk yield; LW = Cow live weight.

[b]m is the mean performance of the A breed; g_B, g_F and g_S are the additive breed effects for Brown Swiss (B), Friesian (F) and Sahiwal (S), respectively; h_{AB}, h_{AS}, h_{BS}, r_{AB}, r_{AS} and r_{BS} are the heterosis (h) and recombination loss (r) effects between A and B, between A and S, and between B and S, respectively; R^2 is the proportion of variation between breed cross explained by the weighted least-squares model.

†P<0.10; *P<0.05; **P<0.01; ***P<0.001.

Genetic parameter estimates

Table 1 shows estimates of genetic parameters for milk production traits and LW and Table 2 estimates for MY and AMY expressed per unit of LW and per unit MW. The additive breed effects are expressed as a deviation from the A breed (m). Additive breed effects for F and were large and significant (P<0.05) for MY, AMY and CI. B showed smaller than F additive effects while S showed the smallest additive breed for these traits. The MY of S was 1802 kg less than that of F. For LL, the breed difference between A and S were larger that those between A and B or F. This indicates that the S breed additive breed effects resulted in reduction in the LL. For LW, significant breed difference between the F and A were estimated. The F contributed 31 kg heavier LW than A. F showed significantly positive additive breed effects for both MY and AMY expressed per unit of LW and MW (Table 2). As to be expected, S had the smallest estimated breed additive effects for these traits. For example, it contributed 18.4 kg less MY per unit of MW than F.

Table 2. Estimates (Est.) and standard errors (SE) of individual crossbreeding effects for MY and AMY expressed per unit of metabolic and live weight[a].

		Per unit metabolic weight[b]					Per unit live weight[b]			
Effect[c]		MY (kg)		AMY (kg)			MY (kg)		AMY (kg)	
	n	Est.	SE	Est.	SE	n	Est.	SE	Est	SE
	1178					1178				
m		34.85	1.91	30.19	1.65		7.64	0.48	6.62	0.42
g_B		4.66	2.93	4.76†	2.52		1.15	0.74	1.16†	0.64
g_F		12.45*	5.55	12.95*	4.74		2.71*	1.40	2.81*	1.21
g_S		-5.98**	1.69	-3.96*	1.44		-1.27**	0.42	-0.81*	0.36
h_{AB}		1.60	2.23	1.02	1.91		0.39	0.56	0.25	0.49
h_{AS}		1.76	2.45	3.25	2.09		0.45	0.62	0.77	0.53
h_{BS}		3.30†	2.09	3.33†	1.79		0.40	0.52	0.41	0.45
r_{AB}		-1.09	6.99	-0.71	6.01		-0.36	1.77	-0.27	1.53
r_{AS}		4.84	3.77	4.36	3.23		1.00	0.31	0.90	0.82
r_{BS}		-4.33	6.81	-0.80	5.82		-1.04	0.55	-0.26	1.49
R^2		0.819		0.752			0.774		0.693	

[a]See footnotes in Table 1 for description of traits, breeds and effects.
†P<0.10; *P<0.05; **P<0.01

The heterosis effects for MY were small and not significant in the crosses A x B and A x S. However the cross B x S showed a significant heterosis effects of 296 kg for MY. As for MY, the heterosis effects for AMY were significant in the cross B x S but not in the crosses A x B and A x S. For CI, the heterosis effects were all favourable and significant (P<0.10) in all the crosses. While none of the heterosis effects for LW were significant, they were positive for all the crosses. For MY and AMY expressed per unit of MW, significant heterosis was only found in the B x S cross. It was estimated that heterozygosity with respect to B and S genes resulted in MY and AMY expressed per unit of MW of about 3.3 kg (10 %) over the mean of the B and S pure-bred.. This indicates that crossbreeding results in an improvement in biological efficiency. Recombination loss effects for MY in the crosses A x B and B x S were negative while those in the A x S were unexpectedly positive and significant.

Breeding systems

Table 3 shows the abbreviation, definition and the predicted mean performance of crossbreeding system for MY. The need of maintaining the parent pure-bred populations necessary to produce the crosses is ignored. The predicted MY of the F x S cross was not different from that of the three-breed rotation and the synthetic breeds However, when compared to $(AS)_{Rot}$, F x S cross produced 745 kg more. Among the synthetic breeds, the $(3/4F\ 1/4S)_{Syn}$ and $(1/8A\ 1/4B\ 1/2F\ 1/8S)_{Syn}$ produced more MY while MY in the $(BFS)_{Syn}$, $(3/8B\ 3/8F\ 1/4S)_{Syn}$ and $(ABFS)_{Syn}$ was similar. Predicted AMY and MY expressed per unit of MW followed a similar trend.

Table 3. Predicted MY for the crossbreeding systems using parameters from analysis of the data

Abbreviation[a]	Crossbreeding system	Breed contribution (%)				Predicted MY
		A	B	F	S	
F x S	First cross			50	50	3922
$(AS)_{Rot}$	Two-breed rotation	50			50	3177
$(BFS)_{Rot}$	Three-breed rotation		33.3	33.3	33.3	3771
$(FS)_{Syn}$	Two-breed synthetic (equal contribution)			50	50	3724
$(3/4F\ 1/4S)_{Syn}$	Two-breed synthetic (unequal contribution)			75	25	4150
$(BFS)_{Syn}$	Three-breed synthetic (equal contribution)		33.3	33.3	33.3	3694
$(3/8B\ 3/8F\ 1/4S)_{Syn}$	Three-breed synthetic (unequal contribution)		37.5	37.5	25	3784
$(ABFS)_{Syn}$	Four-breed synthetic (equal contribution)	25	25	25	25	3627
$(1/8A\ 1/4B\ 1/2F\ 1/8S)_{Syn}$	Four-breed synthetic (unequal contribution)	12.5	25	50	12.5	3908

[a]See footnotes in Table 1 for description of breeds.

Discussion

The mean MY of 3446 kg (SD 1112) was higher than reported by Mackinnon et al. (1996) from a subset of these data. This could be attributed to the introduction of the F breed in the herd because from the time of that analysis to the present analysis there has been no marked change in the management especially as pertains to the feeding programme. In that study, F crosses were not included in the analysis.

Additive genetic effects

The estimated breed differences for MY for F over B (765 kg) and A (1034 kg) are higher than those estimated elsewhere. For example, in an American study, the F contributed 759 and 857 kg more first lactation MY than the B and A, respectively (Robison et al., 1981). As was expected, the breed difference between the mean of the *B. taurus* breeds and S breeds for the MY was large. The estimated difference in MY (1802 kg) between the F and S is more than double the estimate of 773 kg difference between F and S reported by Sharma and Pirchner (1991) utilising data obtained from a number of dairy farms in India. Under a semi-arid and low inputs environment, Thorpe et al. (1993) reported that MY of S was 746 kg less than that of *B. taurus* (A and F). This resulted from a 2.2 kg greater DMY and 46 days longer LL of *B. taurus* than of the S breed. The estimate for the breed difference in CI for F (-22 days) from S is rather small and indicates that the differences between these two breeds were not very high under the conditions of the present study. These results are similar to those reported by Cunningham and Syrstad (1987) using data from 13 projects in the tropics.

The estimate for the breed difference in LW for F from A was significant. It was estimated that F contributed 31 kg heavier LW than the A. As to be expected, at 4½ years the F contributed heavier LW than the S. The breed difference between F and S for LW was 33 kg. This difference is smaller than that reported by Talbott (1994) who estimated that F contributed 68 kg heavier than S at 5 years of age in a study in Pakistan that included information on pure-bred performance of the S breed itself. In that study, the LW of the S was lower than estimated in the present study. Although these estimates were from crossbred cows, they reflect the transmitting effects for LW of the F and S. The ranking of the *B. taurus* breeds for LW (F>B>A) was expected because of the differences in mature weights reported elsewhere (Felius, 1985) and confirms that the use of F sires for crossbreeding would result in heavier LW in its crossbreds and hence an increase in food costs. This demonstrates the importance of including LW as a selection criterion among breeds of *B. taurus* for crossbreeding in tropical dairy production systems, especially for smallholder production where feed resources may be scarce and their availability variable (Walshe et al., 1991).

Given the high levels of management in this herd and the fact that milk volume has a higher monetary value than milk fat or milk protein yield, the use of the F breed is justified because it was superior to the other *B. taurus* breeds for MY and AMY expressed per unit of LW and per unit of MW (Table 3). However, when feed resources are scarce, it would be expected that larger breeds would be less able to meet their feed intake capacity than smaller breeds and may then become less efficient. An important question is whether superior biological efficiency translates to superior economic efficiency, a question that is difficult to answer because of the problems of measuring the inputs of a grazing-based production system - in particular feed intake. Feed intake is an important expense trait in explaining variation among breeds in measures of economic efficiency (Balaine et al., 1981). There is need therefore to establish the nutrient requirements and the utilisation efficiencies of breeds of varying body size so that breeding systems can be matched with different production systems in order to optimise production efficiency. This is important especially in tropical dairy production systems where the choice of *B. taurus* and *B. indicus* breeds to be used in crossbreeding should match the levels of inputs (Madalena et al., 1990) which vary markedly both within and among tropical countries.

Heterotic and recombination effects

For MY, high and mostly significant heterosis effects were estimated in the cross B x S but not in the other crosses. These effects were lower than reported by Sharma and Pirchner (1991) in the F x S cross (333 kg) but higher than reported by Thorpe et al. (1993) in *B. taurus* (A and F) x S (73 kg) cross. The lack of a significant heterosis effect in the cross A x B is expected and is in line with the theory which predicts that the wider the genetic distance or greater the phenotypic difference between parent breeds, the greater the heterosis expressed. The significant effect of heterosis for CI reported in the present study is smaller than that reported by Thorpe et al. (1993). In that study, F_1 cows had CI that were 82 days shorter than the mean of the *B. taurus* (A and F) and S pure-breds. The heterosis estimated in the present study ranged from -13 days in the A x B cross to -36 days in the B x S cross. Cunningham (1981) suggested that when there is a substantial difference between the F_1 and the local strain, production in a poor environment is influenced heavily by heterosis and production in a good environment is largely determined by breed additive effects and small heterotic effects. The differences in the magnitude of the heterosis estimated in the present study where nutritional levels were good, and in that reported by Thorpe et al. (1993) where there was sub-optimal nutrition is supportive of this suggestion. The negative estimates of recombination effects for MY in the crosses A x B are expected. The A and B have been selected for decades with the main aim of increasing MY per cow. Therefore, favourable epistatic interactions between genes on different loci within gametes may have been enriched. By crossing A and B, these interactions are lost due to recombination in the meiosis. Similar negative estimates have been reported in the literature from crosses of *B. taurus* breeds (McAllister, 1986; Ericson, 1987; Van der Werf, 1990).

Breeding system

Prediction was based on previous results on additive breed difference, heterosis and recombination loss effects. The best crossbreeding system (first cross) should be that which maintains the highest levels of heterozygosity. However, the results indicate that the F x S cross is rivalled by the synthetics in MY (Table 3). This indicates that greater improvement in performance may be achieved by the use of synthetic breeds in tropical dairy production systems which vary both within and between countries.

Based on results from Brazil, Madalena (1993) presented an F_1 continuous replacement scheme to capitalise on the superiority of the F_1 hybrid. This system might not be practical because the number of pure-bred females required is too large to be kept in a nucleus or to be found concentrated in a few herds (Kosgey et al., 1998). Rutledge (1996) suggested the use of *in-vitro* fertilisation to continuously produce F_1 embryos in a central laboratory. Such a system is not sustainable because of the technology and the costs involved in the production of the embryos. Also efficient dissemination of embryos would require a well developed infrastructure, which is partially or completely lacking in most developing countries. Furthermore, such a system would be too sophisticated to suit the poor conditions in small farms and villages. While this system can be implemented in dairy ranches supplying F_1 heifers, it may have some drawbacks on a regional scale because of health controls and transport costs (Madalena, 1981) and the initial cost of replacement heifers. Therefore the real challenge is to establish breeding programmes that allow for on-farm raising of replacement heifers, because replacement costs are important in determining profit from any dairy enterprise (Van Arendonk and Brascamp, 1990).

A rotation system could allow for on-farm raising of replacement heifers. However, the utilisation of heterosis through organised breed rotation crossbreeding systems is restricted due to the fact that a high percentage of cattle are kept in management units that are too small (Trail and Gregory, 1981). Although rotation system could be the strategy of choice when organisational and management problems can be overcome, as in large, well organised farms (Syrstad, 1996), the wide fluctuation in breed composition between generations make it difficult to synchronise climatic adaptability and performance characteristics with a given management level and natural environment. Therefore, the use of synthetic breeds for dairying in the tropics should be given more attention. Gregory et al. (1982) have discussed the utilisation of synthetic breeds for dairy production in the tropics.

Because of its organisational simplicity, the synthetic breed strategy is the most realistic approach to utilising the advantage of crossbreeding in small scale dairying (Syrstad, 1996). However, an efficient genetic improvement scheme in the synthetic breed should be established which is comparable to those applied in exotic *B. taurus* breeds. This may be difficult as a sufficient size of the breeding population is necessary. Large private sector herds, such as Kilifi Plantations, which are sources of breeding stock to the surrounding smallholder farmers, have the resources to run a selection scheme. Additional 'genetic lift' can be achieved by selecting the best indigenous *B. indicus* cows to be used to set up synthetic populations. Syrstad and Ruane (1998) have demonstrated how this can be done using a small number of animals. Cunningham (1980), Smith (1988) and Bondoc and Smith (1993) have described the methodology of open nucleus breeding schemes applicable for the specific situation in developing countries. With such a system, the effective population size will be large enough for improvement through within-breed selection. The achieved additive genetic progress will provide benefits for the nucleus herd and for those herds sourcing their replacement from the nucleus.

Conclusions

Our study justifies the use of F sires for crossbreeding to improve biological efficiency in systems where management levels can support a production level of above 3000 kg of milk per lactation and where payment is based on volume of liquid milk. Because of the diversity in tropical dairy production systems, each crossbreeding strategy should be considered in relation to the ecological and socio-economic characteristics of its target production system. An economic evaluation of each crossbreeding strategy using appropriate economic evaluation criteria (Kahi et al., 1998) is needed to determine whether the genetic differences among strategies and breeds lead to greater economic benefits. The generalisation that the F_1 system is best suited for dairying in the tropics could be misleading. The results presented here suggest that there is the need to promote greater awareness of the potential of synthetic breeds.

Acknowledgements

We thank C.D. Wilson of Kilifi Plantations, for permission to use the records from the herd, the German Academic Exchange Service (DAAD) and Hohenheim University for funding the work, and the International Livestock Research Institute (ILRI) for provision of facilities. This paper was written when the first author was on study leave from Egerton University, Njoro, Kenya.

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