Experimentation with a beef production model for the savannas of Colombia

Philip K. Thornton

International Center for Tropical Agriculture, CIAT
April 1987

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EXPERIMENTATION WITH A BEEF PRODUCTION SIMULATION MODEL FOR THE SAVANNAS OF COLOMBIA

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Centro Internacional de Agricultura Tropical

Cattle Production Systems Simulation Project Document Number 6

April 1987

Summary

Experimentation with a computer-based simulation model of the extensive beef operations found in the savannas of Colombia is described. The model was outlined in another document. The experimentation considered consists of the following: a brief survey of validation work and sensitivity analysis carried out for the original beef model at Reading University, a description of the validation work carried out in Colombia to adapt it to local conditions, description and results of further sensitivity analysis of interest, and the experimental program proper. This is in two parts: a description of initial work with a large number of possible management strategies, and the results of crude risk analysis on the most promising alternatives. The document concludes with a consideration of further work needed and some general conclusions.

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1. INTRODUCTION

This document describes the experimentation work carried out with the beef model RUSMOB. User notes and a description of the model may be found elsewhere (Thornton, 1987). The structure of these notes is as follows:

- a brief overview of the original validation work carried out by Kahn (Kahn and Spedding, 1983, 1984, Kahn and Lehrer, 1984);
- a description of the validation experiments carried out for Colombian conditions;
- a description of certain sensitivity analyses for model parameters and for some aspects of the primary production component;
- descriptions of the experimental phase proper, including crude risk analysis;
- future work and recommendations.

The following convention is followed with respect to variable and program names: RUSMOB refers to the entire computer-based system; PASMOD refers to the grass-legume pasture model; FORTRAN names for subroutines are referred to as "subroutine NAME"; any other FORTRAN name in capital letters may be taken as referring to a variable. If the variable name belongs to an array, it will usually be referred to as NAME(i), where *i* may be the letter itself to denote generality, or a number, to denote a particular position in the array, or a range, such as 1-4, denoting the first four positions in the array.

2. VALIDATION WORK

2.1 Original Validation

Kahn (Kahn and Spedding, 1983) was concerned to investigate optimum herd size, in an attempt to balance accuracy against high computational load, and the length of simulation. She found that 30-cow herds gave acceptable estimates of 300-cow herds, and that 10 year runs were sufficient for the coefficients of variation, which arise from the stochasticity inherent in the model, to stabilise. Similar experiments are described below. When the size of the integration time-step was investigated, no significant differences were found in herd-based variables between single-day and

30-day intervals, although there were considerable discrepancies for individual animal calculations. More detailed and accurate information on a per animal basis appeared to necessitate a reduction in the time step.

The important relationships in the model were validated in a number of ways. Those for dry matter intake were tested for accuracy in predicting the weight changes in growing steers for conditions as diverse as those found in Britain and Botswana (Kahn and Spedding, 1984). Predicted weights were generally within 0.4 to 1.5% of measured weights, and the fluctuations in predicted liveweight curves followed the patterns of observed liveweight curves. The reproduction equations were validated using data from commercial herds in Israel (Kahn and Lehrer, 1984), and there was close correspondence between observed and simulated conception distributions. The equations' sensitivity to the nutritional factors which affect reproductive performance was also demonstrated.

2.2 Validation for the Llanos Orientales

The objective was to investigate the performance of the model in simulating a base-line savanna system. Afterwards, the ability of the model to simulate production from a permanent improved pasture-type system was also investigated. The base-line system was used more to reset parameters and to fine-tune model performance; the simulation of improved pasture systems was conducted with the aim of testing these changes to the model, to see if such different systems could be described essentially in terms of diet alone.

Three series of runs are described. Many more were undertaken during the course of program development, and these contributed much in obtaining a feel for the model and the way it would respond to various changes in input parameters. The first series described, Series 3, consisted of five replicates of the base-line model. The subsequent two series quantified the effects of changing various run parameters: run length, *dt* for cows and calves, different herd sizes at year 0, and different herd age structures. The runs are listed in Table 1. For the runs described in the remainder of Section 2, RUSMOB V2.0 was used, although V3.0 was produced concurrently. Note that these versions of RUSMOB have been superseded (the current

Series 3

Five replicates of the standard model - dt = 10/10, 10 years of simulation, and an initial herd size of 34.

Series 4a

Standard run over 5 years.
Standard run over 15 years.
Standard run with dt = 30/10
Standard run with dt = 30/30
Standard run with dt = 5/5

Series 4b

Initial herd size of 10, from same distribution.
Initial herd size of 50, from same distribution over 8 years.
A 30 heifer herd over 10 years.
The same over 20 years.
A 30 member herd of old cows over 10 years.
The same over 20 years.

TABLE 1 RUSMOB SERIES 3, 4A AND 4B VALIDATION RUNS version number is V4.3 of March 1987).

Series 3

For the first series, a herd size of 34 was chosen, in an attempt to maintain approximately 30 breeding individuals throughout the run. Four of the 34 were young replacement calves, newly weaned. The structure of the full herd is shown in Table 2. The integration time step was ten days for both cows and calves, and the run length was ten years. Data for diet quality were taken from Lebdosoekojo (1977); the four replicates reported were averaged. The results for the five replicates are shown in Tables 3 and 4. The first of these shows the average value of a number of production parameters and the variability between replicates and also within replicates between years. Two methods are used to calculate production per animal unit per year; the first involves simply summing the weight of calf sales and cull sales, whilst the second is more involved in that it takes account of the growth of yearlings within the herd, although cullings are not accounted for. The second method was included since it makes possible direct comparison of simulated results with published results from the Llanos (Vera and Sere, 1985); care is needed, however, since some of the farms in the sample were using sown pastures.

Table 4 allows comparison of simulated results with observed results from beef production systems in the Eastern Plains. It is clear from Table 3 that the variation between replicates over ten years is small; this is to be expected, since diet quality is represented by unchanging (deterministic) values from year to year. The variation between years within runs is much greater, however, illustrating the fact that the herd goes through the process of reaching some sort of stability over a ten-year period. This variation between years can be reduced by pairing years together, since with conception rates of 50 to 60 per cent, production over a 24-month period tends to be cyclical. The importance of starting conditions is considered below, but it is worth noting that the original herd of Table 2 was constructed so that its age structure was very similar to that of the "average herd" in the farms sampled in the Llanos (Vera and Sere, 1985), and a fixed proportion of eligible cows were deemed to be pregnant at year 0, with projected calving dates bunching in the fifth to

No.	Age	W	WM	PTIME
1	0.75	129	450	
2	1	160	448	
3	1	150	447	
4	1	155	448	
5	2	200	450	
6	2	215	449	
7	2	195	448	
8	2	210	449	
9	2	205	448	
10	2	185	449	
11	3	270	450	
12	3	250	445	
13	3	260	443	
14	3	280	442	180
15	3	290	452	210
16	3	285	441	210
17	4	300	440	
18	4	310	449	
19	4	300	446	150
20	4	305	447	180
21	4	310	458	
22	5	340	447	180
23	5	290	446	210
24	5	335	442	
25	5	340	442	
26	6	285	445	120
27	6	350	447	150
28	6	345	449	
29	6	320	446	
30	7	305	449	120
31	7	310	458	
32	7	340	447	
33	8	320	446	
34	9	335	442	
X	4.0		447 4	

W = weight

WM = normative weight

PTIME = days pregnant

TABLE 2 RUSMOB VALIDATION SERIES 3 AND 41 - THE STANDARD HERD

	Within Replicates			Between Replicates		
	x	s	CV	x	s	CV
Calf Sales	660.9	360.1	54.5	660.9	3.8	5.3
Conceptions	14.3	3.4	23.8	14.3	1.5	10.3
No. Weaned	8.5	3.7	43.0	8.5	0.8	9.0
Weaning Wt	134.3	4.0	2.9	134.3	1.0	0.7
12 Month Wt	139.3	3.5	2.5	139.3	0.3	0.2
24 Month Wt	193.5	2.7	1.4	193.5	0.1	0.1
Conception Interval	610.1	103.9	17.0	610.1	20.3	3.3
Conception %	55.0	9.5*	17.3	55.0	1.3	2.4
Weaning %	32.7	11.4*	34.9	32.7	0.9	2.8
Age @ 1st Partum	4.06	0.27*	6.6	4.06	0.06	1.4
Cow Mortality %	14.9	8.1*	54.3	14.9	1.2	8.1
kg/AU/yr #	22.0	10.0*	45.4	22.0	1.7	7.6
kg/AU/yr - ETES +	42.4	13.7*	32.4	42.4	1.3	3.0

* based on replicate 1

\# production = (calf sales + cull sales) / animal units

\+ production = (no. of cows * weaning % * wt @ 12 months + No of yearlings * wt gain/yr) / animal units

TABLE 3 RUSMOB VALIDATION SERIES 3 - VARIABILITY BETWEEN REPLICATES AND WITHIN REPLICATES BETWEEN YEARS

	Simulated	Observed*
Conception %	55	
Uncorrected Weaning %	33	35 - 64
Age @ 1st partum, mos	49	45
Sales/AU/yr	22	
Production kg/AU/yr	42	40 - 70
Weaning Weight	134	125 - 130
Yearling Growth kg/yr	54	62
Cow Mortality %	15	10 - 16
Calf Mortality %	11	10
Conception Interval	610	546

* source: Vera and Sere, 1985

TABLE 4 SIMULATED AND OBSERVED PRODUCTION PARAMETER VALUES IN THE LLANOS ORIENTALES - PURE SAVANNA SYSTEMS seventh month, following the results from the Carimagua herd systems experiments from 1974 to 1977 (CIAT, 1978). Clearly, the cyclical nature of production could largely be eliminated by increasing the proportion of pregnant cows at the start of the simulation, if this were deemed necessary. As might be expected, the most variable parameters are those which are stochastic in the model (cow mortality and conception, for example).

The liveweight evolution of cow #1 from replicate 1 is presented in Figure 1. She started the simulation run as a newly-weaned 9 month old weighing 129 kg, and died at age eight and a half, having conceived three times and produced 2 calves, not an impressive production record.

Figure 2 shows frequency histograms for the whole herd age structure for replicate 1. The distribution of ages at year 10 is tolerably close to that at year 0, providing partial vindication at least of the death rates used in the model. Herd stability is considered again below. The relatively low weaning percentages obtained in these runs are partially explained in Figure 3, which shows the fate of conceptions for replicate 1. It appears that a ten-year run is not sufficiently long to enable the conceptions and suckling calves "on hand" at the end of the run to be ignored safely. In addition, the high death rate of older cows results in a comparatively large number of orphans, which, according to the decision rule then operating in the model, were sold immediately; it seems likely that in reality a number of these would survive, in effect entering the followers herd as the result of enforced early weaning.

Series 4a

The runs in series 4a involved changing the length of simulation and the values of the time step *dt* for cow and calf. The resultant values of selected parameters, in comparison with the average values from the base-line simulations, are shown in Table 5. It is apparent that 5 years is insufficient time for an equilibrium to have been reached, whereas the differences between a ten- and a fifteen-year run are slight. The differences induced by varying *dt* are not so straightforward, but it would appear that *dt* for calves should be short rather than long; there is some

FIGURE 1 COW LIVEWEIGHT EVOLUTION

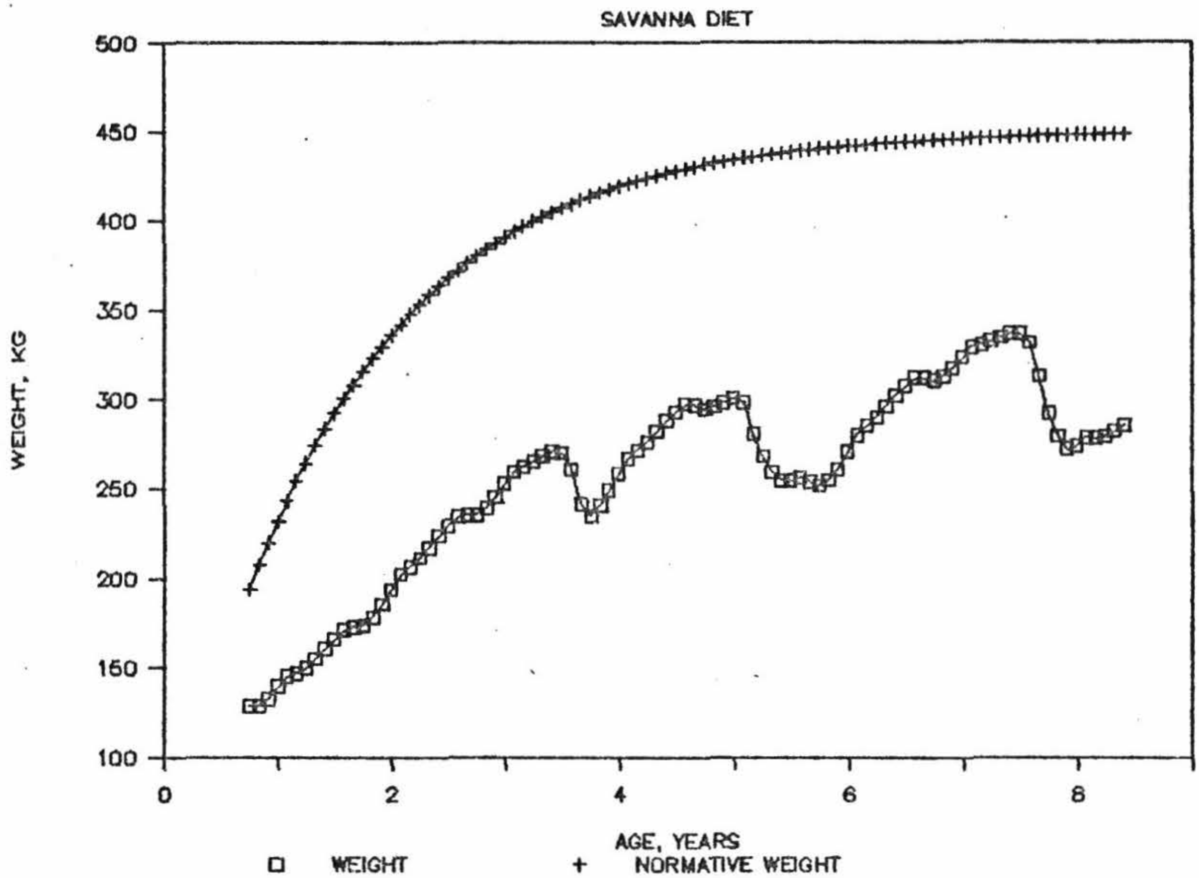
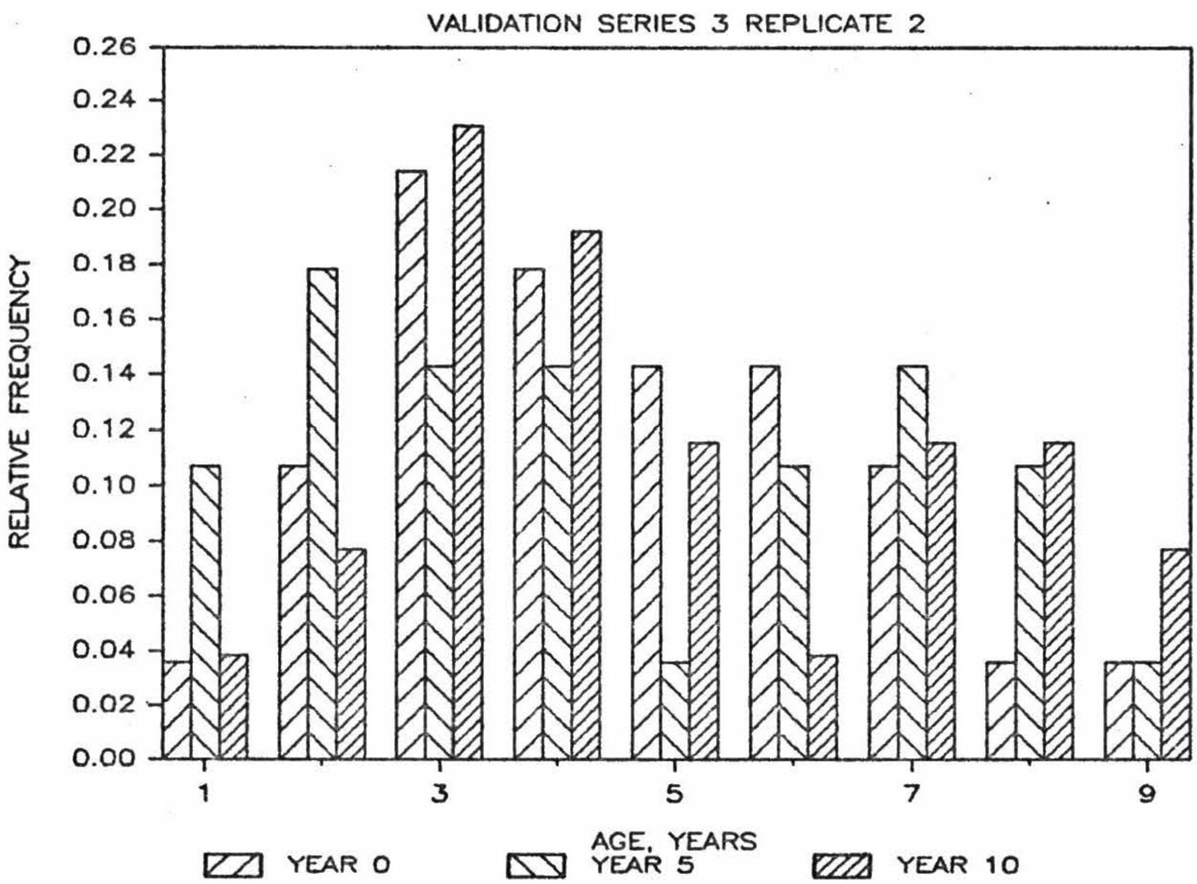


FIGURE 2 HERD AGE DISTRIBUTION



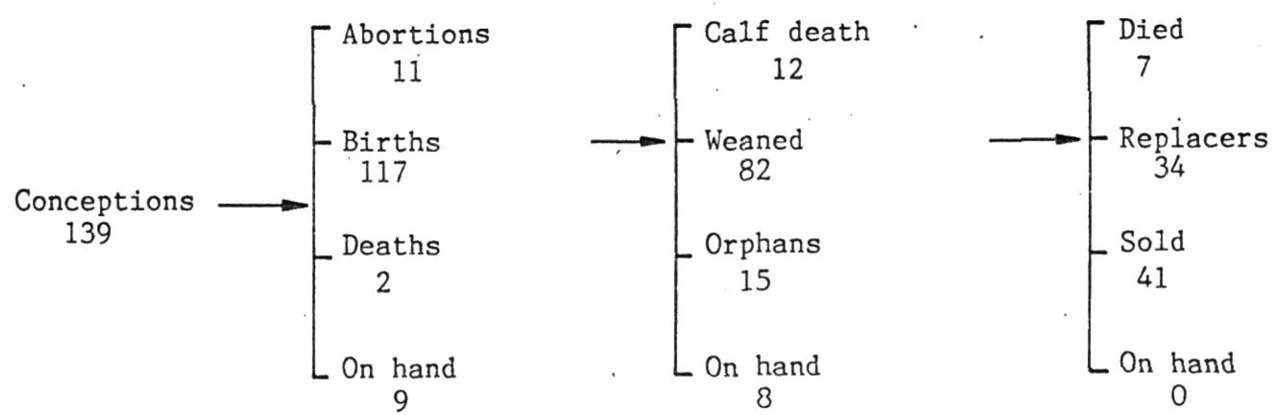


Figure 3 Fate of conceptions, replicate 1, savanna system

Series 3		Changed Run-time Parameters				
		--run length--		----------dt----------		
	X	5 yr	15 yr	30/10	30/30	5/5
Conception %	55	65	55	51	56	60
Weaning %	33	30	32	29	25	35
Cow Mort %	15	13	16	14	17	16
Age 1st calf	4.1	4.2	4.1	4.1	4.2	4.1
Weaning Wt	134	132	134	136	136	133
Concep. Int.	610	516	630	639	654	603
24 Month Wt	194	194	193	193	192	193
kg/AU/yr	22	20	19	19	19	25
kg/AU/yr ETES	42	38	41	39	33	44

TABLE 5 RUSMOB VALIDATION SERIES 4A RESULTS - PRODUCTION PARAMETERS

tendency for the shortening of *dt* to result in higher production levels, but this in not unequivocal. It will be seen that for all runs, those parameters involving weights vary little; this can be explained by the fact that such parameters have no stochasticity attached.

Series 4b

These runs involved changing the nature of the herd at year 0. A small and a large herd were simulated, and it was arranged that these herds had as similar distributional characteristics (in terms of age structure and proportion pregnant) as possible to the original herd shown in Table 2. These herds are shown in Table 6; for the fifty-cow herd, only eight years of simulation could be completed, after which the limits of the program's capacity was reached (up to 100 breeding cows in all, a limitation of early versions of RUSMOB). Two further herds were set up, one consisting of 30 heifers and one of cows approaching the end of their productive life. These herds are shown in Tables 7 and 8. Results are given in Tables 9 and 10 for these runs; the latter shows results for the heifer herd on a year-by-year basis. Different herd sizes from essentially the same herd have limited effects on production parameters; for the small herd of ten beasts, a revealing statistic is the cow mortality rate of 23%, illustrating what might be termed stochastic instability where one individual is equivalent to a large amount of cumulative probability. On the other hand, the simulation of 50 cows is wasteful where a smaller number is still large enough to invoke the law of medium numbers.

Perhaps the most interesting results relate to the heifer and old cow herds. Figure 4 shows the evolution of average age for both these herds over twenty years, together with the limits within which average herd age varied for the five replicates of the base-line simulations. Average age, even for heavily skewed age distributions, quickly reaches values typical of realistic herd age distributions, and tends to oscillate between these limits. The effect of such age distributions can be seen in the production indeces after even twenty years, where, for example, conception percentages are higher for the old herd than for the heifer herd, due in part to the fact that at year 0 all the old herd (in terms of maturity at least) were eligible for conception, whereas this would never be true for the heifer

No.	Age	W	WM	PTIME
1	0.75	129	450	
2	2	200	450	
3	2	210	449	
4	3	260	443	
5	3	280	442	180
6	4	305	447	180
7	5	290	446	210
8	6	345	449	
9	7	310	458	
10	8	320	446	
X	4.1 2.4		448	4.5

No.	Age	W	WM	PTIME
-	Standard herd plus -			
35	1	140	442	
36	1	145	445	120
37	2	195	447	150
38	2	200	449	
39	2	205	446	
40	6	295	449	120
41	3	240	458	
42	3	260	447	
43	3	265	446	
44	7	310	442	
45	4	280	442	210
46	4	290	445	120
47	8	305	447	
48	5	300	449	180
49	5	295	446	
50	6	285	446	210

TABLE 6 RUSMOB VALIDATION SERIES 4B - HERD STRUCTURES

No.	Age	W	WM	PTIME
1	0.75	129	450	
2	0.75	132	448	
3	0.8	140	447	
4	0.75	130	448	
5	0.9	140	450	
6	1.0	150	449	
7	1.0	155	448	
8	1.1	155	449	
9	1.2	160	448	
10	1.3	165	449	
11	1.4	170	450	
12	1.5	160	445	
13	1.6	170	443	
14	1.7	175	442	
15	1.7	170	452	
16	1.8	175	441	
17	1.8	180	440	
18	1.9	190	449	
19	1.1	145	446	
20	1.2	150	447	
21	1.3	150	458	
22	1.4	170	447	
23	0.8	140	446	
24	0.9	135	442	

No.	Age	W	WM	PTIME
25	1.0	140	442	
26	2.0	200	445	
27	2.3	220	447	
28	1.7	185	449	
29	1.6	170	446	
30	1.5	175	449	

W = weight

WM = normative weight

PTIME = days pregnant

TABLE 7 RUSMOB VALIDATION SERIES 4B - HEIFER HERD STRUCTURE

No.	Age	W	WM	PTIME
1	4	310	458	
2	5	310	447	180
3	5	290	446	210
4	5	335	442	
5	5	320	442	
6	6	285	445	120
7	6	320	447	150
8	6	315	449	
9	6	320	446	
10	7	305	449	120
11	7	310	458	
12	7	340	447	
13	8	320	446	
14	9	335	442	
15	6	340	442	
16	6	285	445	
17	6	320	447	210
18	6	345	449	180
19	6	330	446	150
20	6	295	449	90
21	7	310	458	
22	7	340	447	
23	7	290	446	
24	7	335	442	
25	7	340	442	
26	8	265	445	
27	8	350	447	
28	9	345	449	
29	9	320	446	
30	10	360	446	

W = weight

WM = normative weight

PTIME = days pregnant

TABLE 8 RUSMOB VALIDATION SERIES 4B - HERD AGE STRUCTURE

Series 3		Herd Size					
	X	10	50	30 heifers		30 old cows	
yrs		10	8	10	20	10	20
Conception %	55	58	55	52	53	67	62
Weaning %	33	31	33	26	30	31	32
Cow Mort %	15	23	14	12	13	25	24
Age 1st calf	4.1	4.1	4.1	4.0	4.3	4.3	4.1
Weaning Wt	134	130	133	133	134	133	134
Concep. Int.	610	603	613	646	661	590	573
24 Month Wt	194	192	193	193	192	193	194
kg/AU/yr	22	16	23	21	20	20	22
kg/AU/yr ETES	42	39	42	35	40	40	40

TABLE 9 RUSMOB VALIDATION SERIES 4B RESULTS - PRODUCTION PARAMETERS

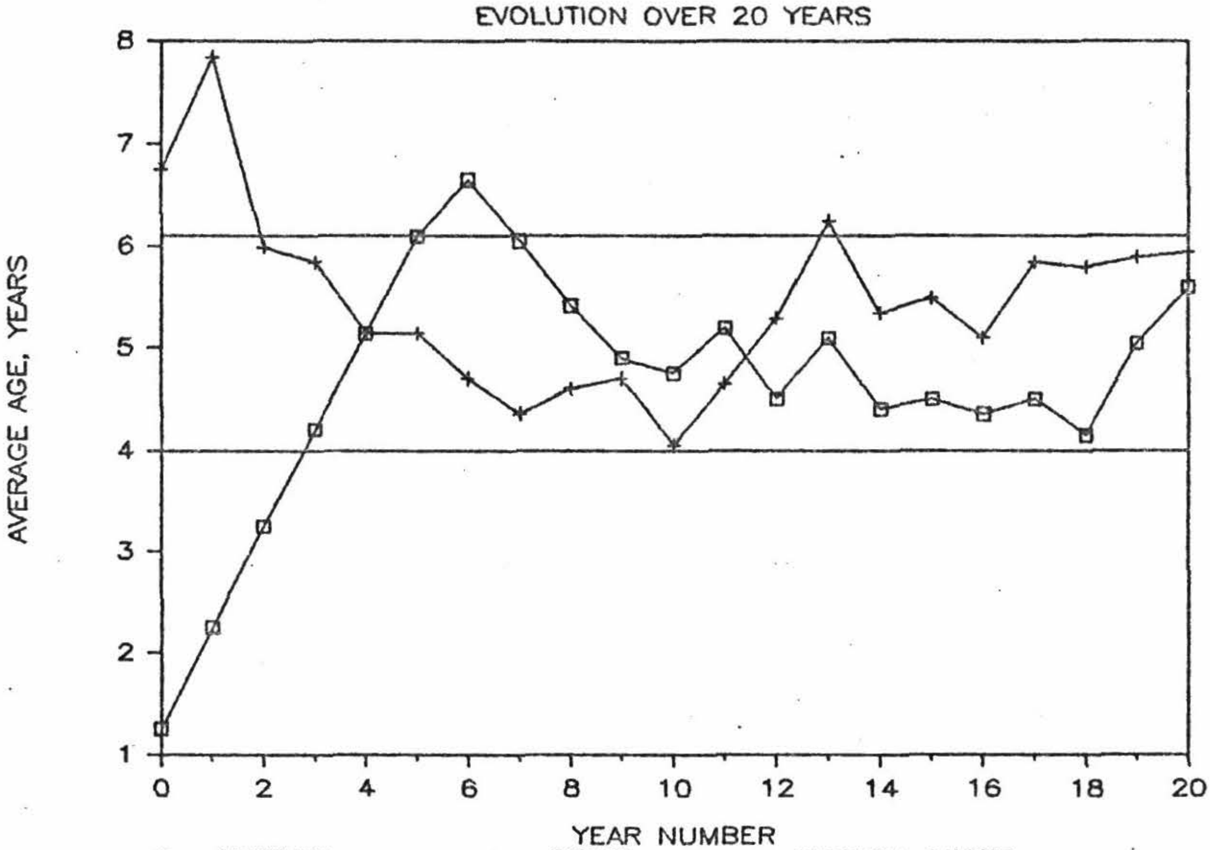
year	1	2	3	4	5	6	7	8	9	10
Av. Age *	1.3	2.3	3.3	4.3	5.2	6.2	6.2	4.9	4.4	4.0
Av. Wt *	161	210	257	258	274	279	264	234	238	243
Conceps	0	20	12	18	14	14	10	8	11	9
Births	0	1	18	14	14	10	6	4	6	8
No W'nd	0	0	3	13	10	11	11	2	4	5
Wean Wt	-	-	129	130	133	135	137	129	134	134
Wean % +	0	0	10	45	33	48	65	13	25	29
Concep % +	0	69	41	62	47	61	59	50	69	53

+ eligible cows by maturity (age > 2 yrs)

* whole breeding herd at start of year.

TABLE 10 RUSMOB VALIDATION SERIES 4B RESULTS BY YEAR - HEIFER HERD TEN-YEAR SIMULATION

FIGURE 4 AVERAGE HERD AGE



herd, due to the presence of young replacers. Figure 6 shows the monthly distribution of conception occurrences for the heifer herd over twenty years; because all herd members became eligible for conception during the life of the simulation run, this was probably the most unbiased conception distribution that could be obtained. The fit with the data of Stonaker *et al.* (1984) is not good, although this is not surprising, in view of the fact that forage availability is not limiting, i.e. the variation is essentially a function of digestibility and the starting conditions experienced in that experiment (breeding was delayed for one year, so that animals were in unreasonably good condition). It is not clear why simulated conceptions should peak at month 9, unless this is a lagged effect; there is no immediately obvious relationship between forage digestibility and the monthly incidence of conception. Table 10 illustrates the evolution of production over time; the initial flush of conceptions is presumably due in part to the homogeneity of the herd.

It is noteworthy that the number of individuals in the older herd fell markedly during the simulation (Figure 5); this suggests that heavily skewed age distributions may have rather long-term effects on the overall stability of the herd in terms of animal numbers as opposed to age distribution.

The most important features of these three series of simulation runs can be summarised as follows:

1) a reasonable compromise for the number of animals in the herd is 30 or so, and ten-year simulations appear to be satisfactory in terms of reaching + reasonably stable situation as far as herd parameters are concerned, whilst twenty-year simulations appear better for animal-based parameters.

2) within these limits, the values of *dt* are not of overriding importance, provided that *dt* for calves is short; this means the choice of *dt* can be made with regard to its appropriateness in conjunction with the pasture component - a value of 5 or 10 days would appear to be satisfactory.

3) starting conditions, in terms of herd age structure and the number and extent of pregnancies, are not important, although efficiency is obviously

FIGURE 5 ANIMAL NUMBERS

EVOLUTION OVER 20 YEARS

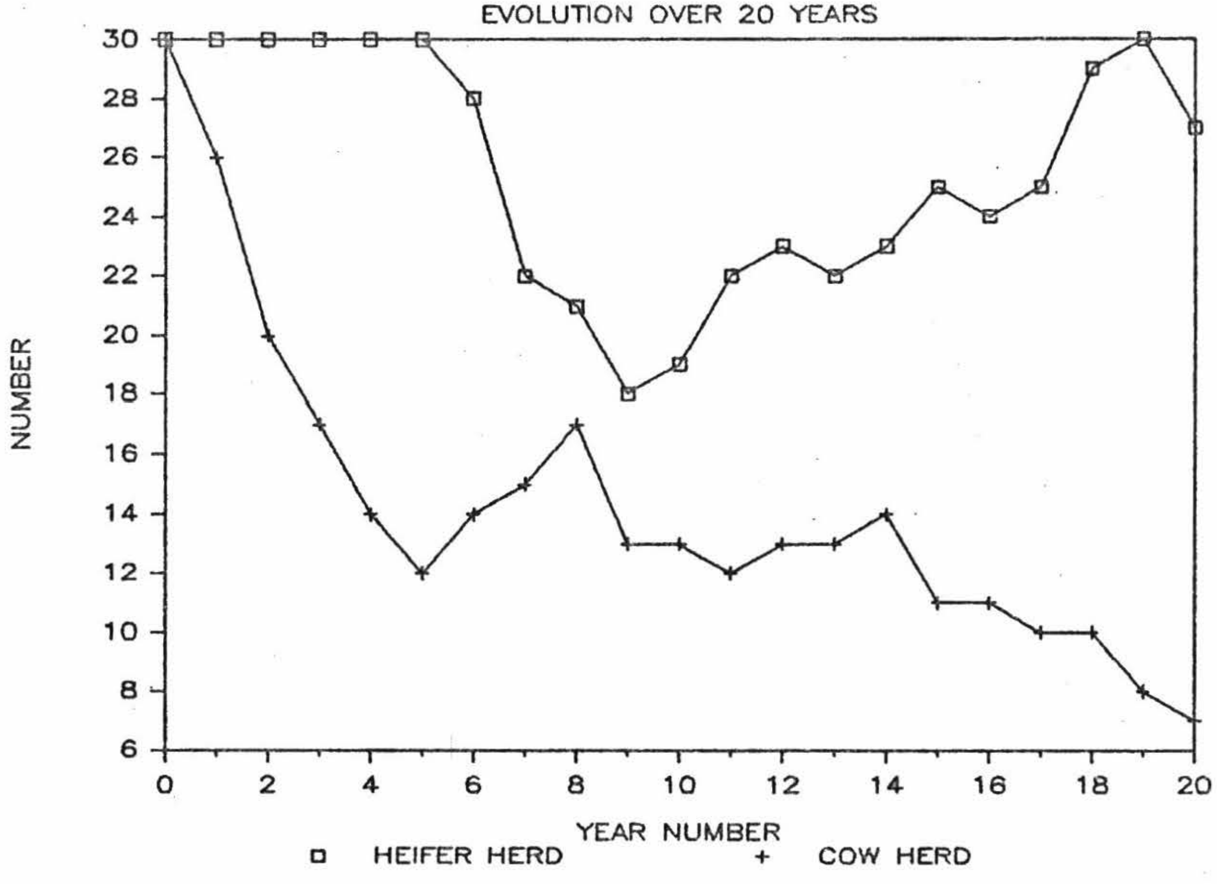
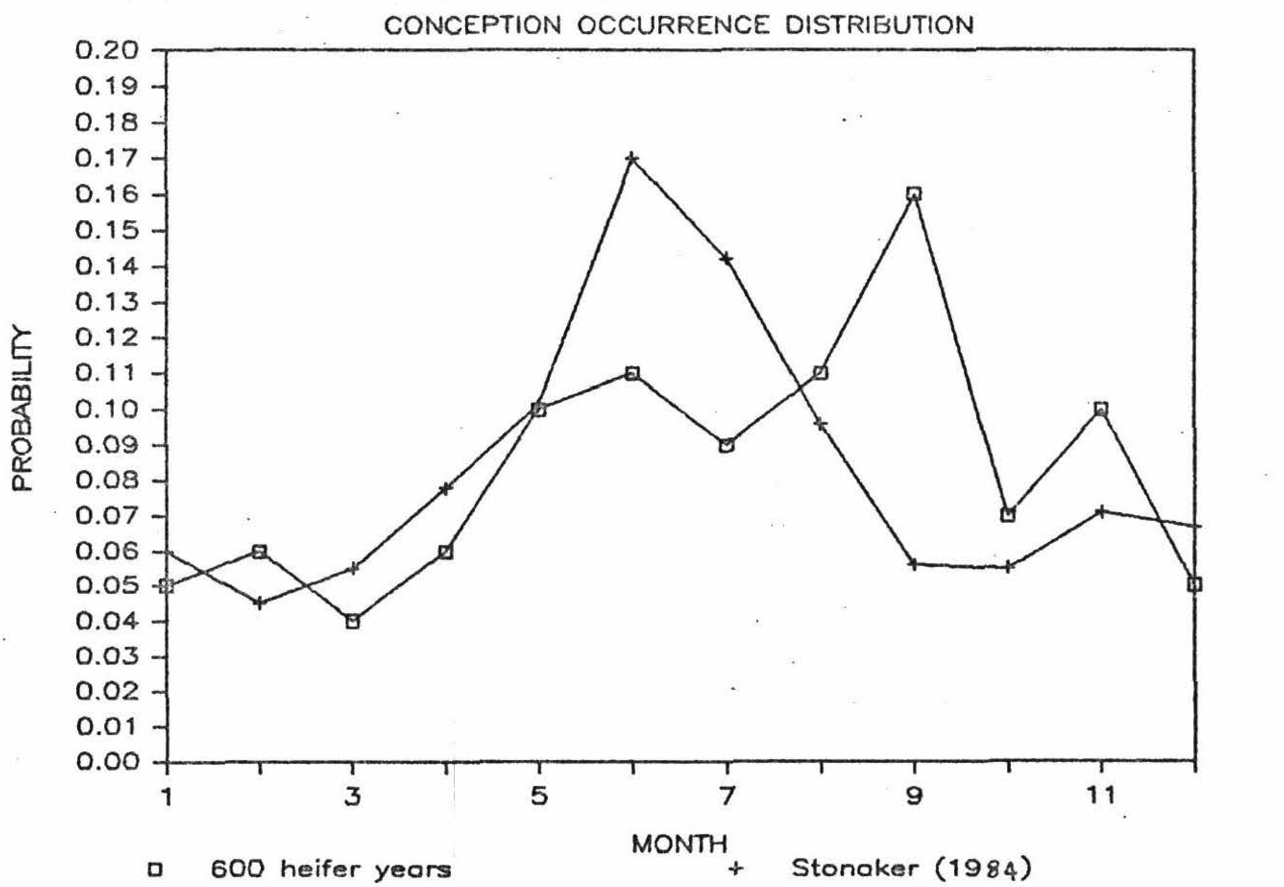


FIGURE 6 RUSMOB VALIDATION SERIES 4B



served if the herd approximates as closely as possible to "real" herds, especially for short simulation runs. The influence of the death rates used is large, and those presently incorporated into the model do at least result in average ages which are not very different from those observed in the Llanos. The cow weights used for the standard herd are rather high, in some cases, but these tend to settle to levels intrinsic to the model(and the parameters being used) fairly rapidly.

4) simulated production parameters are of the right order of magnitude, and in some cases are better still. A number of factors need to be borne in mind, however:

- it is unknown how accurate or appropriate the values of digestibility and crude protein used are; it is shown below that small changes here are capable of large changes in production indeces.

- no account has been taken of forage availability limitations; when imposed, it is likely that production levels would vary, particularly in response to dry-season limitations.

- the influence of compensatory gain on yearly production indeces over long periods of simulated time is essentially unknown. It is possible that its absence interacts with the absence of availability limitations, and that these factors tend to cancel each other out. How well the intake equations presently used could handle day-to-day growth of, for example, steers without more adjustments (possibly in the parameter faecal dry matter output, see Kahn (1982) and Section 3), is a question that is difficult to answer in the absence of reliable and detailed forage data.

5) the simulations of series 3, 4a and 4b accounted for some 70 minutes of CPU time; this highlights the desirability of efficiency in program execution, obtainable by a judicious choice of run-time parameters.

Series 5 - Improved Pasture Simulation

It was intended that the changes made to the model would be examined in relation to production from a high-performance pasture such as *Brachiaria decumbens*. Problems were encountered in finding reliable data pertaining to pasture quality throughout the year. A number of experiments have investigated animal production on such pastures, so it was decided to work backwards to obtain a very general idea of average quality. It is doubtful in any case whether an accurate series of digestibility and protein figures would necessarily result in particularly good model performance, from *a priori* considerations of the way in which the data were collected and the fact that intake in the model is currently simplified by not considering availability. It was therefore decided simply to use better pasture in the model, to see if the results produced were at least reasonable, and to leave rather more rigorous validation until pasture - animal interactions had been incorporated to some degree.

An approximation to the average quality of *Brachiaria decumbens* can be obtained from a consideration of the performance of steers at Carimagua (CIAT, 1983, 1984). Steers were reported to have gained approximately 115 kg during 1983; average energy intake was some 20 MJ ME per 100 kg live weight. Consider a steer of 190 kg at 12 months of age whose normative weight is some 500 kg. The average digestibility of the feed to sustain a growth rate of 0.32 kg per day can then be calculated using the relevant relationships in the model and a trial-and-error approach to the resultant iterative procedure. It appears that digestibilities in the range 50 to 60% will sustain such growth. This estimate may be compared with the average digestibility of the savanna of 45%. A monthly series of digestibility values was constructed, following the general shape of the savanna digestibility time series, with a peak in March and April. The series is tabulated in Table 11. Again, protein and availability were assumed to be unlimiting; both assumptions may be oversimplifications with regard to the dry season and/or older pastures.

Two replicates were run using the same starting conditions and run parameters as for series 3, i.e. 34 beasts, 10 years, and an integration time step of 10 days for adults and calves. The starting weights of the animals are low for this type of production system, but these quickly increase to internally-stable levels. Results are presented in Table 12 in terms of important production parameters. The increase in production levels over the savanna-based system is immediately obvious. Weaning weights are increased, calving intervals are sharply reduced, and meat production is increased three-fold. Mortality rates are reduced, although in fact the same mortality probabilities were used for both systems; this

Month	Digestibility, %
January	45
February	42
March	55
April	61
May	60
June	58
July	55
August	59
September	60
October	57
November	50
December	45

Note - crude protein is assumed to be unlimiting, i.e. CP% > 6.0, as is availability.

TABLE 11 RUSMOB VALIDATION SERIES 5 - IMPROVED PASTURE DIGESTIBILITY VALUES

	Replicate 1	Replicate 2	CV%
Calf Sales	4034	3631	7
Weaning Wt	168	178	4
12 Month Wt	184	189	2
24 Month Wt	263	279	4
Conception Interval	335	333	-
Weaning %	83	78	4
Age @ 1st Partum	2.4	2.5	3
Abortion %	5	4	16
Cow Mortality %	12	12	-
Production kg/AU/yr *	98	95	2
Production kg/AU/yr +	108	110	1

* production = (calf sales + cull sales) / animal units

\+ production = (no. of cows * weaning % * wt @ 12 months +
No of yearlings * wt gain/yr) / animal units

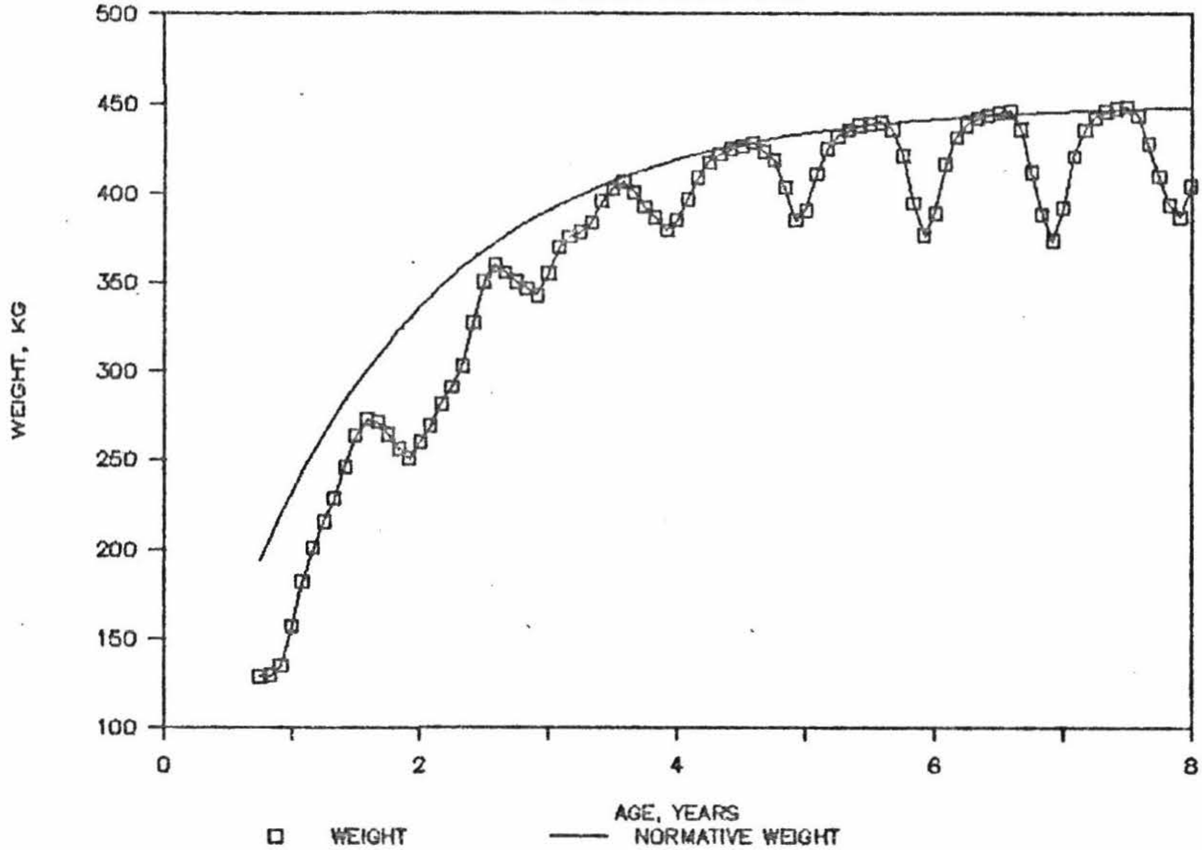
TABLE 12 RUSMOB VALIDATION SERIES 5 RESULTS - IMPROVED PASTURE PRODUCTION SYSTEM, TWO REPLICATES, WITH COEFFICIENT OF VARIATION is due to the absence of death by starvation in the improved system. A reduced abortion probability was used (changed from 15 to 5%), and this is reflected directly in the results. Cow liveweight evolution is illustrated in Figure 7, for Cow #1 with death suppressed. Oscillations in weight are marked, and are characterised by a much higher average value and a shorter period, compared with the liveweight oscillations obtained in the pure savanna system.

Assessment of whether such results are reasonable can proceed by comparing these with results obtained directly from experimentation. Typical production levels from *B. decumbens* are shown in Table 13, taken from CIAT and ICA experiments at Carimagua during 1983 and 1984. Direct comparison, while not necessarily being very fair to the model, does reveal problems related to reproduction performance. The problem appears to be the maturity factor in the conception equations; it is apparent that this factor would have little part to play in the savanna runs, since normative weight increases irrespective of nutrition (unless death occurs) and first parturitions were occurring at 48 to 52 months. The modified maturity factor defines maturity to have no effect on conception ability once the ratio WM/WMA has reached values in excess of 0.6. Its shape needed to be adjusted, to inhibit conceptions at low liveweights and in comparatively immature animals. As noted above, the actual shape will have little or no effect on savanna simulations. Runs were undertaken to modify this factor, and a satisfactory two-linear-segment function was derived (see Thornton, 1987, but see also Section 4).

A further problem is that of weaning weights, which are rather low in comparison with those which could be expected on *B. decumbens*. This might be due either to inadequate forage digestibilities or to a low value of milk yield potential. The effect of increasing this parameter is to increase weaning weight while allowing the cow to lose rather more weight during lactation, thus increasing the length of the reproduction cycle. It is possible that plane of nutrition acts on milk production potential in a way not accounted for in the model, when diverse production systems are considered (in effect, milk potential may change *per se* depending on plane of nutrition - at least this is the way it might have to be represented in the model). Further runs were undertaken with the milk potential

FIGURE 7 COW LIVEWEIGHT EVOLUTION

IMPROVED PASTURE DIET



	Observed	Simulated*
Weaning %	80	80
Age @ 1st partum, mos	39	30
Production kg/AU/yr		109
Weaning Weight	180-220	173
Yearling Growth kg/yr	115	85
Cow Mortality %		12
Conception Interval		334

* source: CIAT, 1983, 1984

TABLE 13 SIMULATED AND OBSERVED PRODUCTION LEVELS, *BRACHIARIA DECUMBENS* increased to 10 kg per day. Weaning weights increased to 201 kg, and weight losses during lactation of 80 to 90 kg were recorded over six months (including the dry season); at weaning time most, if not all, of this weight loss had been made up due to the high quality forage available in the wet season. This may be compared with the results of experiments at Carimagua, where weight losses of 0.34 kg per day were recorded for cows whose calves were weaned at 7 to 8 months of age (CIAT, 1984). No immediately obvious relationship exists between weight of dam at birth and weight loss during lactation from the data of this experiment; this would appear to be the case for the simulation runs also. A milk potential of 10 kg is excessive, but the model responds in a sensible fashion. This parameter is thus a measure of genetic potential coupled with the overall quality of the diet in the relevant production system; for practical purposes this finding poses no real problems, although it is realised that conceptually it is slightly unsatisfactory.

Summary - Exploratory Validation Runs

The use of somewhat arbitrary pasture digestibilities helped to highlight certain problems with the model, notably in relation to the conception and weight relationship. This has been adjusted (and can be done again in the future) without difficulty, and also in such a way as to leave intact the validity of the savanna simulations. Calculated weaning percentages tend to be underestimated, since animals on hand at the end of the run are not considered. For preserving observed age distributions in savanna production systems, it is necessary to use particular death rates; these tend to be high, and it may be presumed that reasonably severe culling is practised. The limited amount of work carried out on the effect of milk production potential suggests that the model responds satisfactorily to increases in this parameter. The results obtained thus far tend to suggest that diverse production systems can be represented primarily by dietary parameters.

3 SENSITIVITY ANALYSIS

There are four series of experiments to be described; the first two deal with the sensitivity of the beef model, the third with the effects of different preference functions on beef production, and the fourth series investigates the sensitivity of the improved pasture model.

3.1 RUSMOB Sensitivity Analysis

Series 1

The effects of changes to a number of the parameters of the beef model, for example the time step and herd size, were documented above. The objective was to look at a variety of other parameters, perturb them by 10%, and look at the effects of such perturbations on model output, in an attempt to identify highly sensitive parameters. Table 14 shows the eleven treatments. Five replicates of each were carried out. Output was measured as conception and weaning percentages, the age at first calving, weaning weight, conception interval, production per animal unit per year, and mortality percentage. Results are shown in Table 15 in terms of the mean and average coefficient of variations for the five replicates.

All variances are low (3 replicates would probably have been sufficient), with the exception of that for mortality - this is not surprising, since this event is treated stochastically. Note also that no statistics are quoted; simular experimentation differs from real-life experimentation in a number of respects, which include the following:

- there is no experimental error;
- statistically significant differences can be derived by wholesale replication (by lowering the value of Student's t statistic, for example); the experimenter has to be careful, therefore, that treatment effects are not specious, otherwise these "statistical differences" are simply by-products of the model and have no counterpart in reality;
- at this stage, only some of the variability in the real system is accounted for in the model; simulated and observed variances will not necessarily be of the same order of magnitude, therefore.

TABLE 14 RUSMOB SENSITIVITY ANALYSIS - SERIES 1 TREATMENTS

Number	Parameter		Standard	Perturbed
1	baseline			
2	VIP	faecal dry matter output, DM/kgLW/day	0.0094	0.0103
3	WMAX	mobilisable tissue for lactation, kg/day	1.40	1.54
4	PP	relative birth weight	15.0	13.6
5	PMA	potential milk yield, kg/day	5.0	5.5
6	NWEAN	weaning age, days	270	245
7	DIG	mean diet digestibility, %	44.6	49.1
8	DIGGEN	energy content of feed, MJ/kg	15.185	16.704
9	RATE	normative weight curve parameter	0.054	0.059
10	MANDAT(1)	first yearly management date	210	0
11	MANDAT(2)	second yearly management date	330	0

TABLE 15 RUSMOB SENSITIVITY ANALYSIS - SERIES 1 - RESULTS SUMMARY

Treatment		Conception %	Weaning %	Age@1st Partum	Weaning Weight	Conception Interval	Production kg/AU/yr	Mortality %
		Ouput Parameter						
baseline		48	30	4.0	130	598	38	19
VIP	+	60	42	3.4	145	505	52	13
WMAX	+	45	31	4.1	132	632	39	20
PP	-	48	30	4.0	132	601	38	20
PMA	+	46	29	4.0	135	621	37	19
NWEAN	-	48	32	4.0	125	597	40	14
DIG	+	83	57	3.1	157	381	72	12
DIGGEN	+	64	44	3.3	146	490	54	13
RATE	+	46	30	3.9	133	612	39	20
MANDAT1	-	47	31	4.0	132	601	38	25
MANDAT2	-	49	31	4.0	132	598	37	25
Average CV%		3	6	3	2	3	5	13

With a model of this resolution, only comparatively gross effects are likely to be of real relevance or interest.

The importance of faecal dry matter output (VIP) is underlined; a 10% increase in this parameter leads to an increase in production of some 37%. It is also clear that an increase in system quality will lead to increases in conception and weaning percentages, in weaning weight and production, but to reductions in age at first calving, in conception interval and in mortality.

The maximum amount of tissue mobilisable per day to meet lactation potential (WMAX) has little effect: a slight increase in production and weaning weight, but a month is added on to the conception interval, presumably because the animal is, relatively speaking, more out of condition and it is thus taking longer for it to reach "conceptable" weights.

Birth weight (PP), expressed as the divisor of maximum normative weight, has little effect, except for a slight increase in weaning weight, which is a logical effect.

The effect of maximum milk potential (PMA) is equivocal; weaning weights are increased, but production is reduced. Like WMAX, this is probably because the cow needs more time to reach a weight at which conception is likely. On a better plain of nutrition, this effect would not be expected; here, the animal is being penalised for higher milk yield, and 5 kg extra at weaning presumably does not cancel out the 23 extra days needed for reconception, resulting in a dip in production.

A 10% decrease in weaning age (NWEAN) results in only 4% less weight at weaning. Overall production increases slightly, but there is little effect on conception interval, as might be expected. Subsequent experimentation showed that conception probabilities may have been overestimated; early weaning is discussed below in Section 4.

Average diet digestibility (DIG) clearly has a profound effect - a 10% increase leads to a 90% increase in production. Being an energy-based model, such an effect is not really surprising, especially when it is remembered that the pure savanna base-line system is close to being the worst biologically feasible system there is. It should be pointed out that the shape of the monthly digestibility distribution remained unchanged; the effects of changes in the shape rather than in the location of this distribution are investigated in a subsequent experiment.

The effect of the energy content of feed (DIGGEN) is similar to the effect of changes in DIG, although to a lesser extent; according to the relationships in the model, an increase in digestibility directly stimulates higher levels of intake, in contradistinction to an increase in DIGGEN *per se*.

A steeper normative weight growth curve (RATE) has little effect; there are slight increases in weaning weight (to be expected, as voluntary intake is related to normative weight), reflected in increased production, but offset by increased conception intervals.

Changing the two default management dates (MANDAT) at which the followers herd is dispersed and culling takes place had little effect, except in the mortality of followers. This effect may well be specious; it was found during the original validation runs that intake between 9 and 12 months for newly-weaned animals needs to be increased slightly, so steps have been taken to stave off unrealistic mortality for this class of animal.

In summary, it can be said that faecal dry matter output (VIP), average diet digestibility (DIG) and the energy content of feed (DIGGEN) have very important effects, and there may be some potential for lowering the age at weaning, though this may be offset to a degree by increased follower death. The effects of changes in PMA and WMAX are of interest, but can be explained by reference to the functions operating in the model.

A supplemental series of runs was carried out to look at the response curve of production to diet digestibility and to changes in the variance of the monthly digestibility values. Four more three-replicate treatments were carried out (see Table 16).

Figure 8 shows the graph of monthly transformed digestibilities. The response curve of changes in mean digestibility, shown in Figure 9, is steep and slightly convex (denoting diminishing marginal returns to increases in average digestibility). From the table of results (Table 16), the action of changing the variance is not immediately obvious, although the dry-season high-variance digestibility distribution is having profound effects on calf mortality through starvation (low Variance diet: 9% mean, 21% coefficient of variation (cv); standard Variance diet: 16%, 18% cv; high Variance diet: 37%, 7% cv). The reaction of the model to the low-variance diet appears to suggest that production is increasingly adversely affected by increasing variability in the diet.

Series 2

To gain a deeper insight into the action of the model, a four-factor full factorial experiment was set up, with the main aim of identifying important interactions. The factors chosen were faecal dry matter output (VIP), average diet digestibility (DIG), maximum amount of mobilisable tissue to support lactation (WMAX), and potential milk yield (PMA), Table 17 - the first two because of their highly sensitive nature, and the last two because of their opposing tendencies both to raise and lower different output parameters. Three replicates of each were carried out. Five percent perturbations were used. Note that it was not feasible to perturb the parameters in such a way as to reduce production; it was found that the system crashed too easily.

ANOVA on the sixteen treatments was carried out in GENSTAT for all interactions up to and including those of the second order. Table 18 lists the only significant interactions found for the seven output parameters. Principal components analysis was then carried out, in an attempt to relate model output to parameter changes in as simple a way as possible. The data correlation matrix was used, rather than the data values themselves, to by-pass the problem of different units in the parameters.

Results are shown in Table 19, for the first two components only, which between them explained some 97% of the variability in the transformed data. That is, most of the variation in any particular model run can be described

FIG 8 SENSITIVITY ANALYSIS - SERIES 1
DIGESTIBILITY TIME SERIES

VARIANCE= 4.1 VARIANCE= 1.0 VARIANCE=17.2

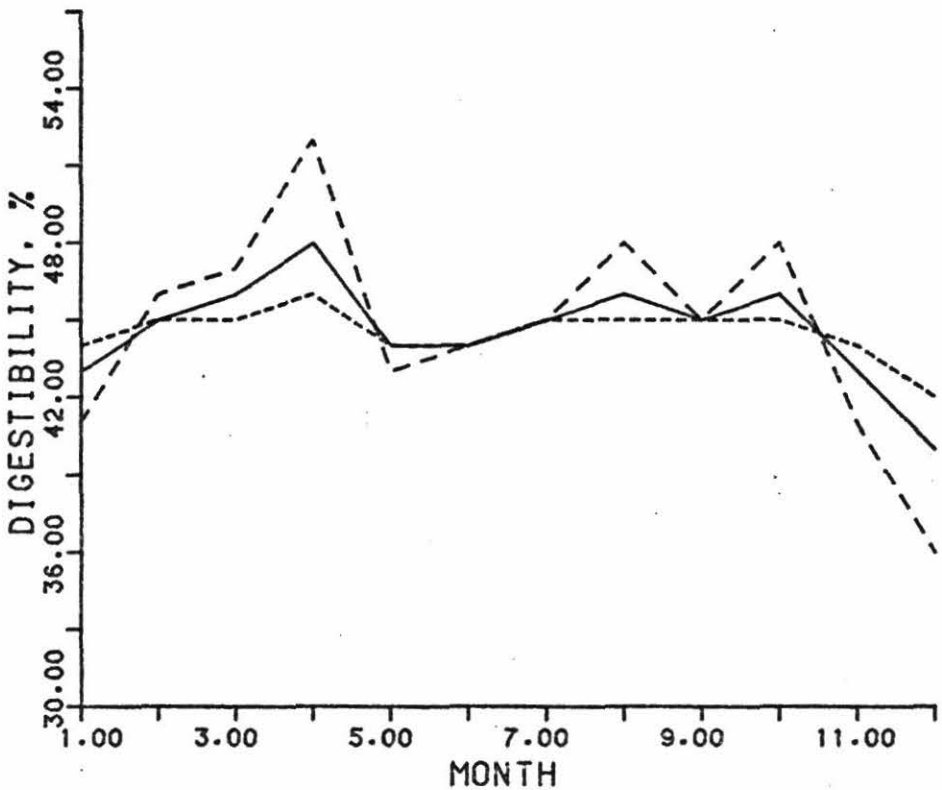


FIG 9 SENSITIVITY ANALYSIS - SERIES 1
RESPONSE OF RUSMOB TO AN
INCREASE IN DIET QUALITY

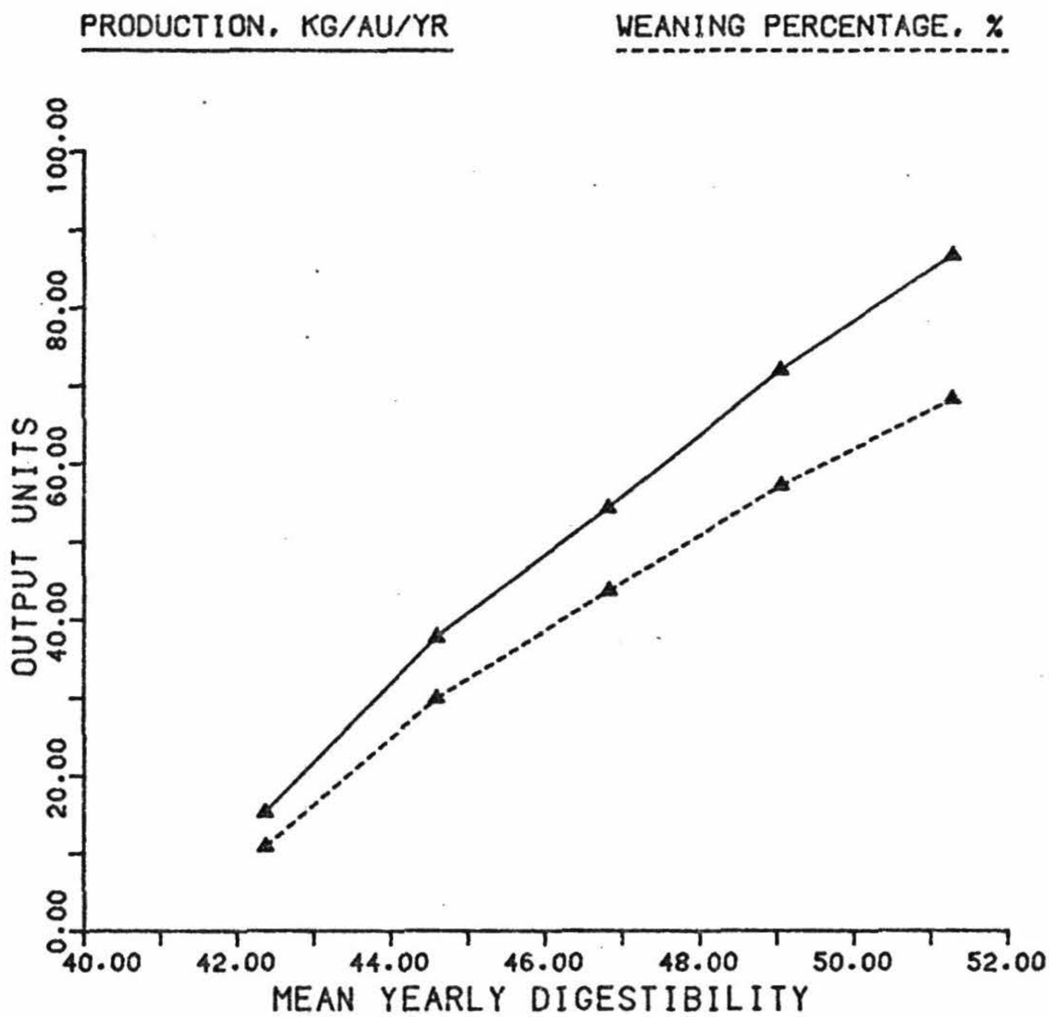


TABLE 16 RUSMOB SENSITIVITY ANALYSIS - SERIES 1 - EXTRA TREATMENT RESULTS

	Output Parameter						
Treatment	Conception %	Weaning %	Age@1st Partum	Weaning Weight	Conception Interval	Production kg/AU/yr	Mortality %
mean - 5%	50	11	4.4	113	644	15	27
baseline	48	30	4.0	130	598	38	19
mean + 5%	62	44	3.3	146	493	54	12
mean + 10%	83	57	3.1	157	381	72	12
mean + 15%	97	68	2.8	166	338	87	13
variance -	44	32	4.1	135	630	39	19
baseline	48	30	4.0	130	598	38	19
variance +	54	25	3.9	122	553	34	20
Average CV%	3	6	3	2	3	5	13

TABLE 17 RUSMOB SENSITIVITY ANALYSIS - SERIES 2 TREATMENTS

	VIP	DIG	WMAX	PMA
1	-	-	-	-
2	-	-	-	+
3	-	-	+	-
4	-	-	+	+
5	-	+	-	-
6	-	+	-	+
7	-	+	+	-
8	-	+	+	+
9	+	-	-	-
10	+	-	-	+
11	+	-	+	-
12	+	-	+	+
13	+	+	-	-
14	+	+	-	+
15	+	+	+	-
16	+	+	+	+

	-	+
VIP	0.0094	0.0099
DIG	44.6	46.8
WMAX	1.40	1.47
PMA	5.0	5.25

TABLE 18 RUSMOB SENSITIVITY ANALYSIS - SERIES 2 ANOVA RESULTS

Output Parameter	Significance Table		
Conception %	VIP**	DIG**	
Weaning %	VIP**	DIG**	
Mortality %	VIP*	DIG*	VIP.DIG*
Age@1st partum	VIP**	DIG**	
Weaning Weight kg	VIP**	DIG**	PMA*
Conception Interval	VIP**	DIG**	
Production kg/AU/yr	VIP**	DIG**	

* p<0.05 ** p<0.01

TABLE 19 RUSMOB SENSITIVITY ANALYSIS - SERIES 2 PRINCIPAL COMPONENTS ANALYSIS OF THE CORRELATION MATRIX

Output Parameter	Component				
	1	2	3	4	...
Conception %	0.386*	0.282*			
Weaning %	0.391*	0.155			
Mortality %	-0.300*	0.912*			
Age@1st partum	-0.390*	0.039	...	...	...
Weaning Weight kg	0.388*	-0.045			
Conception Interval	-0.388*	-0.185			
Production kg/AU/yr	0.393*	0.166			
Variance Accounted For %	90.0	7.3	1.0	0.9	...
Cumulated % Variance	90.0	97.3	98.3	99.2	...

with reference to two new output parameters (the first two principal orthogonal components) instead of the seven originally considered, with the important proviso that they are amenable to interpretation.

1) the first component, explaining 90% of the variability, is a linear combination of nearly equally-weighted variables, but with three working against the other four (refer to the signs of the coefficients) - an increase in production system quality results in increased conception and weaning percentages, weaning weights and production per animal unit, but results in decreases in mortality, age at first calving and conception interval.

2) the second component, explaining 7%, is dominated by mortality, and we may ignore all the others with the exception of conception percentage. This is an interesting effect, which can perhaps be explained as follows. There are two aspects to mortality - one is the base probability of death, increasing as age increases, and the other is related to the quality of the production system through starvation. This latter aspect is obviously taken up to some extent in the first component (since its sign is negative). The question then arises, why should conception increase move in the same direction as an increase in mortality? It is perhaps because as increase in base mortality affects older, less fertile cows, leading to replacement with young heifers who may conceive under circumstances where older cows would not. There are certainly mechanisms in the model to allow this kind of balance to take place. This phenomenon might be termed herd rejuvenation.

The next stage was to run an ANOVA on the data as transformed onto the axes of the first two principal components. Note that now the means and values themselves have no real meaning, but it is interesting to look at the sums of squares. For the first principal component (Table 20), over 98% of the variability is accounted for by faecal dry matter output, VIP, and mean diet digestibility, DIG, alone (whose variance ratios are obviously highly significant), and that the contribution of latter is four times that of the former. The data are not noisy (i.e. little randomness), since the residual sum of squares is small.

TABLE 20 RUSMOB SENSITIVITY ANALYSIS - SERIES 2 - ANOVA, DATA POINTS TRANSFORMED ONTO THE FIRST PRINCIPAL COMPONENT AXIS

	df	SS	SS%	MS	VR
replicates	2	0.011	0.18	0.005	
VIP	1	1.277	20.26	1.277	716.7***
DIG	1	4.933	78.29	4.933	2769.9***
WMAX	1	0.001	0.02	0.001	0.6
PMA	1	0.005	0.08	0.005	2.9
:	:	:	:	:	:
:	:	:	:	:	:
residual	31	0.055	0.88	0.140	
grand total	47	6.302	100.00		

For the second principal component (Table 21), the faecal dry matter - diet digestibility interaction variance ratio alone is significant. Nearly 60% of the variability is taken up by this interaction, but note that nearly 30% of the total is attributable to the residual term. Two questions need to be addressed: is the first principal component reasonable in terms of the overwhelming importance of diet digestibility (DIG) and, to a lesser extent, faecal dry matter output (VIP)?, and how can the interaction between the two be related to the dominating effect of mortality for the second principal component, and why should it be so noisy?

The first of these is straightforward, since the first component exhibits signs operating in exactly the intuitive directions. The relative importance of mean diet digestibility over faecal dry matter output is to be expected, in view of the results of the first series of runs. For the second question, the problem of noise can be explained by reference to the fact that part of mortality is directly stochastic - from series 1, the coefficients of variation for mortality are of the order of 13%; these values are much higher than for any other output parameter considered. Noise is thus to be expected. The relationship between the faecal dry matter output - diet digestibility (VIP-DIG) interaction and mortality is more problematic. Faecal dry matter output per kg liveweight per day operates thus: an increase in this factor implies an increase in gut capacity, which in turn implies an increase in voluntary intake, at least at low digestibilities (67%, quoted by Kahn, 1982).

Figure 10 shows the effect of faecal dry matter output and mean diet digestibility on mortality from the original factorial experiment (Tables 17 and 18). It is clear that when digestibility is higher, increasing intake has scant effect; when digestibility is lower, increasing gut capacity reduces mortality by approximately 35%. There would thus appear to be a threshold operating on mortality: one can expect a certain level of mortality from natural replacement anyway; add to this the mortality from starvation, and apparently there will be some threshold plane of nutrition where starvation ceases to be a problem.

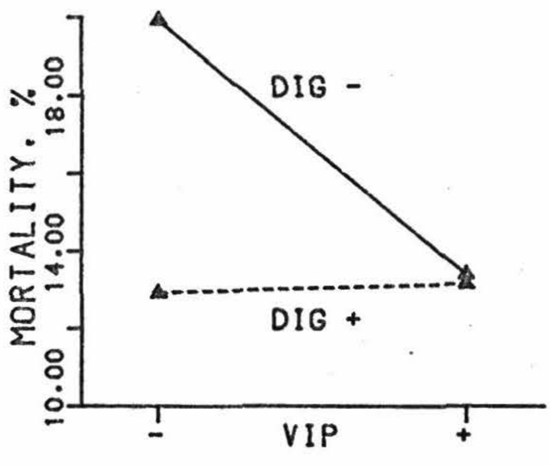
The second principal component can then be interpreted as follows: it is concerned with mortality; part of this must be the random component which

TABLE 21 RUSMOB SENSITIVITY ANALYSIS - SERIES 2 - ANOVA, DATA POINTS TRANSFORMED ONTO THE SECOND PRINCIPAL COMPONENT AXIS

	df	SS	SS%	MS	VR
replicates	2	0.001	0.24	0.001	
VIP	1	0.022	4.39	0.022	4.8
DIG	1	0.013	2.58	0.013	2.8
WMAX	1	0.000	0.00	0.000	0.0
PMA	1	0.001	0.25	0.001	0.3
VIP.DIG	1	0.294	57.34	0.294	63.1*
:	:	:	:	:	:
:	:	:	:	:	:
residual	31	0.145	28.19	0.005	
grand total	47	0.513	100.00		

FIGURE 10

SENSITIVITY ANALYSIS - SERIES 2
MORTALITY AND THE FAECAL DRY MATTER
OUTPUT : DIGESTIBILITY INTERACTION



affects all herds, regardless of plane of nutrition, but part must also be the starvation effect, since the faecal dry matter - digestibility interaction accounts for much of the variability. The nature of this interaction can be explained by reference to a threshold effect; mortality cannot be decreased below a certain level by nutritional means, so whatever factor can take up energy consumption will do so. However, combined effects at high levels of system quality will have nothing to show for them. With this emphasis on death, older less fertile cows will tend to be replaced by younger, more fecund animals, and this may be reflected in increased numbers of conceptions.

Series 1 and 2 : Summary

1. Diet digestibility is of crucial importance to the operation of the model, and the model is highly sensitive to this factor. Faecal dry matter output operates in a similar way, but is of less importance.

2. The model is clearly energy-sensitive, since the only real way in which to affect significantly the output variables is to change those inputs which deal more or less directly with it. Conversely, a variable such as potential milk yield has no clear effect on system quality taken as a whole at such low digestibilities, since the output parameters move in ways which tend to be self-balancing.

3. There is a threshold level in terms of the energy status of the herd above which starvation ceases to be important. If starvation mortality can be reduced, then standard probabilistic mortality tends to favour younger, more fertile animals at the expense of older, less fertile animals. This is possibly an effect over and above the obvious one whereby energy increases lead to better system quality.

3.2 PASMOD Sensitivity Analysis

Series 3

The third series of sensitivity analysis runs was aimed at investigating the effects on beef production of changes in improved forage preference functions. In effect, one year runs were used, as at the end of each year respective grass and legume biomasses were set to their original values as at the start of the run. There were five treatments with three replicates of ten-year runs. The PASMOD growth functions used are shown in Figure 11; the senescence function has been changed slightly since this experiment. Preference functions appear in Figure 12. The extent of preference might perhaps be expressed in terms of the area of the shape above or below the straight diagonal (preference function type V) formed by the function used. If this area is then divided by the total area above or below the line, and providing the function is reasonably symmetrical about its mid-point, we can define the Preference Function Index (PFI). This ratio can be reduced algebraically to the quantity (y-x), adjusted for sign, where the coordinates (x,y) define the elbow of the preference function (this holds even if the two linear segments of the function are not of the same length).

Treatments are shown in Table 22. The results which follow depend to a certain extent on the actual digestibility values used for the legume and the grass (here, legume digestibility = grass digestibility *1.1).

An idea of the effects of each treatment is given in Figures 13 and 14, consisting of biomass plots for treatments 1 and 4; legume, grass and total biomass were assembled and averaged to produce these curves. Results for the five treatments are shown in Table 23. Apart from the fact that large differences between treatments exist, and that production is highest for the treatment with the most extreme negative selection function, it is easier to interpret these results by comparing average monthly ingested digestibilities with the digestibility of forage on offer (Table 24) - average ingested digestibility rank-correlates perfectly with production per AU per year.

FIGURE 11

PASMOD FUNCTIONS I, II AND III
LEGUME —— GRASS -----

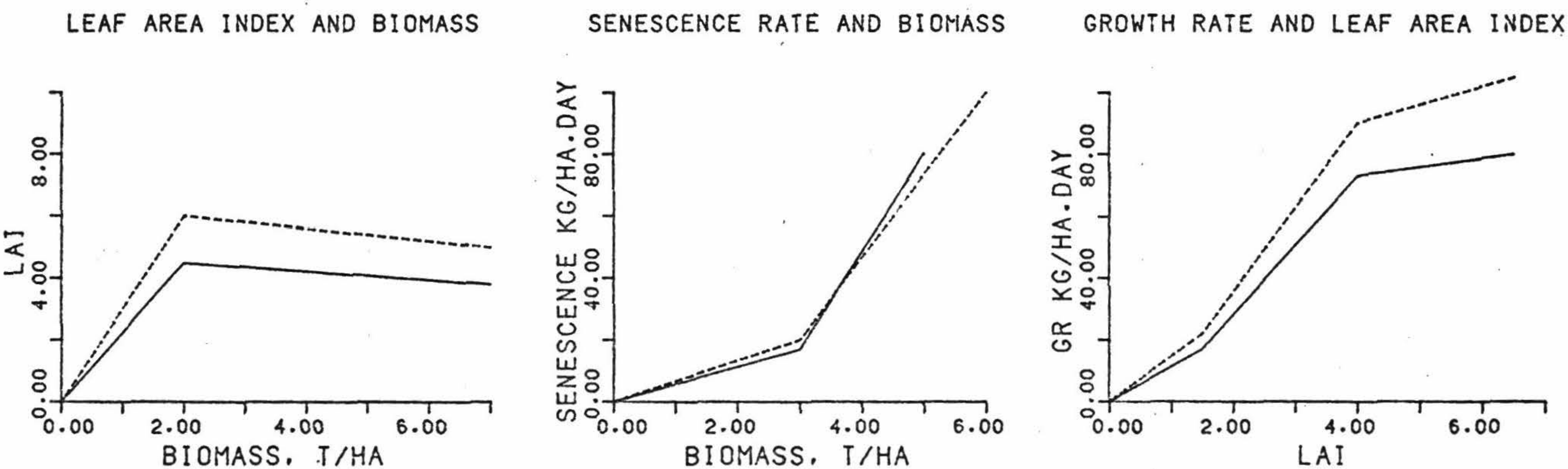


FIGURE 12

SENSITIVITY ANALYSIS - SERIES 3
PREFERENCE FUNCTION TREATMENTS

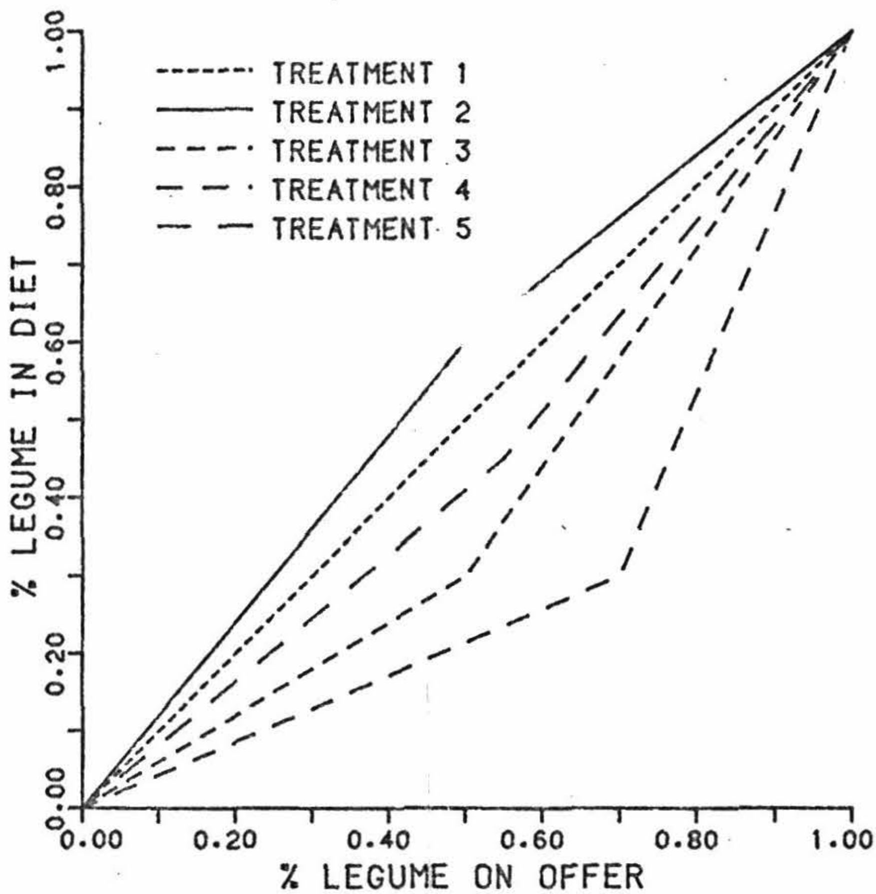


TABLE 22 RUSMOB SENSITIVITY ANALYSIS - SERIES 3 TREATMENTS

Treatment	Preference Function	PFI*
1	V	0.0
2	IV	+0.1
3	I	-0.2
4	I	-0.4
5	I	-0.1

* preference function area index, defined as PFI = y - x, where the elbow of the function has coordinates (x,y).

TABLE 23 RUSMOB SENSITIVITY ANALYSIS - SERIES 3 - RESULTS SUMMARY

Treatment	Conception %	Weaning %	Age@1st Partum	Weaning Weight	Conception Interval	Production kg/AU/yr	Mortality %
	Ouput Parameter						
1 PFI= 0.0	72	49	3.3	134	433	61	14
(s.d	3	2	0.1	1	5	3	0)
2 PFI=+0.1	75	50	3.2	135	420	62	14
(s.d	2	2	0.1	2	3	1	1)
3 PFI=-0.2	68	46	3.3	134	446	58	14
(s.d	1	1	0.1	1	4	1	1)
4 PFI=-0.4	85	61	3.1	148	373	72	13
(s.d	3	2	0.1	2	5	3	1)
5 PFI=-0.1	73	50	3.3	133	440	61	14
(s.d	2	2	0.1	1	4	3	2)

TABLE 24 RUSMOB SENSITIVITY ANALYSIS - SERIES 3 RESULTS

Treatment	Digestibility Forage on Offer		Digestibility Ingested			Production kg/AU/yr		
	X	s	X	s	rank	X	s	rank
1	47.1	3.8	47.1	3.8	3	61.1	2.9	3
2	46.9	3.6	47.2	3.8	2	62.4	1.2	2
3	47.8	4.2	46.8	3.8	5	58.0	1.2	5
4	52.5	3.7	49.6	3.6	1	72.0	3.1	1
5	47.5	4.1	47.0	3.9	4	60.8	2.6	4

Values of digestibility given were assembled into ten-year monthly averages, which were themselves averaged.

The importance of selection arises because it changes the effective digestibility of the diet. For treatment 2 (legume actively selected for), the animals select a diet of higher digestibility than the one on offer, whereas for treatments 3, 4 and 5, the animals are penalising themselves. It would be interesting to follow through the ramifications of this for the concept of the maximisation of net energy intake. What is of more importance is the size of the changes; if treatments 1 and 4 are compared, it can be seen that an increase in ingested digestibility of 5.3% increases production by 18%. The production levels for treatment 2 are within the bounds set by treatments 1 and 4.

The effect of selection on production was investigated in a supplemental factorial experiment, by ignoring animal effects on pasture. A series of one-year simulation experiments was carried out with two factors: location of the digestibility-over-time distribution, and the preference function area index. A constant relative differential factor was kept between the grass and legume digestibilities. There were three levels of the digestibilities factor, with mean yearly forage digestibilities ranging from 53 to 64% for the legume, and from 43 to 53% for the grass. The PFI was varied from -1.0 to +1.0 in increments of 0.25 (Table 25). Each treatment was run for ten one-year seasons, and these ten seasons were continuous as far as herd development was concerned. Three outputs were derived: the yearly average digestibility of the forage on offer (weighted by availability) and the forage ingested, and production per animal unit per year. Two replicates were carried out, since the coefficient of variation for production per animal unit per year is of the order of 5% only. Results are shown in Figure 15, a graph of digestibility of forage of offer against the PFI, with values of production (kg/AU/year).

The limitations of this analysis are numerous; for instance, the digestibility time series are based on little real data and may be unrealistic, preference is defined to be constant over time, and the full effects of the dry season are not accounted for (since dry matter is assumed to be unlimiting, among other reasons). The details of Figure 15 may thus be somewhat specious, but as an exercise in sensitivity analysis, useful conclusions can be drawn.

TABLE 25 RUSMOB SENSITIVITY ANALYSIS - SERIES 3 SUPPLEMENTARY EXPERIMENTAL TREATMENTS

Factor	Level	Description
X	1	Mean digestibility * 0.96
	2	* 1.06
	3	* 1.17
Y	0	PFI = -1.00
	1	-0.75
	2	-0.50
	3	-0.25
	4	0.00
	5	+0.25
	6	+0.50
	7	+0.75
	8	+1.00

FIGURE 13

SENSITIVITY ANALYSIS - SERIES 3

BIOMASS AGAINST TIME (10 YEAR AVERAGE) - TREATMENT 1

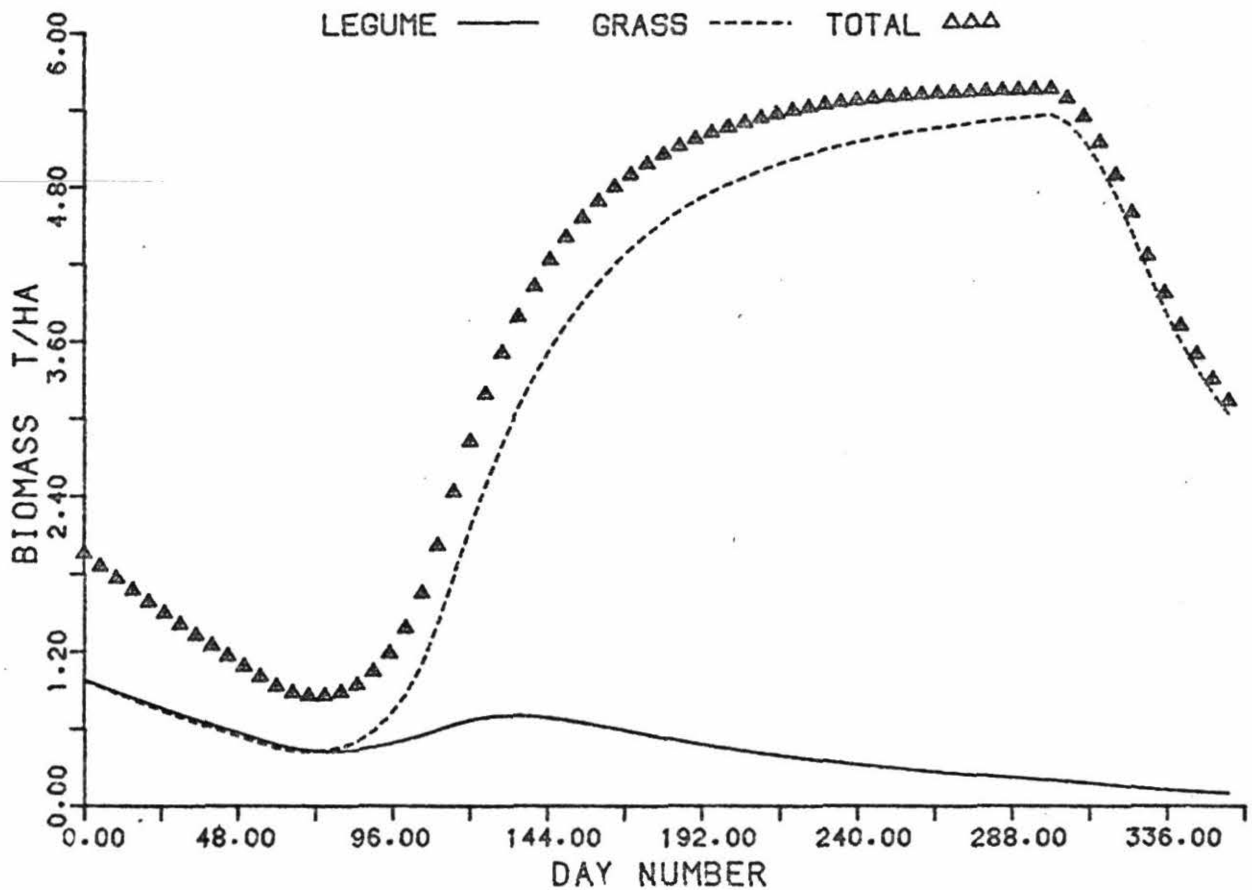


FIGURE 14

SENSITIVITY ANALYSIS - SERIES 3

BIOMASS AGAINST TIME (10 YEAR AVERAGE) - TREATMENT 4

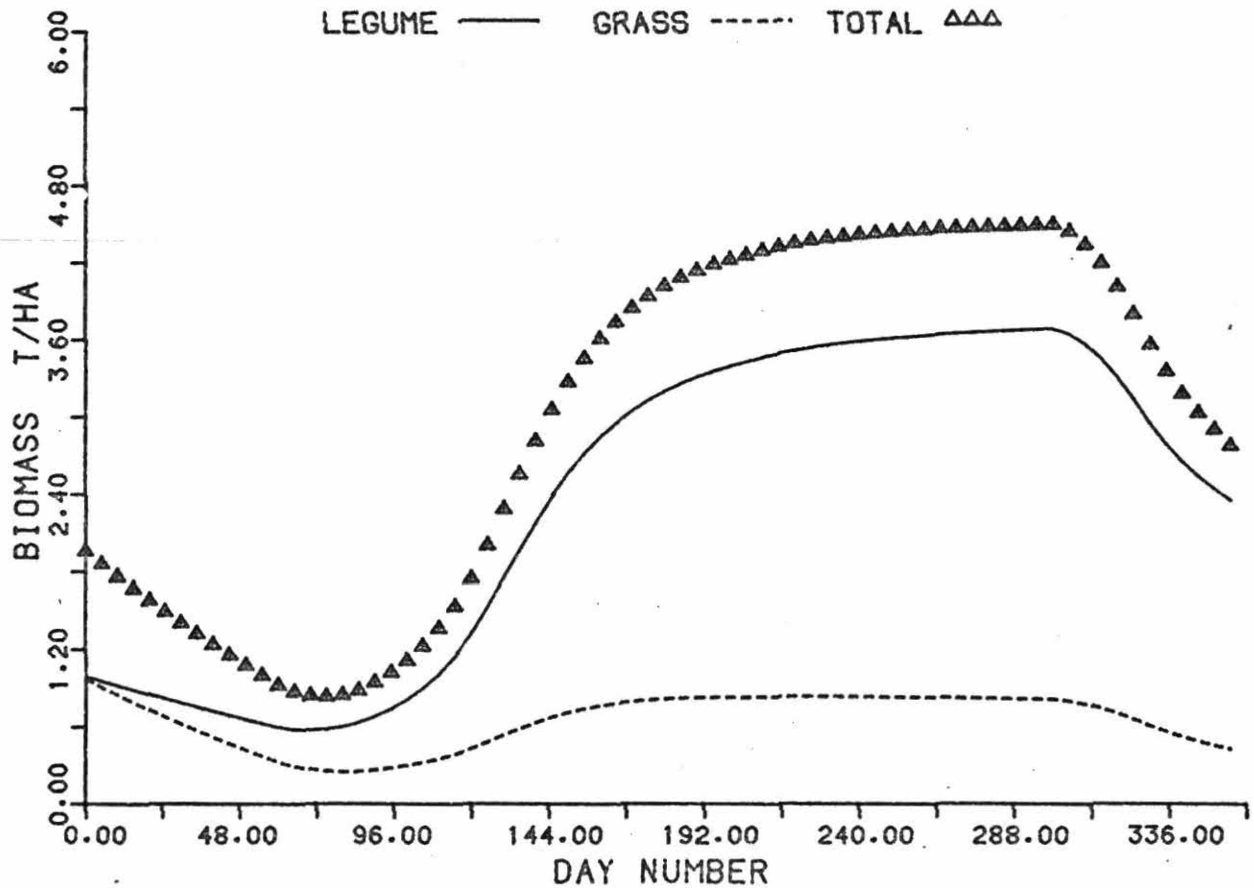
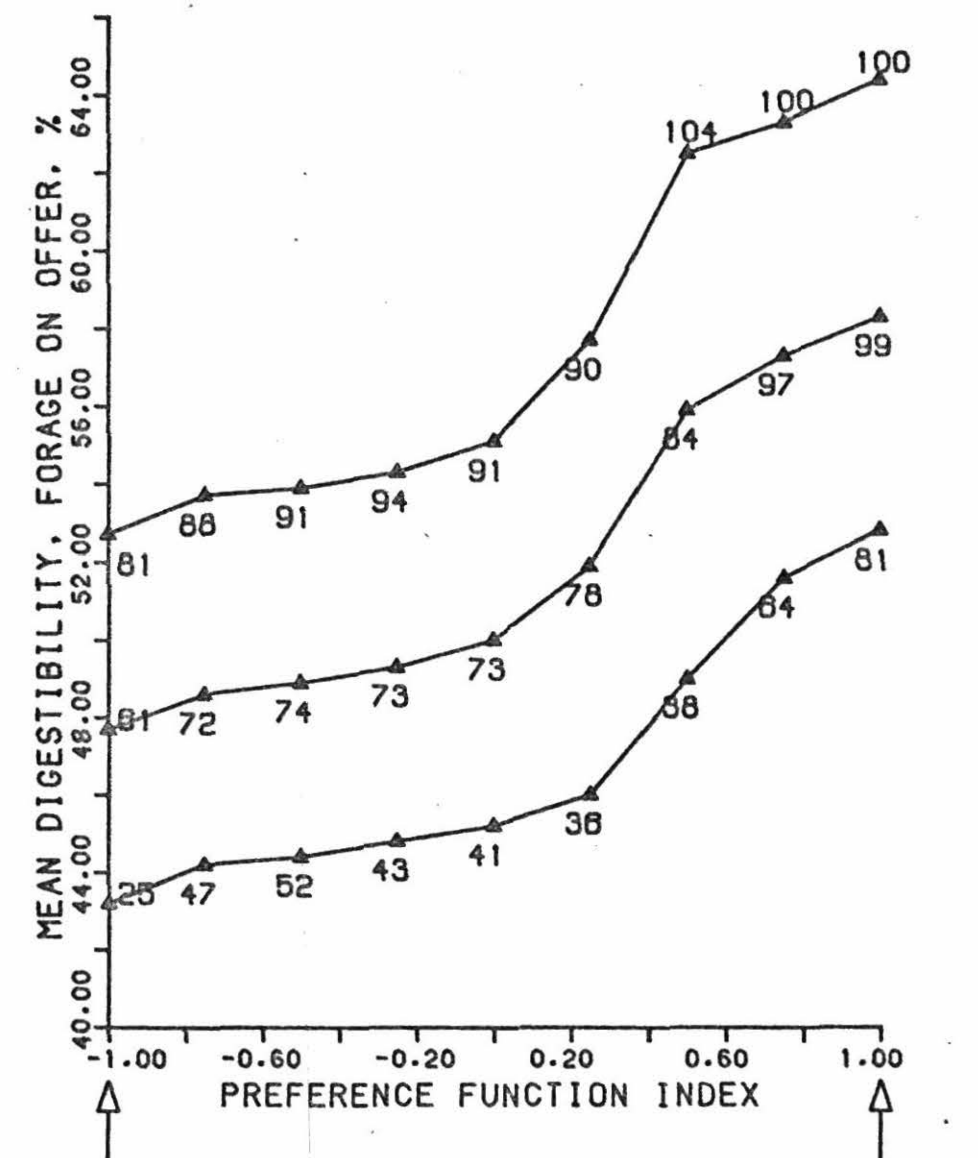


FIGURE 15

THE RELATIONSHIP BETWEEN PRERERENCE, DIGESTIBILITY OF FORAGE ON OFFER, AND ANIMAL PRODUCTION, KG/AU/YR FOR THREE DIGESTIBILITY DISTRIBUTIONS



First, the results again demonstrate the high correlation between the digestibility of forage ingested and production. Second, forage on offer varies in a characteristic and non-linear manner for the three levels of the digestibility factor between the two extremes of pure grass and pure legume, the two points defining the differential digestibility between the component species (here a factor of 1.22 in favour of the legume). The actual shape of the relationship is presumably a function of the differential growth rate between legume and grass.

Third, all other things being equal, the value of the PFI can precipitate much variation in animal production. It is unlikely that animal preference functions in reasonably palatable grass-legume associations will exhibit PFIs in excess of ± 0.3 or so, for the simple reason that pastures with larger absolute values are not likely to be stable in terms of their component parts, although this remains conjectural in the absence of pertinent data. Especially at lower digestibilities, where the variability appears to be larger, a range of PFI of -0.25 to +0.25 implies changes in production of some 19%. Even if this variability is substantially overestimated due to the limitations of the experiment, it still constitutes a compelling reason for generating field data with the aim of rendering previously conceptual relationships empirical.

Series 4

The final series of sensitivity analysis experiments investigated the robustness of primary production *per se* to changes in the growth functions in PASMOD, the forage component. Such analysis is difficult to plan and to analyse, mainly because the parameters of the model at this stage are no more than coordinates in the x-y plane. A number of one replicate (no variability) treatments were set up, without animals; one set was concerned with pure pasture, and the second, with mixtures and hence competition.

For the first set, the problem was how to vary the model parameters; it was decided to move the coordinates defining the first three PASMOD functions (Figure 11) in three ways: an increase in 10% in the y direction, 10% in the *x* direction, and 10% in the *x* and y direction. The resultant areas under the functions are thus increased by factors of 1.10, 1.10, and 1.21

respectively. It is also quite possible that a three-function model like this is amenable to mathematical analysis. However, 300-day runs take only some 5 seconds; there are more problems in analysing the large quantities of resultant output than in carrying out the runs themselves.

The ten treatments for the legume pasture are shown in Table 26, with results in terms of the ceiling yield, days to ceiling yield, and cumulative production (area under the curve) to that time. Ceiling yield was defined to have been attained if the biomass on day t differed from that of day $t-1$ by less than 1.0 kg. The actual values are of less importance than the changes that can be observed. A crude gauge of the sensitivity of each function can be obtained from summing and averaging the absolute values of the percentage changes observed; these are 1.5%, 7.8% and 3.6%, respectively. Senescence is of greatest sensitivity; this is not surprising, since this is a one-stage process, whereas growth is a two-stage process, derived from two functions rather than one. In view of this, some more treatments were set up to examine changes over a wider range for the senescence function. Results are shown in Figure 16, where it can be seen that changes in the x-y direction tend to damp down, to some extent, the large but opposing tendencies which exist if changes are made to the parameters in the x and y directions separately. The response is approximately linear, a 10% change in parameters leading to a 6% change in cumulative production.

Similar results were obtained for the pure grass pasture, Table 27, although (owing to the nature of the functions) ceiling yields were higher and growth rates were faster than those of the pure legume pasture.

Another set of treatments looked at the effects of 10% perturbations in the y-direction only to the growth functions for a grass legume mixture. No non-spatial competition was introduced at this stage. The effects on persistence of the legume, measured as the legume content ratio over time, were not marked (Table 28); neither were those on yield or cumulative production to day 210. Apparently, changes in the growth functions for mixtures lead to considerably dampened effects compared with the same changes made to mono-component pastures.

TABLE 26 SENSITIVITY ANALYSIS - SERIES 4 - RESULTS, TREATMENTS 1-10: LEGUME PASTURE, SENSITIVITY TO 10% PERTURBATIONS IN PASMOD FUNCTIONS

Treatment			Ceiling Yield t/ha		Days to Ceiling Yield		Cumulative Production Mt/ha	
1	-	-	4.76		208		0.653	
2	I	y	4.79	(+1)	200	(-4)	0.652	(0)
3	I	x	4.76	(0)	219	(+5)	0.665	(+2)
4	I	xy	4.80	(+1)	208	(0)	0.657	(+1)
5	II	y	4.55	(-4)	198	(-5)	0.584	(-10)
6	II	x	5.23	(+10)	224	(+8)	0.781	(+20)
7	II	xy	5.00	(+5)	212	(+2)	0.695	(+7)
8	III	y	4.99	(+5)	203	(-2)	0.683	(+5)
9	III	x	4.58	(-4)	209	(0)	0.604	(-7)
10	III	xy	4.77	(0)	201	(-3)	0.621	(-5)

(-) percentage change from value in Treatment 1; I, II and III are PASMOD function numbers; x, y, or xy indicates direction of perturbation.

FIGURE 16

SENSITIVITY ANALYSIS - SERIES 4
LEGUME SENESCENCE FUNCTION PARAMETER PERTURBATION
AND CUMULATIVE PRODUCTION TO DAY 210

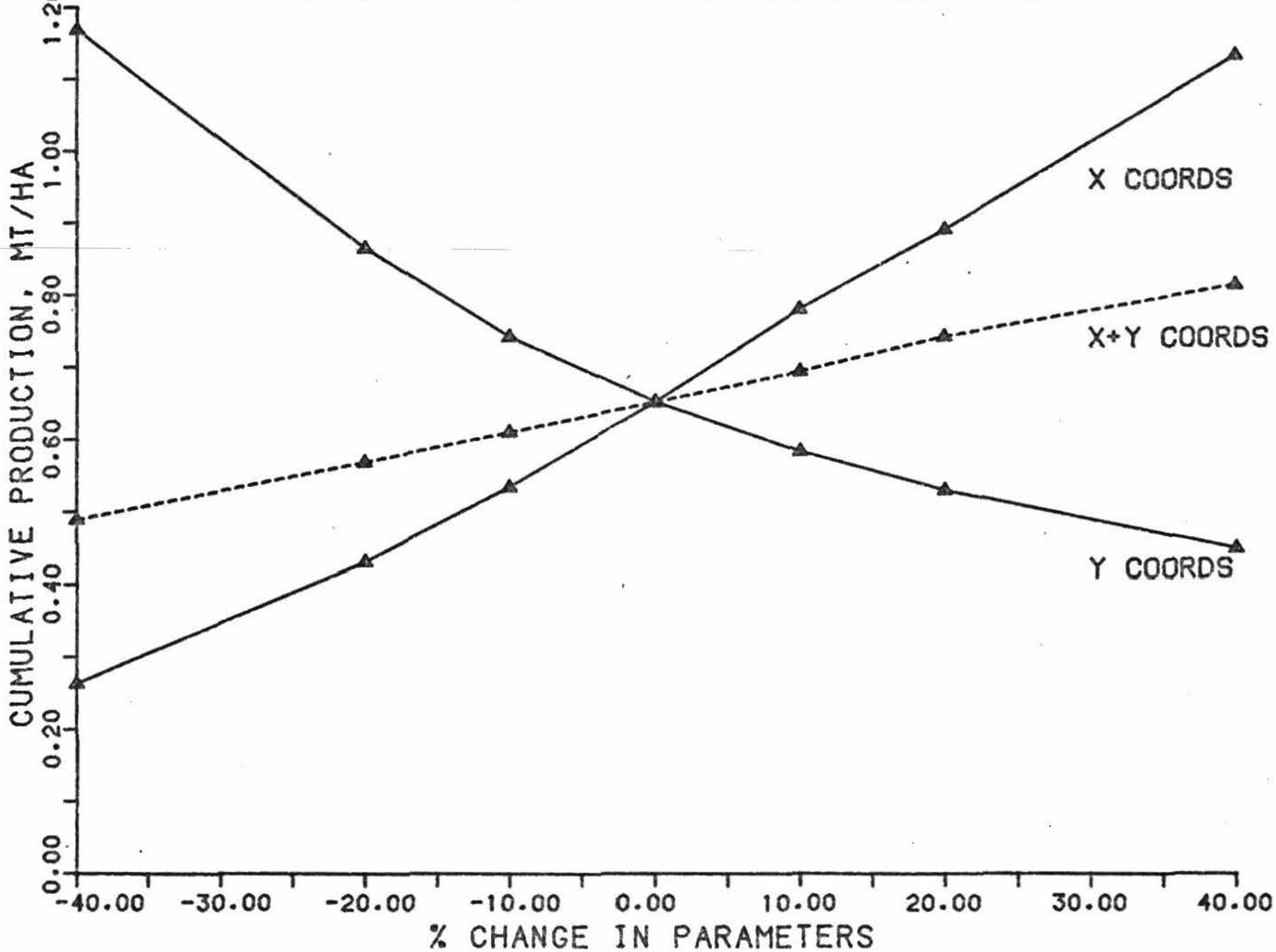


TABLE 27 SENSITIVITY ANALYSIS - SERIES 4 - RESULTS, TREATMENTS 11-20: GRASS PASTURE, SENSITIVITY TO 10% PERTURBATIONS IN PASMOD FUNCTIONS

Treatment			Ceiling Yield t/ha		Days to Ceiling Yield		Cumulative Production Mt/ha	
11			5.86		203		0.889	
12	I	y	5.98	(+2)	200	(-2)	0.906	(+2)
13	I	x	5.89	(0)	208	(+2)	0.898	(+1)
14	I	xy	6.10	(+4)	203	(0)	0.923	(+4)
15	II	y	5.55	(-5)	189	(-7)	0.777	(-13)
16	II	x	6.42	(+10)	221	(+9)	1.065	(+20)
17	II	xy	6.08	(+4)	206	(+1)	0.933	(+5)
18	III	y	6.21	(+6)	202	(0)	0.949	(+7)
19	III	x	5.76	(-2)	207	(+2)	0.876	(-2)
20	III	xy	6.10	(+4)	205	(+1)	0.930	(+5)

(-) percentage change from values in Treatment 11; I, II and III are PASMOD function numbers; x, y, or xy indicates direction of perturbation.

TABLE 28 SENSITIVITY ANALYSIS - SERIES 4 - RESULTS, TREATMENTS 21-27 MIXED PASTURES, SENSITIVITY TO 10% PERTURBATIONS IN PASMOD FUNCTIONS

Treatment			Yield day 210 t/ha		Cumulative Production Mt/ha		Legume Content Ratio day 0	70	140	210
21	-		5.95		0.991		0.50	0.17	0.09	0.06
22	I	L y	5.99	(+1)	1.000	(+1)	0.50	0.19	0.09	0.07
23	I	G y	6.10	(+3)	1.021	(+3)	0.50	0.15	0.08	0.05
24	II	L y	5.92	(-1)	0.985	(-1)	0.50	0.16	0.08	0.04
25	II	G y	5.65	(-5)	0.955	(-4)	0.50	0.17	0.09	0.06
26	III	L y	5.99	(+1)	1.000	(+1)	0.50	0.18	0.10	0.07
27	III	G y	6.79	(+14)	1.072	(+8)	0.50	0.14	0.08	0.05

(-) percentage change from values in Treatment 21; I, II and III are PASMOD function numbers; L and G refer to legume and grass, and y indicates the direction of the perturbation.

The last subset of treatments looked at the response to changes in the competition function. Some of the functions are illustrated in Figure 17, represent medium, low and high levels of competition, relating potential growth rate to actual growth rate. Results for these and other treatments appear in Table 29, which can be summarised as follows:

- the first three treatments show the effect of the three competition functions just shown on yield and persistence. This latter is obviously affected greatly, but yield is remarkably stable over the range from no competition to severe competition.

- for the second set of three treatments (31-33), the legume was made to compete against the grass using the same three competition effects. Medium and high levels of competition are in fact overriding the greater growth rates of the grass, leading to grass extinction, eventually. The accompanying large changes in yield are to be expected, since the legume has a much lower ceiling yield than the grass.

- the last two treatments show the effect of mutually beneficial and mutually detrimental competition, where total yield is enhanced and reduced, respectively.

Competition effects can be studied by deriving de Wit replacement diagrams, where relative yields after a certain length of time are plotted against a range of plant densities at time zero, in effect. Seven "replicates" of each of these treatments were carried out, but with the initial ratio of legume-to-total-biomass set at 0.0, 0.1, 0.3, 0.5, 0.7, 0.9 and 1.0, the total biomass being kept constant at 800 kg/ha.

The resultant forage growth curves for treatment 28 are shown in Figure 18, for the seven different starting combinations. As the proportion of grass at time t=0 decreases, the persistence of the legume increases.

De Wit diagrams can then be drawn, which show what happens by day 84 for the various levels of competition, Figure 19; these illustrate classic expression of such effects, where component relative yields are changing for increasingly severe competition. The effects on total relative yield

FIGURE 17

SENSITIVITY ANALYSIS - SERIES 4
COMPETITION FUNCTIONS, TREATMENTS 28 - 30
ACTUAL GROWTH RATE RATIO AND POTENTIAL GROWTH RATE RATIO
LEGUME —— GRASS -----

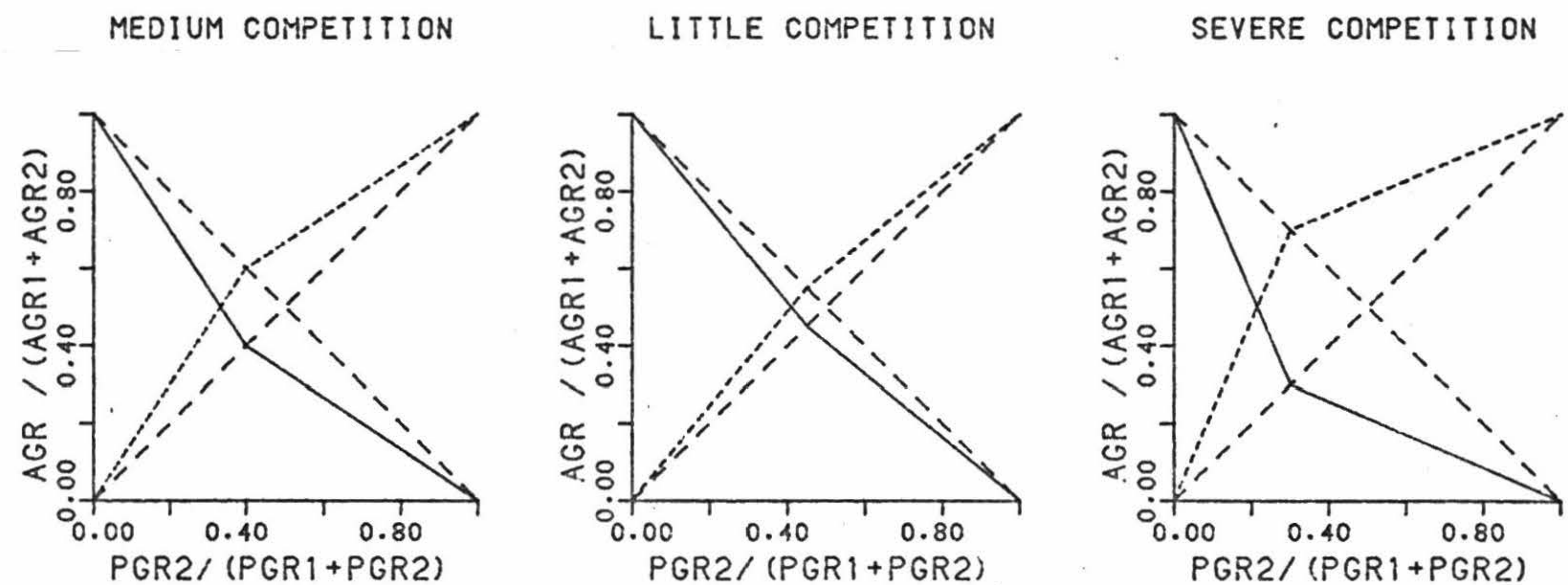


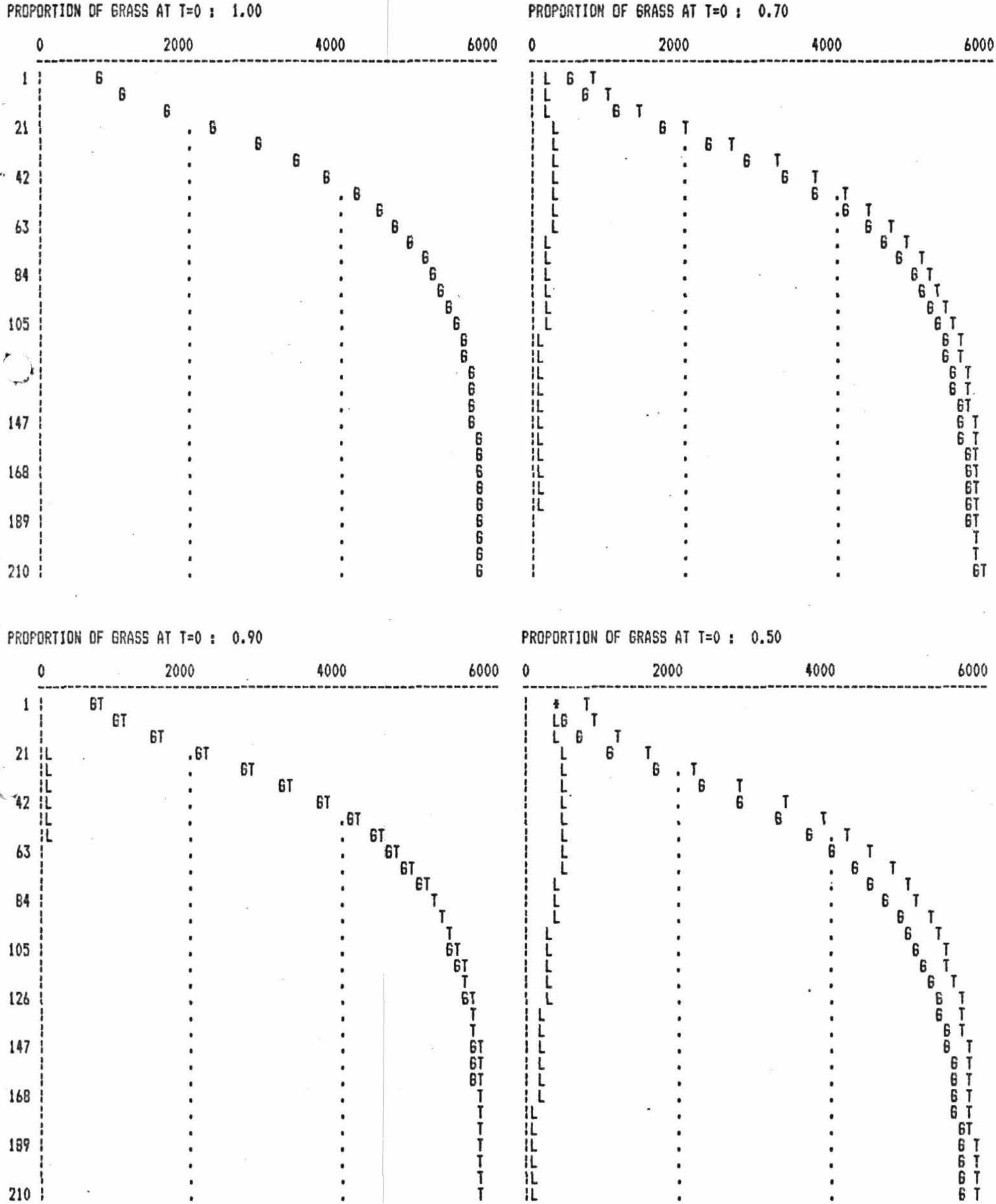
TABLE 29 SENSITIVITY ANALYSIS - SERIES 4 - RESULTS, TREATMENTS 28-35
MIXED PASTURES, SENSITIVITY TO DIFFERENT COMPETITION FUNCTIONS

Treatment		Yield day 210 t/ha		Cumulative Production Mt/ha		Legume Content Ratio day 0	70	140	210
28 IV G>L	m	5.91	(-1)	0.992	(0)	0.50	0.11	0.05	0.02
29 IV	s	5.93	(0)	0.991	(0)	0.50	0.13	0.06	0.04
30 IV	l	5.90	(-1)	0.993	(0)	0.50	0.08	0.03	0.01
31 IV L>G	m	4.82	(-19)	0.840	(-15)	0.50	0.62	0.68	0.73
32 IV	s	6.02	(+1)	0.989	(0)	0.50	0.25	0.15	0.11
33 IV	l	4.83	(-19)	0.817	(-18)	0.50	0.83	0.90	0.94
34 IV ben		6.78	(+14)	1.095	(+11)	0.50	0.23	0.17	0.13
35 IV det		5.85	(-2)	0.923	(-7)	0.50	0.15	0.06	0.03

(-) percentage change from values in Treatment 21; L and G refer to legume and grass; m, s and l to medium, small and large competition effects, ben and det to mutually beneficial and detrimental competition.

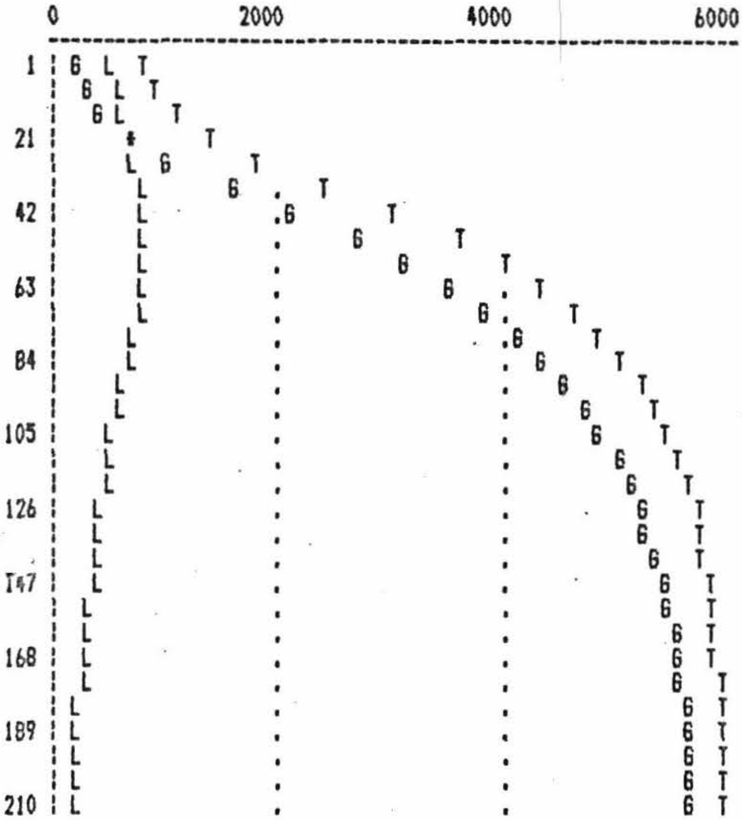
FIGURE 18

TREATMENT 2B BIOMASS CURVES, KG PER HA (L LEGUME, G GRASS, T TOTAL, * L&G)

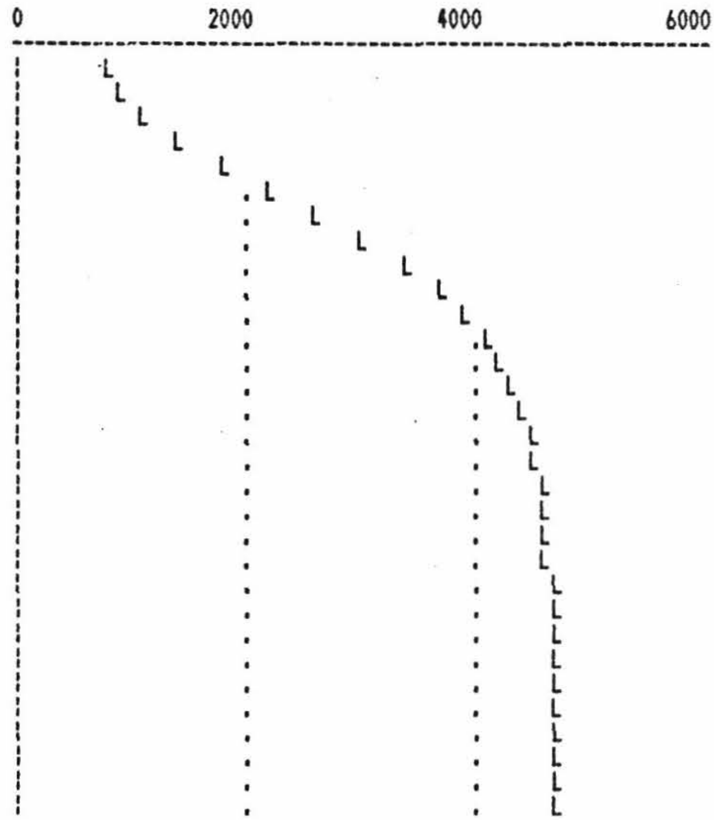


(TREATMENT 28 BIOMASS CURVES -continued-)

PROPORTION OF GRASS AT T=0 : 0.30



PROPORTION OF GRASS AT T=0 : 0.00



PROPORTION OF GRASS AT T=0 : 0.10

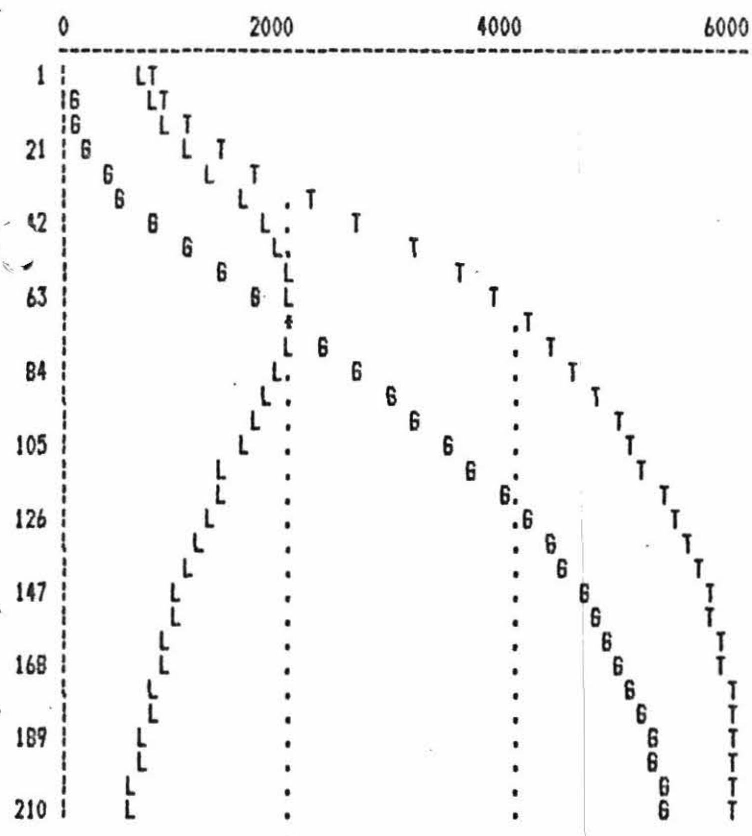
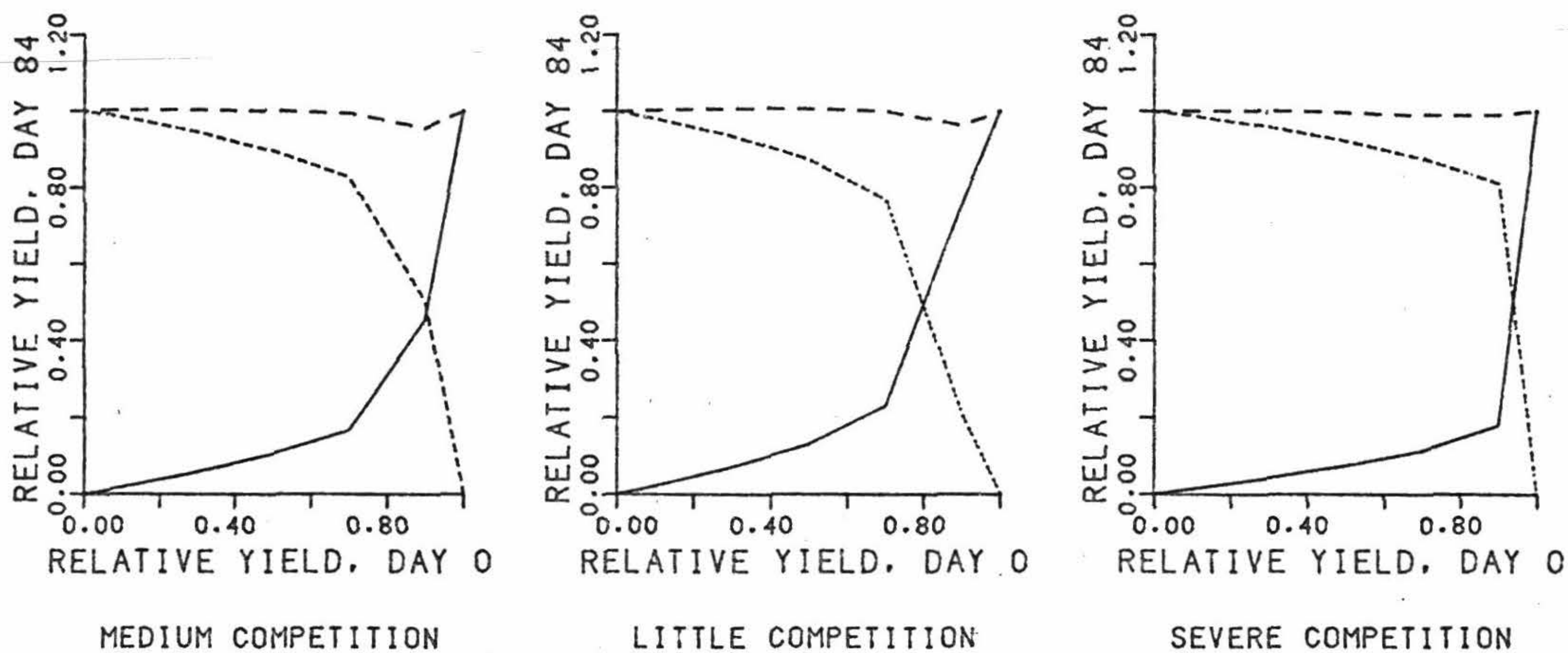


FIGURE 19

SENSITIVITY ANALYSIS - SERIES 4
DE WIT DIAGRAMS, TREATMENTS 28, 29 AND 30
LEGUME —— GRASS ----- TOTAL - - -



are included to show the ability of the competition function alone to produce marked changes in total biomass, for the cases where the function produces mutually detrimental and beneficial changes (Figure 20).

These results can be summarised in a few points:

- in pure swards, senescence is particularly sensitive;

- for mixed swards, functions I, II and III (the leaf area index, senescence and growth rate functions,) tend to act on yield and persistence to a limited degree only, while function IV (the competition function) tends to act on legume persistence to the exclusion of yield.

- for mixed swards, making the legume act more like the grass tends to stabilise the system, in terms of the speed of decline of legume persistence, while increasing the discrepancy works in the opposite direction.

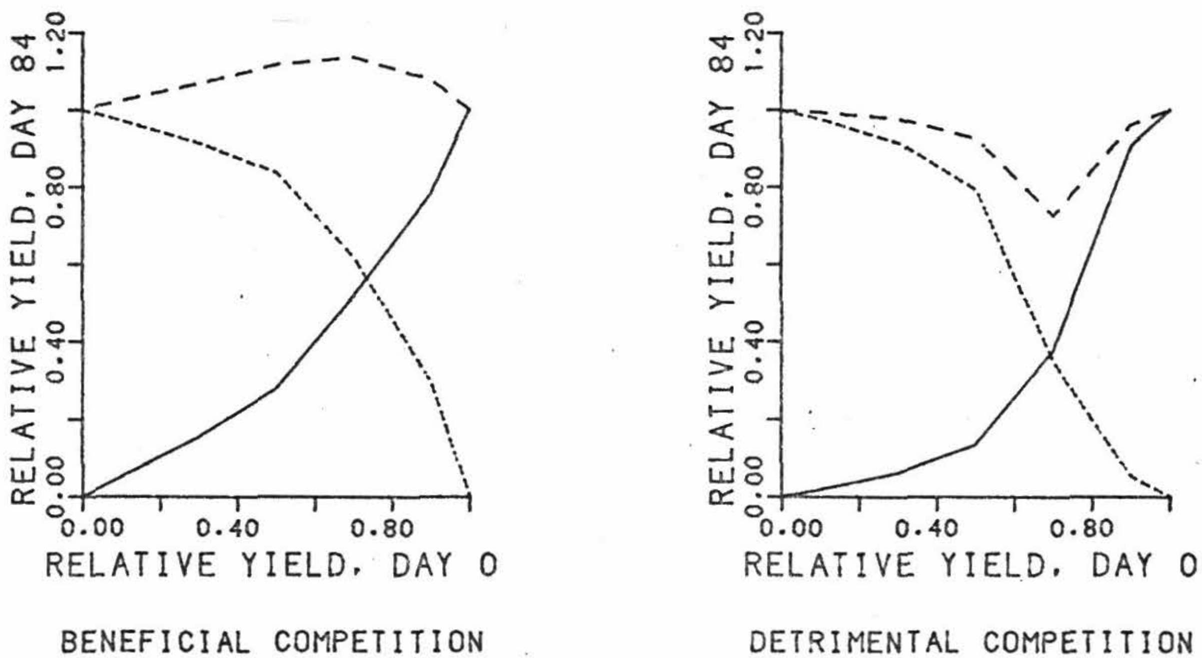
- where one species both competes successfully and has higher growth rates, the actual form of the competition function has little effect on yield. By making the successfully competing component the competed-against, the effect of higher growth rates can easily be offset by a sufficiently severe competition function.

- the form of competition function used has results which are reflected in a sensible way in replacement diagrams, i.e., many of the classic responses can be obtained by changing this function alone.

It may be concluded that, as a conceptual model, PASMOD reacts in a reasonable fashion to changes in its functions (see Fisher and Thornton, 1987, and Thornton and Fisher, 1987, for further experimental results.)

FIGURE 20

SENSITIVITY ANALYSIS - SERIES 4
DE WIT DIAGRAMS, TREATMENTS 34 AND 35
LEGUME —— GRASS ----- TOTAL - - -



4. EXPERIMENTATION PROGRAM

4.1 Introduction

The experimental program was carried out in two stages. The first series contained a large number of treatments of different types, often without replication, whose aim was to identify a small number of promising strategies. These were then examined in the second series, with comparatively large amounts of replication, and were then analysed using standard decision analysis.

A number of points relate to all experimentation. Essentially, the object was the identification of management practices that are capable of inducing sizeable changes in the quality of the system. Analysis tended to concentrate more on the relative performance of various options than on their absolute performance. For most treatments, 150 ha of land was considered to be available, with improved pastures being introduced as required. Costs were calculated on this total amount of land. The costs of improved pasture were assumed to accrue in the May of the year in which they were incurred. Any improved pasture was usually resown at the beginning of year 10, halfway through the run, and maintenance fertiliser was applied every third year. These really constitute artifices for the cash flow; the lack of total feedback between pasture and animal is discussed below. The prices and costs used were those pertaining in early 1986, as far as can be ascertained.

The quality of the standard improved pasture used was not particularly high, with average digestibilities of only 48% and 58% for the grass and legume, respectively. This was done deliberately, so that any erring would occur on the side of caution. Despite the problems previously experienced in the stability of the system once left alone and allowed to run unchecked, the weather-related growth functions for the improved pasture (see below) usually restored a semblance of balance between the proportions of grass and legume by the end of the dry season. The small proportion of legume usually available to the animal (from a 50-50 mixture at each planting) undoubtedly exacerbates the rather mediocre quality of the overall pasture, owing to this component's lower digestibility.

The set of management rules in force was that described elsewhere (Thornton, 1987), unless the treatment concerned was in the process of modifying one or other of them. The most important were as follows: weaning at 270 days, culling twice a year on the basis of age and successive negative pregnancy tests, and disposal of the followers herd at these same times.

The problems of pasture-animal feedback are not faced in their entirety; the model is still incomplete in some important respects. In particular, the question of availability of forage remains. For some of the treatments, ration rules were imposed; such rules are difficult to arrive at, since the behaviour of the farmer in this context may be extremely complex. The approach taken here was simply to say that if availability of improved pasture per animal unit fell below a certain level, then the relevant mobs were moved to the savanna buffer until such a time as this threshold was exceeded. Note that once animals are moved off improved pasture in this way, they cannot be moved back until a minimum of five days have elapsed (*dt*, the integration time step). Real life decision making is unlikely to be so crude and inflexible; performance from treatments with such ration rules could be expected to be rather better than is indicated, therefore, as far as this factor is concerned.

Another problem of feedback exists in the lack of a relationship between digestibility and biomass (see below). In addition, the effects of pasture resowing on herd dynamics are not easy to incorporate. For some of the treatments, where the effect of resowing was being investigated explicitly, the herd was subjected to one year on savanna before being allowed to graze improved pasture. As will be seen below, the effects of such a year had little effect over 18 years on biological parameters, whilst the effects on the economic parameters were profound.

Variability in the System

It is the case that 18 years constitute a considerable period of time, and it is interesting to speculate on the size of variances that could be expected from 18-year replicates of the same treatment in real production systems. The year-to-year variation is damped down to a great extent over such a period of time, as was indicated in the sensitivity analysis. The main purpose of addressing this aspect at all relates to the fundamental unchanging nature of digestibility from year to year as it is set up in the model, and the fact that availability is rarely allowed to be limiting. The other question of interest relates to what happens in years of pasture failure.

There are currently three distinct sources of random variation in the system model:
- within the animal component, death and conception, for instance, are stochastic and directly account for a certain amount of variability.
- buying prices are stochastic, introducing a limited amount of variability to the economic output variables.
- the third source is the inclusion and use of extant evapotranspiration data from Carimagua to modify pasture growth rates. This process is discussed below.

A number of ways exists in which this variability could be increased. First, the pasture model could be left with tabular digestibilities, exhibiting coefficients of variation of approximately 8% for economic parameters and 3% for biological parameters which are not directly stochastic between 18-year replicates. To this can be added a consideration of pasture failure. A second possibility would be the arming of the improved pasture model with new bi-seasonal functions relating digestibility to biomass in some way, in an attempt to obtain more biological variability, principally. A third method is to take the most important input variable for which information is most limiting, impute a triangular distribution to its value, and observe what happens to the variability between replicates. Conceptually, this is flawed by the fact that all variability can be ascribed to imperfect knowledge, in which case the correct procedure would be to impute distributions to all variables for which information was lacking. Much of the variation so induced would undoubtedly be self-cancelling, leaving, in theory, a system-dependent quantity of variation. Digestibility is an example of a variable which be used directly in such a way; similarly, any of the parameters in the pasture growth model could be used without difficulty. The order of magnitude of the variability that could be expected from such a procedure is completely unknown. Lack of time prohibits the investigation of this rather intriguing possibility, unfortunately.

The simplest method of attempting to include reasonable levels of variability is to treat the probability and consequences of pasture failure in an explicit fashion. Total failure of a planted pasture is presumably rare; it is more likely that one of the components, in comparatively small, well-defined areas will require replacement. However, it is useful to assume, for example, that one year in 21 will result in complete pasture loss, with subsequent incursion of replacement costs, or, more realistically, a certain proportion of them, and the herd being sustained by the native savanna until establishment. If this is seen as being the worst possible outcome, in economic terms, then such an event fixes the left-hand end of the cumulative probability distribution. This rationale is in accord with the risk-averseness exhibited by the vast majority of producers, and is discussed in section 4.3.

Selection of Output Criteria

It is difficult to identify a number of criteria which, when taken in their entirety, are capable of giving an accurate indication of the biological and economic performance of a particular treatment. This is due in part to the complexity of the system, and in part to the fact that it is unknown what it is farmers seek to maximise, if indeed their behaviour can be explained in such a fashion.

Biological Performance. The indices used to calculate production per animal unit per year have certain problems. The calculation of production per unit area was judged to be too controversial, given the current limitations of the model with respect to forage availability. The expression used to calculate production, as taken from the ETES project report (Vera and Sere, 1985), fails to take account of cullings. It is the case that culling policies must be reasonably severe, if the relevant age distributions are to be preserved over long periods of time. Presumably, a number of deaths due to starvation in the savanna system could be expected to be converted into sales, thus raising production levels somewhat. The summation of sales over time appears to be sensitive to the decision rules operating in the model, so again comparative study requires care. It is worth noting that very high values of such production indices can be obtained, but at the expense of numbers of animals in the herd falling to such low levels that extinction is the only possible outcome. Clearly, for a supposedly self-replacing herd, this will not do; some measure of herd stability has to be included in the general assessment process. The problems with weaning percentages as calculated in the model have been discussed elsewhere, but suffice it to say that these are usually substantially underestimated for a given conception percentage.

Economic Performance. The merits and demerits of traditional investment criteria are well-known. A subjective element exists in both the internal rate of return, in imputing a value to the decision maker's time horizon, and the net present value of an investment, where a rate of time preference has to be imputed. Such criteria can be of use, but it is likely that there are even more fundamental considerations. For instance, an examination of net revenue over time and of the amount of negative months or quarters in the cash flow is likely to yield important information as to the probability of new technology being taken up. Of course, the influence of risk may be decisive, in certain situations. As is described below, attractive options exist for reducing cash flow squeeze and for pushing the producer higher up the mean-variance utility frontier.

In summary, it is necessary to look at a large number of factors when assessing the feasibility of any particular treatment. This entails the extraction of large quantities of data for which analysis, in a classical statistical sense, is not always forthcoming or feasible. This places further constraints on the sheer quantity of experimentation that can be carried out, in addition to that imposed by available computing resources.

Model Adjustments, V4.2 to V4.3, January to March, 1987

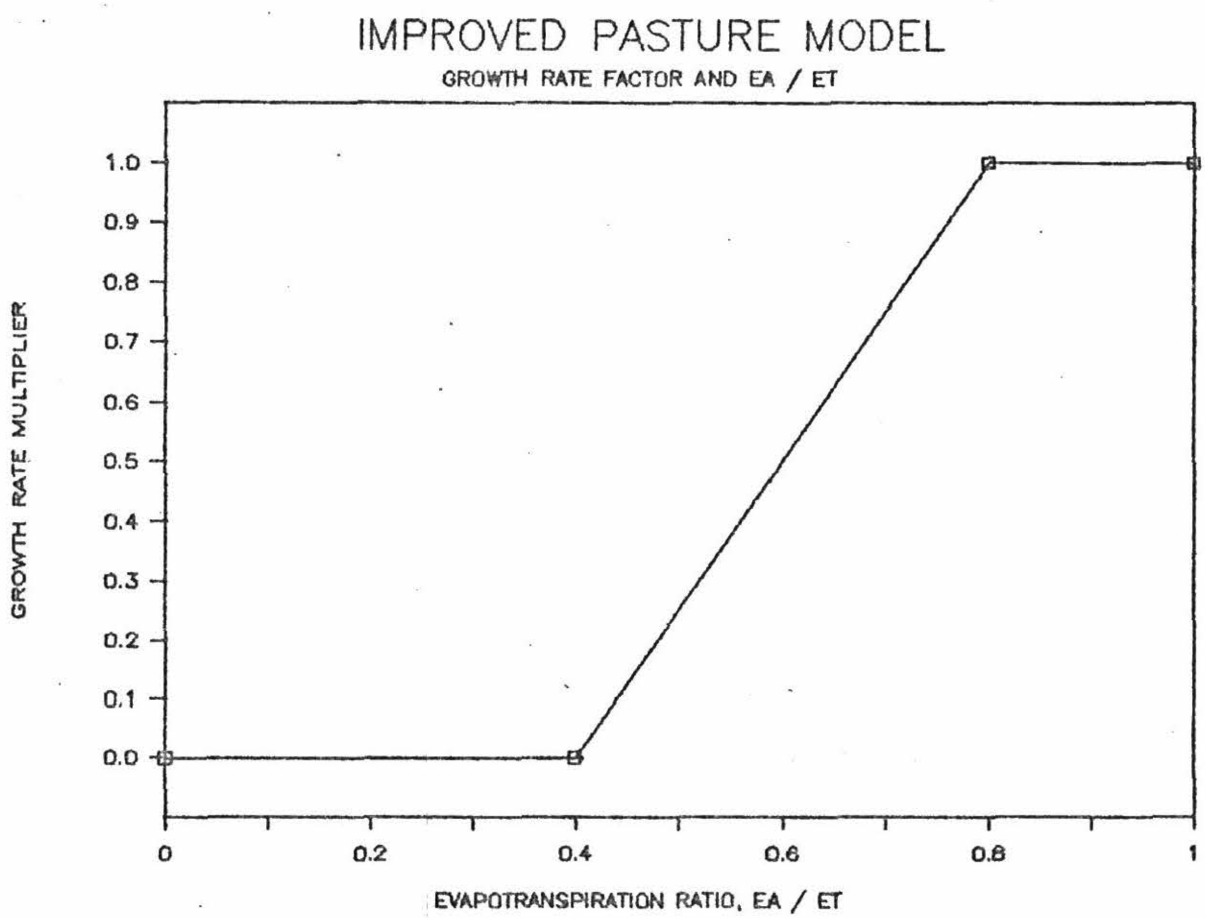
Both series of model runs accounted for in excess of 600 18-year experiments. At 2.7 minutes CPU time per run, this amounted to some 28 hours of central processor time. The length of run was set at 18 years to allow the completion of three complete price cycles; for most runs, therefore, animals were bought at the start of the run and sold at the end of the run with the cosine function at identical points. A number of runs were carried out to investigate the effects of different cosine phases on the economic performance of certain treatments.

The most important adjustment to the model concerned the tentative inclusion of weather on primary production, to an extent. It appears that the start and cessation of growth in the savannas are primarily a function of the water in the soil. There exist twelve complete years of water balance information from Carimagua, covering the period 1974 to 1985 (Figure A1 in the Appendix). The beginning and end of each year are critical; the time series (created using WATBAL, a water balance model, by P G Jones) was chopped up into 11 years starting on June 30, when all years showed a value of the evapotranspiration ratio, E_A/E_T (actual to potential evapotranspiration), of 1.0, to avoid the problem of trying to splice disparate years. The daily data were assembled into pentads, averaged, and written to a computer file, one year per record. To determine the status of the soil water at any time during a simulation run, a year is selected at random from 1 to 11 (using a third independently-seeded random number generator, subroutine RAN3) since no autocorrelation could be detected between years, and that year is used sequentially up until June 30 of simulated time, when a new year is chosen. The variability introduced by this method is strictly limited, and is obviously of most importance when forage is limiting during the dry season (since the start and duration of the dry season can be seen as quasi-random variables).

Once the ratio of actual to potential evapotranspiration has been calculated for the relevant pentad, actual growth rate for the grass and legume (AGR_i) are modified by a factor whose value is specified by a ramp function (Figure 21). This process can be turned off by specifying a value for the appropriate random number seed of 9999. These calculations are carried out in subroutine EVAP.

The Carimagua data were transformed by WATBAL using a value of 100mm for soil water capacity, so theoretically soils of different water holding capacity could be catered for. It is acknowledged that no account is taken of species that exploit water from different profiles, for example; the

FIGURE 21


IMPROVED PASTURE MODEL
GROWTH RATE FACTOR AND EA / ET
GROWTH RATE MULTIPLIER
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
0.2
0.4
0.6
0.8
1
EVAPOTRANSPIRATION RATIO, EA / ET

addressing of such factors, however, lies in the future for a model of this resolution.

Other modifications made to the system model were minor, including a print out showing whether the cash flow for a particular quarter-year was positive or negative, to allow easy comparison between treatments, and a random number seeder based on the clock in the computer itself. If the time is hh-mm-ss, then NSEED, the seed for subroutine RANDOM, is set to ssmm. Two other variables, NOX2 and NOX3, which seed RAN2 and RAN3, the other random number generators, are then set to NSEED+100 and NSEED+200 respectively. All seeds can be set manually by setting NSEED not equal to the value 9999.

4.2 First Series

A list of the major treatments is shown in Table 30. It should be noted that these runs are not necessarily directly comparable with each other, although they are so within each factorial set. Selected output is summarised in Table 31 (the treatments are described in Table 32), showing both economic and biological parameters. All incremental internal rates of return were calculated in comparison with the baseline savanna system. These IRRs tended to be volatile, and there were a number of cases where the iterative procedure used to calculate them converged on a "solution" for a cashflow which was in fact ill-conditioned (in addition to those cases where no solution could be found at all). Treatments and their main effects are summarised below.

The first subset consisted of various treatments with 20, 30 and 40 ha of improved pasture. For most of these treatments, no complete costings were carried out; interpretation of the economic parameters is thus restricted to a consideration of relative performance. A lax ration rule was used, so that in effect biomass was not limiting for these runs. The sensitivity of the internal rate of return was thus overestimated, since 20 ha of improved pasture simply will not support the same number of beasts in the same way that 40 ha can, in the long run. Provision of improved pasture, in conjunction with standard decision rules, resulted in clear increases in production and profitability levels for all mobs.

TABLE 30 FIRST SERIES, MAJOR TREATMENT LIST

Baseline Savanna

Improved Pasture:

3 areas X 11 weaning, culling, selling, breeding strategies
4 seasonal periods X 9 mobs
3 areas X 2 replacement weights
2 milk offtake rates X 3 areas X 4 seasonal periods
3 areas X 2 buying strategies
2 mobs X 3 areas X 3 replicates X 2 ration rules
3 mobs X 3 replicates X 3 seasonal periods X 2 milk offtake rates
2 seasonal mating strategies X 2 dates of imposition
2 resowing treatments X 2 pasture renewal strategies
2 activity expenditure treatments
4 increase herd size treatments
3 correlation coefficients buy/sell price X 3 reps
price cycles: 4 lengths X 3 amplitudes X 3 reps
4 costs X 3 levels X 3 reps
3 milk prices X 3 reps
5 increased pasture quality levels X 5 reps

TABLE 31 FIRST SERIES RESULTS SUMMARY - SELECTED TREATMENTS

Treatment	NR	IRR	INC	AU	AGE	CON	ET	CP	WP	WT	DA	DC	SL	E2
0	0.58	4	-	34	4.0	610	40	47	31	132	11	14	34	38
1	4.17	17	64	40	3.0	362	93	86	64	153	9	3	94	76
4	4.21	19	67	38	3.0	366	93	83	62	155	8	2	102	73
7	3.00	12	27	38	3.0	389	82	84	62	131	6	2	87	73
10	1.86	10	-	36	3.0	383	84	83	62	105	8	2	74	72
13	-1.10	-	-	16	3.1	369	102	95	79	81	9	3	96	90
13A	-0.24	-	-	35	3.9	?	83	90	66	80	14	1	85	76
16	5.75	23	74	42	2.9	353	86	93	66	158	6	3	101	80
19	6.13	24	82	42	2.9	354	99	92	70	161	5	2	103	83
22	7.90	25	51	53	2.9	347	73	96	74	158	9	4	73	88
25	11.29	26	50	87	3.7	345	59	101	74	155	9	4	77	60
28	5.65	20	56	42	2.8	353	86	94	67	160	7	4	96	80
31	5.48	22	71	42	2.8	351	88	94	70	159	9	4	93	83
49	5.61	24	121	42	2.9	353	90	93	71	159	8	3	95	84
50	1.10	6	28	36	3.5	523	55	57	43	138	9	4	48	52
51	3.78	16	63	41	3.2	404	65	81	57	131	8	3	75	63
52	1.52	7	18	37	3.5	516	51	59	42	140	7	5	50	50
81	5.67	22	68	42	2.8	352	89	93	70	159	7	3	97	83
123	4.94	20	63	42	2.9	386	88	93	69	159	10	2	90	82
87	5.12	23	84	41	2.9	351	84	88	65	145	9	4	84	77
88	5.60	23	76	42	2.8	348	86	95	70	150	8	2	89	81
89	5.68	23	80	42	2.8	352	86	91	69	153	8	2	92	81
90	5.53	22	77	42	2.9	353	86	91	69	153	8	2	92	81
99	-2.25	-	-	10	3.4	336	2							
100	1.90	9	21	35	2.9	345	57							
101	3.86	16	48	38	2.8	349	72							
102	3.83	15	43	39	2.9	343	72							
1ABC	-0.84	-	-	32	3.3	536	38	57	27	119	10	37	29	35
2ABC	4.84	22	138	42	3.0	374	77	87	64	147	7	3	88	74
3ABC	4.31	19	106	41	3.0	377	77	86	63	150	9	3	84	73
4ABC	4.63	22	-	41	3.1	389	68	81	59	144	8	2	76	67

[- TABLE 31 cont -]

5ABC	5.18	23	194	42	3.0	373	76	87	64	150	8	1	87	73
6ABC	4.57	21	109	42	3.0	376	76	87	63	149	8	4	85	72
7ABC	1.31	7	-	37	4.0	423	50	66	45	123	16	7	42	49
8ABC	2.24	11	63	39	4.0	368	59	75	54	134	16	3	56	56
9ABC	1.84	9	34	39	4.0	377	57	71	52	135	14	3	55	54
10ABC	2.27	12	-	40	4.0	374	59	76	55	133	18	2	50	57
11ABC	2.04	11	50	39	4.0	367	59	75	54	134	17	3	54	57
12ABC	1.98	9	30	39	4.0	379	57	73	52	135	14	3	55	55
140	4.14	16	43	41	3.1	394	69	82	59	133	10	5	72	66
141	3.84	15	38	40	3.2	402	71	78	57	131	10	3	74	66
142	2.86	11	25	38	3.3	432	69	71	51	133	8	3	71	59
143	4.03	17	43	39	3.1	381	59	82	47	126	7	25	66	56
144	3.56	15	37	39	3.1	380	62	81	49	122	11	22	61	58
145	2.99	12	27	37	3.5	420	62	71	44	126	7	19	62	53
200	0.84	5	-	34	4.0	631	40	45	32	145	8	15	37	39
203	0.04	0	-	26	4.0	626	43	47	34	146	9	12	47	42
206	0.06	0	-	32	4.0	625	41	48	32	147	9	9	39	40
227	2.18	9	17	41	3.0	391	73	81	59	146	7	3	82	68
230	1.37	5	7	39	3.2	430	72	74	54	147	8	2	76	64
233	1.97	8	16	40	3.1	398	72	80	58	147	9	4	77	68
236	1.44	6	11	39	3.1	421	72	75	55	147	8	2	78	65
S001	3.15	13	31	41	3.1	399	72	82	60	148	7	4	81	69
S006	3.53	15	46	41	3.0	399	72	82	59	149	6	3	82	69
S011	3.63	13	34	42	3.0	388	72	82	59	147	9	3	79	68
S016	3.61	14	31	42	2.9	372	82	92	66	151	9	3	86	77
S017	1.73	6	9	40	3.1	404	70	79	57	149	8	5	77	67
S018	5.85	23	60	42	3.1	381	70	85	61	132	8	6	75	68
S020	5.49	22	61	41	3.1	389	69	81	59	133	8	5	75	66
S026	5.53	23	83	40	3.1	385	64	84	59	128	9	13	68	62
S027	5.30	22	75											
S028	6.01	25	92											

[- TABLE 31 cont -]

S091	5.12	18	37	41	3.2	402	66	78	58	130	9	3	71	68
S094	2.78	11	26	40	3.0	390	72	82	61	143	8	3	76	68
S097	4.93	21	152	42	3.0	389	72	85	62	144	8	3	80	70
S100	4.74	20	73	42	3.0	376	77	85	63	149	8	2	85	72
S103	5.35	23	112	43	3.0	376	76	87	65	149	8	2	86	73
S106	4.57	19	75	42	3.0	375	78	87	64	149	9	3	83	73
S109	5.73	18	38	56	3.1	387	62	91	67	148	10	2	78	75
S112	9.12	19	32	94	3.9	365	55	101	72	148	12	3	66	51
S080	-0.29	-	-	34	3.8	604	44	49	33	134	8	9	41	43
S083	0.50	3	-	34	3.9	598	43	48	33	135	8	10	40	42
S086	0.27	2	-	33	4.0	615	41	48	32	132	8	12	39	40

Key :
NR net revenue, $millions
IRR internal rate of return, %
INC incremental IRR compared with pure savanna system
AU average number of animal units at any time
AGE age at first parturition, years
CON conception interval, days
ET production, kg/AU/yr
CP conception percentage
WP weaning percentage
WT weaning weight, kg
DA adult mortality, %
DC calf mortality, %
SL sales, kg/AU/yr
E2 production, kg/AU/yr, using true average animal numbers

TABLE 32 FIRST SERIES SELECTED TREATMENT DESCRIPTIONS

Treatment	Description
0	Pure savanna, 150 ha
1	IP all, breeding season 5-7, 30 ha
4	8-10
7	IP all, wean 210 days
10	150
13	90
13A	90, animals bought in
16	cull animals after 8 years of age
19	cull animals after 4 negative pregnancy tests
22	sell followers herd at 200 kg
25	sell followers herd at 300 kg
28	sell off all orphans
31	standard set of management rules, 30ha IP fed to all mobs
49	IP all, 15 ha, fed all year
50	fed during dry season
51	fed during early wet season
52	fed during late wet season
81	IP all, 30 ha, all mobs, replacers over 150kg selected
123	replacers bought
87	Milk offtake 0.25 all year, 30 ha IP to all mobs
88	wet season only
89	early wet season only
90	late wet season only
99	Milk offtake 0.50 all year, 30 ha IP to all mobs
100	wet season only
101	early wet season only
102	late wet season only

[- TABLE 32 cont -]

1ABC	IP all mobs, 3 ha
2ABC	9 ha
3ABC	15 ha
4ABC	3 ha, stricter ration rule
5ABC	9 ha,
6ABC	15 ha,
7ABC	IP to pregnant and lactating cows, 3 ha
8ABC	9 ha
9ABC	15 ha
10ABC	3 ha, stricter ration rule
11ABC	9 ha
12ABC	15 ha
140	IP to all, 50 ha, offtake 0.25
141	open season months 5-10
142	5-7
143	0.375
144	5-10
145	5-7
200	IP to calves only, 3 ha
203	9 ha
206	15 ha
227	IP to all, 50 ha, seasonal breeding months 5-10 imposed in year 4
230	5-7
233	5-10 B
236	5-7
S001	IP all, 30 ha, price correlation coefficient 0.90
S006	0.50
S011	0.70
S016	IP all, 30 ha, biomass reset every year
S017	IP all, 50 ha, biomass not reset every year
S018	IP all, 30 ha, milk offtake 0.25
S020	IP all, 30 ha

[- TABLE 32 cont -]

S026	IP all, 30 ha, offtake 0.333
S027	as S026, milk price - 10%
S028	as S026, milk price + 10%
S091	IP all, 30 ha, seasonal breeding 8-11, offtake 0.25
S097	IP all, 6 ha
S100	12 ha
S103	6 ha, stricter ration rule
S106	12 ha
S109	IP all, 30 ha, sell followers at 200 kg
S112	300
S080	30 ha, IP to those for whom W/WM < 0.6
S083	15 ha,
S086	15 ha, 0.55

The treatments involving early weaning were repeated owing to a problem in the code of the model that did not, fortunately, affect any other runs. These runs were fully costed, and may be compared with the later treatments. It is hard to identify any long-term benefit arising from early weaning (Figure 22); the expected response, a reduction in calving interval, was not observed to any great degree. The inbuilt decision rule not to accept female animals of less than 100kg liveweight as replacers eventually leads to herd extinction in conjunction with 90-day weaning (since replacers are never selected, but sold). When animals were bought to keep 30 breeding animals in the herd, economic performance improved to some degree. The early weaning results are discussed in a wider context below.

For systems involving seasonal mating, it appears that sales are increased, but that this is offset by longer calving intervals and lower weaning weights. Successful seasonal mating thus appears to depend on obtaining calving intervals less than or equal to one year for as much as the herd as possible. Clearly, in these treatments a number of animals are not conceiving by the end of the breeding season, and are having to wait for its resumption before being able to conceive. Standard conception-by-month distributions for the pure savanna and improved pasture systems are shown in Figure 23, while Figure 24 shows the effect of shortening the breeding season on the distribution of conceptions.

Culling policy can have an important effect on production, through reducing adult death rates of animals which would otherwise be lost to the system. The system may also receive a boost in terms of efficiency by the more rapid removal of older, less fertile cows, an effect noted in the sensitivity analysis (Section 3.1). As discussed above, culling policies must be fairly strict, since in its absence, somewhat unrealistic death rates are required to preserve observed cattle age distributions.

On changing the production system somewhat, by keeping followers on the farm until predetermined bodyweights were reached (200 or 300 kg), economic performance was much enhanced. This effect is, however, exaggerated, since the pasture was supporting up to 90 animal units, taking advantage of the unrealistic quantities of edible forage. This problem was addressed to some

FIGURE 22

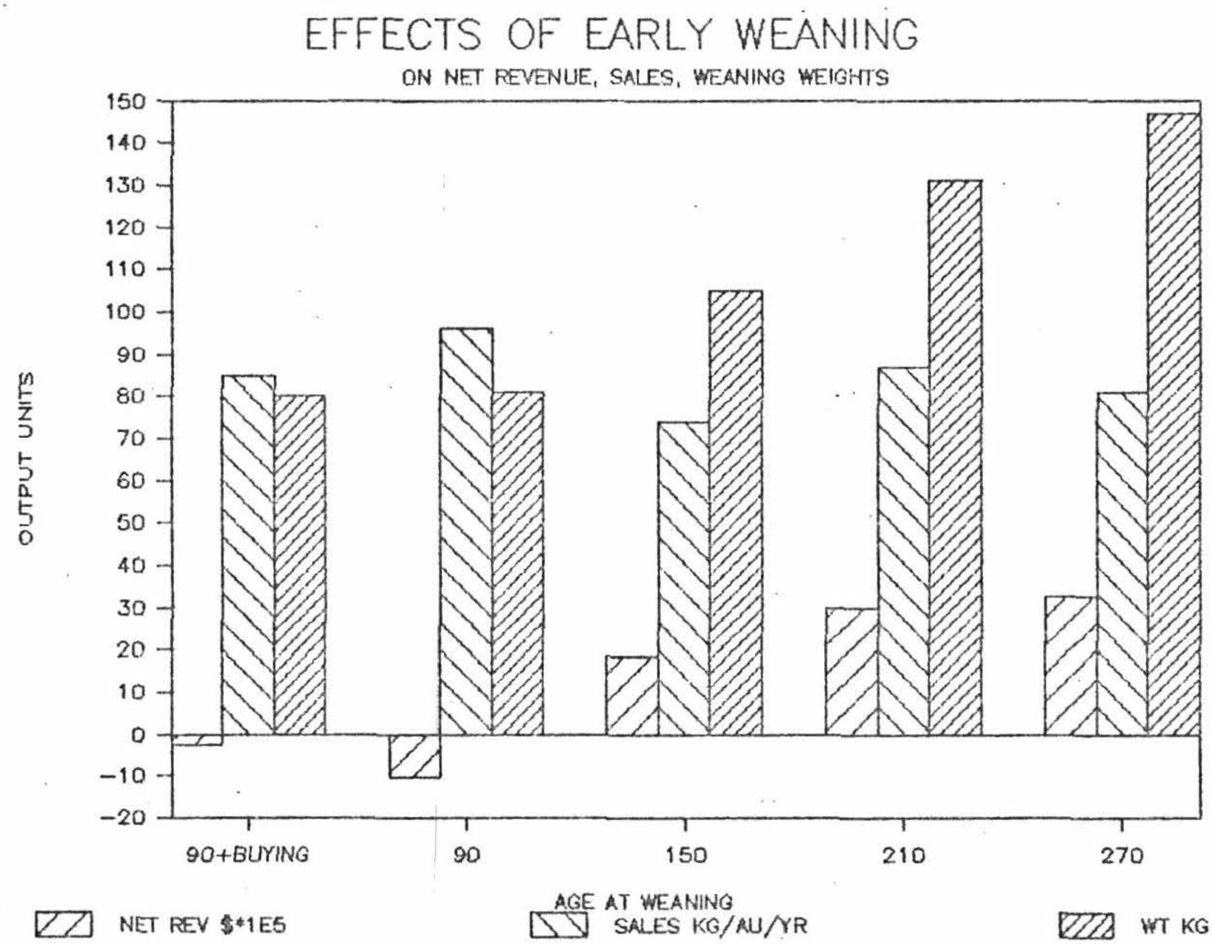
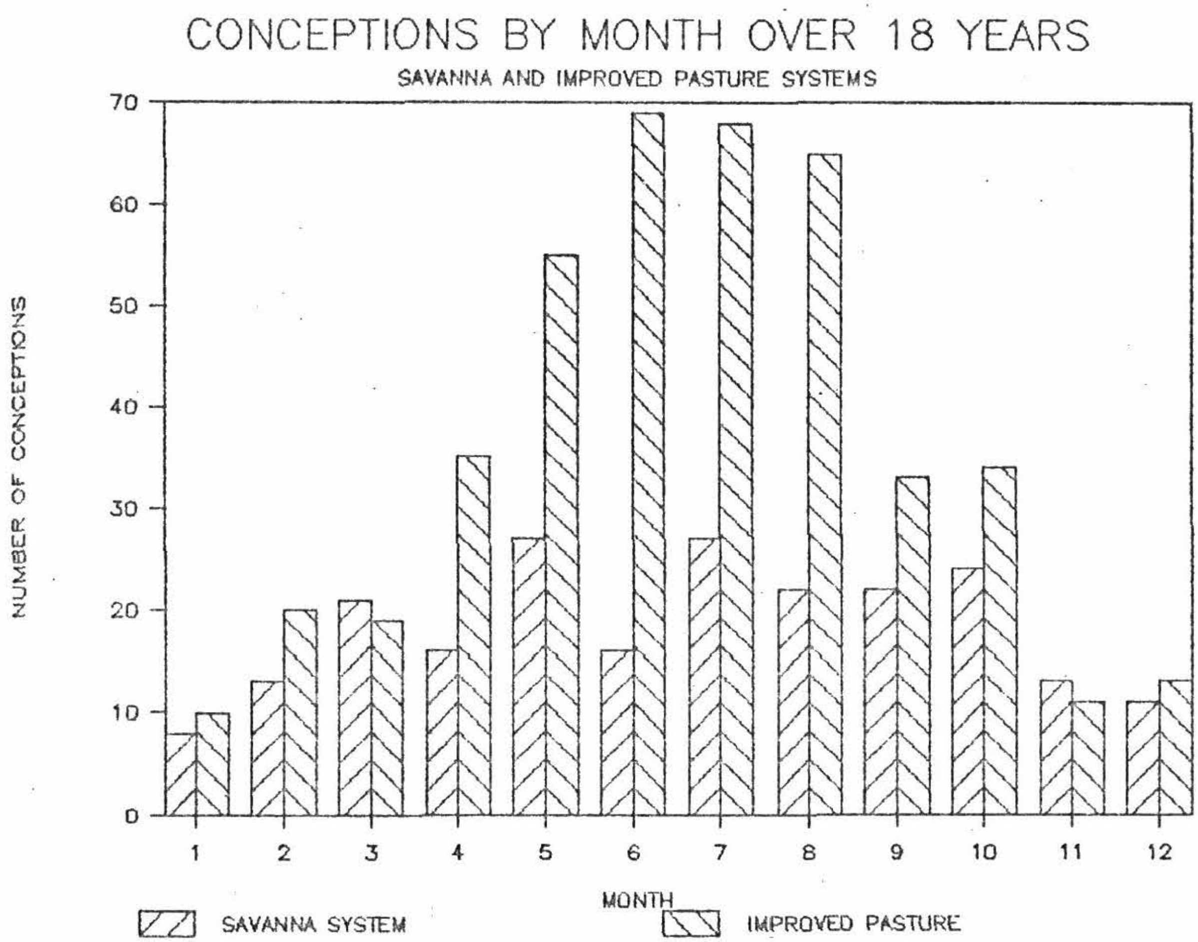
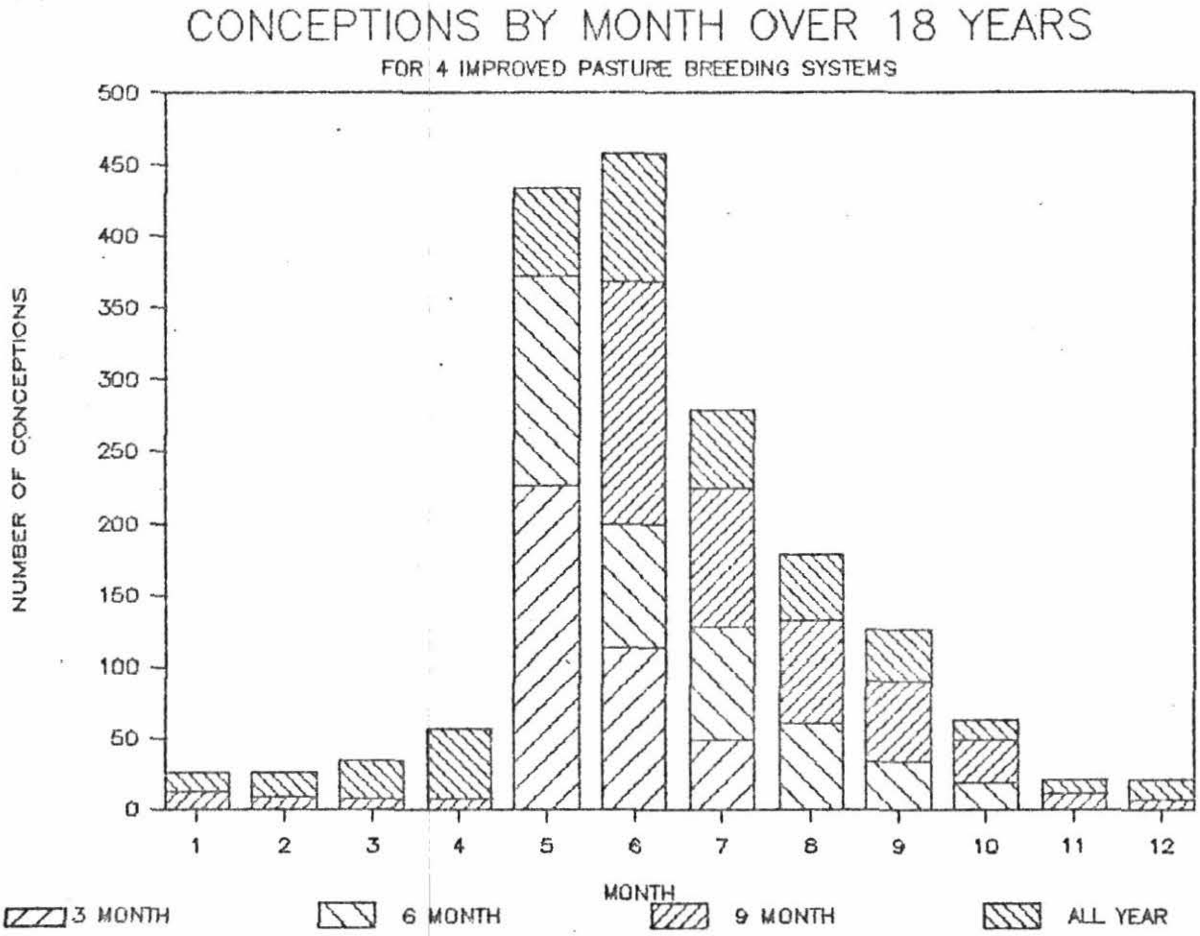

EFFECTS OF EARLY WEANING
ON NET REVENUE, SALES, WEANING WEIGHTS
OUTPUT UNITS
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
−10
−20
90+BUYING
90
150
210
270
AGE AT WEANING
NET REV $*1E5
SALES KG/AU/YR
WT KG

FIGURE 23



CONCEPTIONS BY MONTH OVER 18 YEARS
SAVANNA AND IMPROVED PASTURE SYSTEMS
NUMBER OF CONCEPTIONS
0
10
20
30
40
50
60
70
1
2
3
4
5
6
7
8
9
10
11
12
MONTH
SAVANNA SYSTEM
IMPROVED PASTURE

FIGURE 24


CONCEPTIONS BY MONTH OVER 18 YEARS
FOR 4 IMPROVED PASTURE BREEDING SYSTEMS
NUMBER OF CONCEPTIONS
500
450
400
350
300
250
200
150
100
50
0
1
2
3
4
5
6
7
8
9
10
11
12
MONTH
3 MONTH
6 MONTH
9 MONTH
ALL YEAR

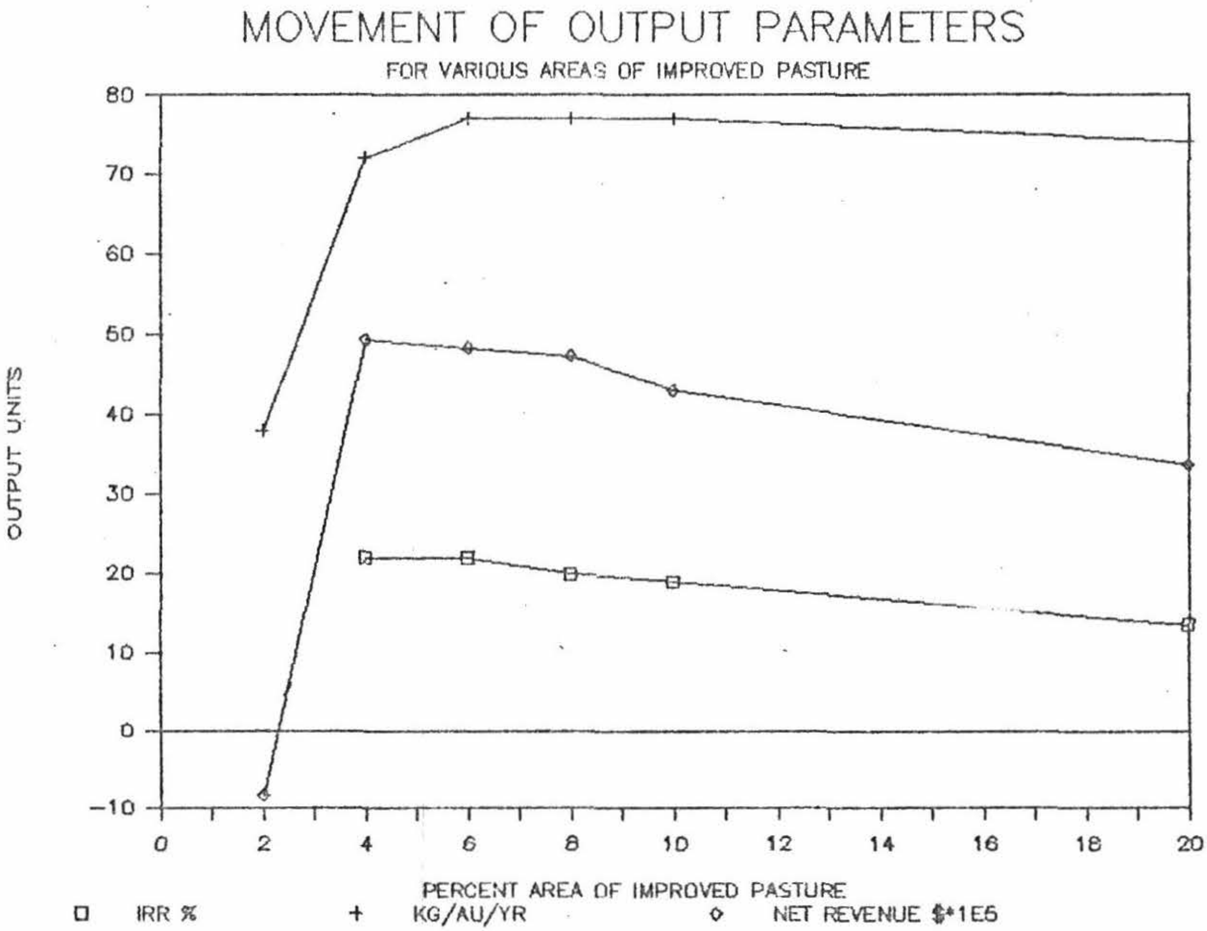
extent in later treatments by imposing stricter ration rules, with limited success only.

A further subset of treatments involved the feeding of improved pasture to various mobs by season, where the year was split into a dry period (Julian days 331 to 90), and an early and a late wet period (Julian days 91 to 210 and 211 to 330, respectively). The economic performance indicators are biased downwards, since the improved pasture was utilised at certain times of the year only. For most of the mobs, there were clear benefits to the grazing of improved pasture during the early wet season. This period appears to produce a subsequent flush of conceptions (Figure 23), a result probably due to the high relative quality of the forage at this time. A consequence of this flush is that certain numbers of calves are born during the dry season, and there would appear to be scope for avoiding this; this was investigated in the second series of runs. There are close similarities between the performance of the breeding herd mob and those animals under some physiological stress, those lactating or in pregnancy; this is not surprising, since at any time most of the herd is in one or both of these states. Conceptions by month for four breeding systems combined with improved pasture are shown in Figure 24.

The selection of heavier replacer animals had a beneficial effect, simply through allowing the system to operate more efficiently, whereas before, replacers were selected at random, provided that bodyweight exceeded 100kg. The selection of heavier replacers in fact implies a change in production system, to allow the keeping of followers for longer periods of time to reach higher liveweights.

The response of the model to changes in the area of improved pasture with more rigid ration rules is shown in Figure 25, for all mobs with constant herd numbers. The plateau of the production curve occurs at some 9 ha, or 6%, although in view of the problems with biomass feedback this is likely to have been underestimated. Basically, internal rates of return and production levels are reasonably stable over the range 6 to 20% of the 150 ha put into improved pasture, in that neither of their rates of decline are particularly big. The situation does not change when only pregnant and lactating animals have access to improved pasture.

FIGURE 25


MOVEMENT OF OUTPUT PARAMETERS
FOR VARIOUS AREAS OF IMPROVED PASTURE
OUTPUT UNITS
80
70
60
50
40
30
20
10
0
-10
0
2
4
6
8
10
12
14
16
18
20
PERCENT AREA OF IMPROVED PASTURE
IRR %
KG/AU/YR
NET REVENUE $*1E6

There is clear scope for dual-purpose systems, even with milk yield potentials of only 5 kg per day. Offtake rates of between 25 and 50% are both biologically and economically feasible (Figure 26); net revenue and the internal rate of return both exhibit a reasonably well-defined optimum, and such systems do a great deal to alleviate cash flow problems (Table 33). Two effects are worthy of note:

1) there is a benefit to seasonal production in the absence of seasonal mating, i.e., to the use of year-round mating when milk offtake ceases during the dry season.

2) there appears to be no benefit to milk offtake in conjunction with a seasonal mating policy.

Quite why this should be so is not immediately obvious, except that conception intervals are well in excess of 360 days, and as the breeding season gets shorter, so the conception interval increases. A possible explanation is that the quality (in overall terms) of the system is not good enough to support the notion of seasonal mating, since 360-day cycles are not being generated in response to the diet. There is, in energy terms, a clear production benefit, and in cash flow terms there are obvious felicities, to dual purpose systems. A number of these options were investigated during the second series of treatments.

The effects of price changes and other price-related parameters on the cash flow and subsequent profitability were investigated in a number of treatments. There are no obvious movements related to the value of the correlation coefficient between buying and selling cattle prices, except that it could be expected a *priori* that the variance of the economic parameters would tend to increase with a decreasing correlation coefficient; this was not actually borne out by the treatments concerned. Table 34 summarises the effects of 10 percent changes in costs and prices; these were all carried out for the same biological run, so although actual prices were still random variables, there is a certain amount of bias to consider. The responses are thus masked somewhat by the stochastic generation of buying price. This applies equally to a series of runs where price cycle parameters were changed (Table 35). The response of the internal rate of return and net revenue is rather muted, although replication is needed before definitive statements can be made about the

FIGURE 26

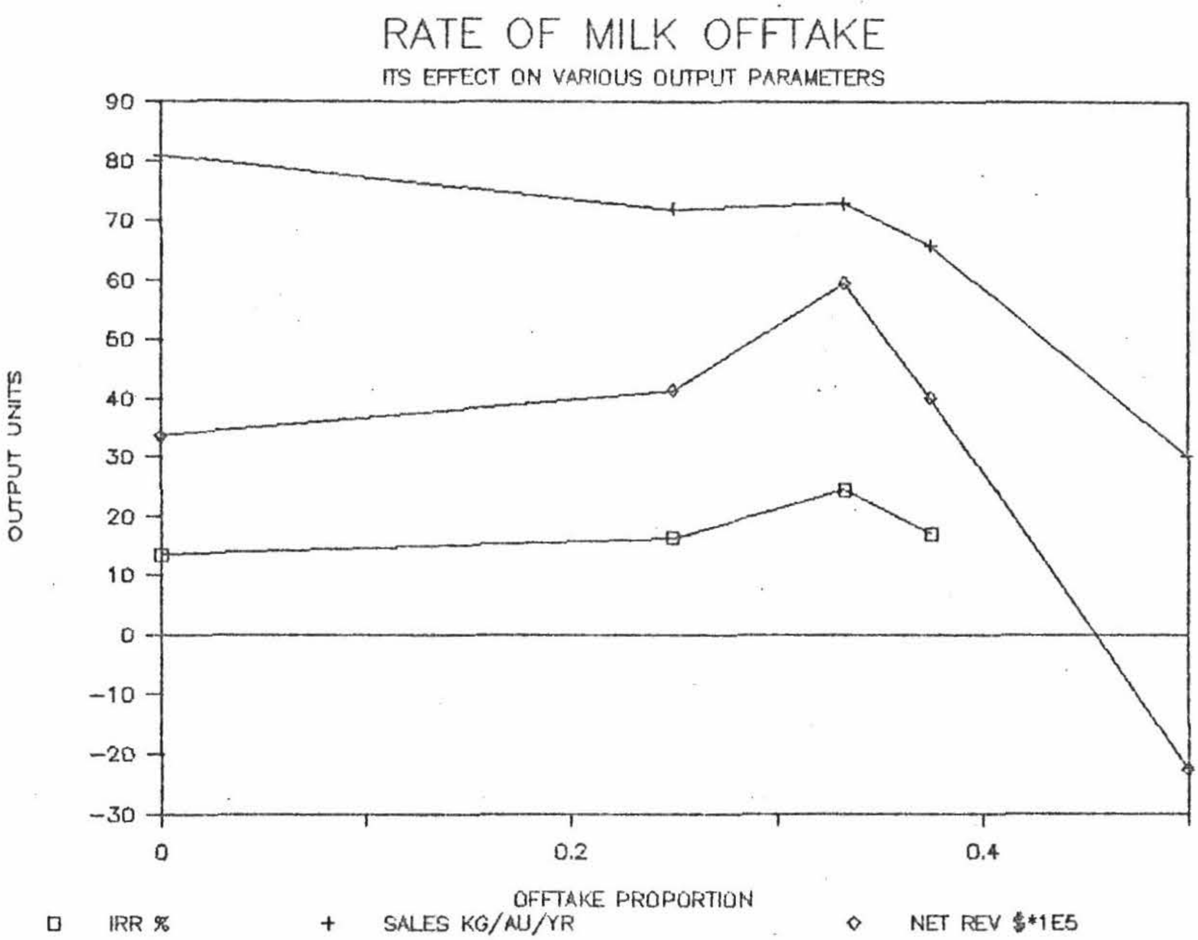

RATE OF MILK OFFTAKE
ITS EFFECT ON VARIOUS OUTPUT PARAMETERS
90
80
70
60
50
40
30
20
10
0
−10
−20
−30
OUTPUT UNITS
0
0.2
0.4
OFFTAKE PROPORTION
IRR %
SALES KG/AU/YR
NET REV $*1E5

TABLE 33 CASH FLOWS. NEGATIVE AND POSITIVE QUARTERS FOR EIGHTEEN YEARS FOR VARIOUS TREATMENTS

Pure Savanna

```
---+ --++ --++ --++ --++ --++ --++ --+- --+-
--+- --+- --++ --++ --++ --++ --++ --++ --++
```

Improved Pasture, Sell Followers at 150 kg

```
---- --++ --++ --++ --++ --++ --++ --++ --++
--++ --++ --++ --++ --++ --++ --++ --+- --++
```

Improved Pasture, Sell Followers at 250 kg

```
---- --+- --++ --++ --++ --++ --++ --++ --++
--+- --++ --++ --++ --++ --+- --++ --++ --++
```

Improved Pasture, Dual Purpose, Offtake 0.375

```
--++ ++++ ++++ +-++ ++++ ++++ +-++ -+++ -+++
+-++ ++++ ++++ +-++ ++++ ++++ --++ ++++ -+++
```

Dual Purpose, Offtake 0.375, Seasonal Breeding Months V - VII

```
---+ ++++ -+++ +-++ ++++ ++++ --++ -+++ -+++
--++ ++++ ++++ +-++ -+++ ++++ +-++ -+++ ++++
```

TABLE 34 MOVEMENT OF ECONOMIC PARAMETERS IN RESPONSE TO TEN PERCENT CHANGES IN COSTS AND PRICES - STOCHASTIC RESPONSE

	PERCENTAGE CHANGE	
	Net Revenue ($Millions)	Internal Rate of Return
Milk Price		
- 10%	-4	-5
0%	(5.53)	(22.8)
+ 10%	+9	+8
Starting Prices		
- 10%	-9	-1
0%	(5.85)	(23.3)
+ 10%	+3	+13
Variable Costs		
- 10%	+3	+3
0%	(5.85)	(23.3)
+ 10%	+1	+0
Fixed Costs		
- 10%	+4	+4
0%	(5.85)	(23.3)
+ 10%	+1	+1

TABLE 35 MOVEMENT OF NET REVENUE (NR, $MILLIONS) AND THE INTERNAL RATE OF RETURN (IRR, %) IN RESPONSE TO CHANGES IN THE LENGTH AND THE AMPLITUDE OF THE PRICE CYCLE - STOCHASTIC RESPONSE

Price Cycle Length, Years	Cos N_1	Cos N_2	AMPLITUDE X 1.0 NR	X 1.0 IRR	X 0.5 NR	X 0.5 IRR	X 1.5 NR	X 1.5 IRR
6	1.00	1.00	5.49	21.7	5.53	23.0	5.57	21.2
5	1.00	-0.81	5.21	22.0	5.36	22.9	5.29	21.2
8	1.00	0.00	5.39	22.0	5.45	22.9	5.42	21.2
14	1.00	-0.22	5.47	22.7	5.49	23.3	5.56	22.1

N_1 = angle at time t=0

N_2 = angle at end of run

importance of price cycles on long-term economic performance

Finally, Figure 27 shows the effects of increases in digestibility on economic parameter output; the marginal effect of small increases in digestibility on economic output is comparable with their effect on biological output (see Figure 9), and note diminishing marginal returns to overall (grass and legume) digestibility increases.

4.3 Second Series

The second series of simulations involved sixteen treatments of twenty-three replicates each, twenty-one of which were used in subsequent analysis. Treatments ranged from a pure savanna system to dual-purpose systems (Table 36). For each, twenty replicates were carried out; the final three included the effects of pasture failure in various forms, thus affecting the economic performance (primarily) of these systems. These three special replicates included resowing in year 2, resowing in year 10, and resowing in years 2 and 10. For the year(s) prior to resowing, all mobs were grazing savanna. Cash flow analyses were carried out with 100 and 50 per cent of the sowing costs being incurred in the years of resowing. In deciding which of these replicates to use to define the lower left-hand end of the outcome distributions, a number of factors was considered. First, even where only 50 percent of sowing costs were incurred in the year of resowing, the stochastic nature of the model meant that the economic performance of such systems was often no worse than systems where all the sowing costs were re-incurred. Second, the effects of re-sowing in year 10 only were usually much less devastating than those arising from resowing in year 2 or years 2 and 10. Thus for all treatments, the twenty-first replicate for subsequent decision analysis involved resowing in year 2, incurring all pasture establishment costs again. This was felt to be a reasonable compromise, in the circumstances. For the savanna treatment, T1, one more "normal" replicate was carried out, so that this treatment would conform with the 20-linear-segment cumulative probability functions of the other 15 treatments.

Production parameters for each treatment are shown in Tables 37 and 38, as means and coefficients of variation, respectively, and the cumulative

FIGURE 27

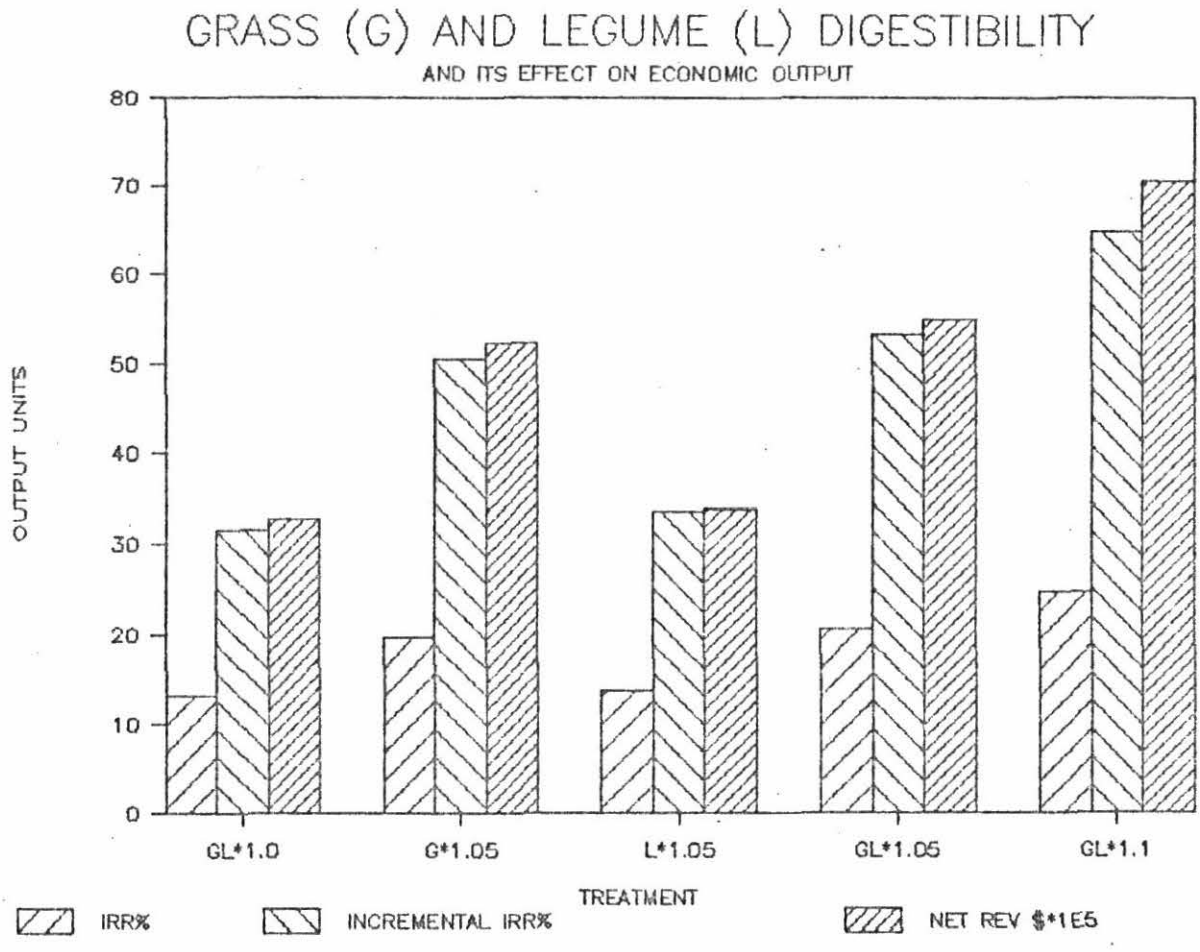

GRASS (G) AND LEGUME (L) DIGESTIBILITY
AND ITS EFFECT ON ECONOMIC OUTPUT
OUTPUT UNITS
0
10
20
30
40
50
60
70
80
GL*1.0
G*1.05
L*1.05
GL*1.05
GL*1.1
TREATMENT
IRR%
INCREMENTAL IRR%
NET REV $*1E5

TABLE 36 SECOND SERIES TREATMENT LIST

T1	150 ha pure savanna system
2	30 ha improved pasture, all mobs
3	30 ha IP, all mobs, culling after 8 yrs or 4 negative pregnancy tests
4	30 ha IP for all, breeding season months v-x, and milk offtake of 0.333
5	30 ha IP for all, breeding season months v-vii, and milk offtake of 0.333
6	30 ha IP for all, breeding season months viii-x, and milk offtake of 0.333
7	9 ha IP fed to breeding herd only
8	30 ha IP for all, heavy culling and followers sold at 200kg
9	30 ha IP for all, early weaning @ 210 days, followers sold at 150kg
10	30 ha IP to breeders, heavy culling, followers sold at 250 kg
11	30 ha IP to breeders (wet season) and followers(dry season), heavy culling, followers sold at 200kg
12	30 ha IP to all, milk offtake 0.333
13	30 ha IP to all, seasonal breeding months v-vii
14	30 ha IP to all, breeding season closed for months iii-v
15	30 ha IP to all, milk offtake 0.333 during wet season only
16	30 ha IP to all, heavy culling, milk offtake 0.333 during wet season, closed breeding season months iii-v

TABLE 37 SECOND SERIES RESULTS SUMMARY - MEANS OF TWENTY-ONE REPLICATES

Treat	NR	IRR	INC	AU	AGE	CON	ET	CP	WP	WT	DA	DC	SL	E2
1	0.51	3.0	-	32	4.01	626	40	47	31	133	11	12	34	39
2	3.32	13.5	26.0	42	3.05	389	74	83	61	148	8	3	81	70
3	3.63	14.4	36.9	41	3.04	396	71	84	58	148	5	3	86	68
4	5.66	22.5	68.0	41	3.17	385	68	83	56	126	8	9	74	63
5	4.42	19.2	59.8	38	3.25	419	67	73	50	128	8	9	69	58
6	5.49	22.3	62.3	40	3.24	407	62	76	53	124	8	8	68	63
7	2.76	12.1	40.0	42	3.08	372	69	87	64	148	7	3	60	66
8	5.88	17.6	33.6	55	3.07	391	60	93	64	148	7	3	83	73
9	3.94	14.5	32.5	45	3.05	385	66	85	64	131	7	3	79	70
10	6.45	15.7	26.0	89	3.99	386	51	96	63	150	7	3	56	41
11	6.38	21.1	47.6	61	3.44	398	50	89	60	142	6	3	69	59
12	5.96	24.5	65.8	40	3.06	382	67	85	55	129	7	13	73	64
13	2.27	9.6	24.3	39	3.26	431	74	72	53	148	7	3	81	64
14	4.06	14.9	33.8	43	3.14	389	71	84	61	144	7	3	85	71
15	5.82	23.2	64.7	41	3.07	388	71	84	59	133	7	6	79	68
16	6.61	25.5	65.8	42	3.12	390	65	85	56	131	5	6	85	65

Key : NR net revenue, $millions
IRR internal rate of return, %
INC incremental IRR compared with pure savanna system
AU average number of animal units at any time
AGE age at first parturition, years
CON conception interval, days
ET production, kg/AU/yr
CP conception percentage
WP weaning percentage
WT weaning weight, kg
DA adult mortality, %
DC calf mortality, %
SL sales, kg/AU/yr
E2 production, kg/AU/yr, using true average animal numbers

TABLE 38 SECOND SERIES RESULTS SUMMARY - COEFFICIENTS OF VARIATION FOR TWENTY-ONE REPLICATES

Treat	NR	IRR	INC	AU	AGE	CON	ET	CP	WP	WT	DA	DC	SL	E2
1	27	27	-	4	1	3	3	2	3	1	7	22	7	2
2	12	16	54	2	2	1	2	3	3	1	11	30	3	2
3	8	10	24	1	1	1	2	2	3	1	16	36	3	2
4	4	9	27	1	2	1	2	2	3	1	11	9	3	2
5	9	12	27	2	2	2	2	4	4	1	13	18	5	2
6	9	14	41	2	1	1	3	2	4	1	15	18	5	2
7	11	12	29	1	1	1	2	2	3	1	10	22	5	2
8	7	9	16	1	1	1	2	2	2	1	18	24	3	2
9	10	13	21	2	1	1	2	3	4	1	12	27	4	2
10	5	8	12	1	1	1	1	1	2	1	13	27	3	1
11	4	6	48	1	1	1	1	2	2	1	14	30	2	1
12	6	13	56	1	1	1	3	3	3	1	10	12	4	2
13	20	25	54	1	3	2	3	3	3	1	10	36	4	3
14	7	9	19	1	1	1	2	3	3	1	12	34	3	2
15	7	10	30	1	1	1	2	3	3	1	16	21	4	2
16	6	9	38	2	1	1	2	2	3	1	22	24	3	2

Key : NR net revenue, \$millions
IRR internal rate of return, %
INC incremental IRR compared with pure savanna system
AU average number of animal units at any time
AGE age at first parturition, years
CON conception interval, days ET production, kg/AU/yr
CP conception percentage
WP weaning percentage
WT weaning weight, kg
DA adult mortality, %
DC calf mortality, %
SL sales, kg/AU/yr
E2 production, kg/AU/yr, using true average animal numbers

distribution functions for four output parameters (internal rate of return, net revenue, production per animal unit per year and sales per animal unit per year) for treatments T1 (savanna system), T2 (standard improved pasture system), and T16 (a dual-purpose system with various enhancements), are shown in the Appendix, Figures A3, A4 and A5. Similarly, cashflows for selected treatments are presented in Figures A6, A7 and A8; these compare improved pasture systems (treatments T2, T10 and T12 and T15) with the savanna system, in terms of the cumulative cashflow, the yearly cashflow, and the average monthly cashflow. Raw data output for all sixteen treatments may be found appended in Table A1.

General Results

Treatments were devised in response to the results of previous treatments, so that the tendency exists for the latter treatments to be somewhat more productive than the earlier ones. A number of general observations may be made.

1. The effect of stricter culling is marked, and this practice was often incorporated into later treatments, where it can usually be supposed to have had a beneficial marginal effect through herd rejuvenation.

2. The effect of seasonal mating, as three- or six-month periods, was usually detrimental in comparison with the corresponding pure (all-year breeding) treatment. The reason is clearly shown in treatment T13, where the conception interval, and hence the reproductive parameters, are lower than in treatment T2. As noted above, seasonal breeding will tend to be successful in situations where conception intervals are less than 360 days; this was not in fact achieved in any of the sixteen treatments. It may reasonably be concluded that the plane of nutrition was not high enough to maintain short breeding seasons.

3. If, however, the breeding season is open for nine months of the year, and closed when calves would be born during the dry season, thus putting energetic pressure on their dams at a critical time of the year (T14), then all production parameters increase.

4. The one early weaning treatment, T9, where weaning was carried out at 7 months, exhibited unequivocal effects. A four-day decrease in conception interval will not bring about great benefits to the production system, but the overall benefit seems to stem from the fact that more animals are kept in the followers herd at any one time, compared with later weaning. As shown in Section 4.2, the effects of decreasing weaning age much further soon become detrimental, so it may be concluded that the benefits of early weaning arise from things to which the model is simply not sensitive, or alternatively problems exist in the specification of the model.

5. Dual-purpose systems show increased returns over other types of system, generally in the absence of seasonal breeding (T4, T5 and T6), although when offtake is stopped for one third of the year during the dry season (T15), production and performance suffer hardly at all. When the nine-month breeding season is imposed on top of this system (T16), returns are the highest of the sixteen treatments. This is a logical effect, in energy terms: animals are not calving when most liable to stress, and energy that would have been used in milk production can go to build up body weight. In other words, there is an excess of energy during most of the wet season, when energy can safely be removed from the system for financial gain; such an excess does not exist during the dry season. Lower weaning weights are more than made up for by the income derived from milk offtake, and the longterm stability of the herd, moreover, is not disturbed thereby.

6. For treatments where the followers herd is kept until weights of 200 or 250 kg (T8, T10, T11), much of the economic benefit would appear to come from herd capitalisation at year 18 (compare T10, 89 animal units, on average, at any time, with the 42 animal units usually present in Treatment T2, for example). Growth is comparatively slow, reflected in a low level of sales per year. It is the case for treatments T10 and T11 in particular, that the improved pasture is being seriously overloaded; these levels of production are thus substantially overestimated.

All treatments are ranked in Table 39 according to four output parameters, to which a fifth is added - the average number of quarter-years where a negative cash flow is experienced. This ranges from 2.3 for the pure savanna system to 0.6 for the all-year dual-purpose production system.

TABLE 39 SUMMARY OF OUTPUT CRITERIA FOR THE SIXTEEN TREATMENTS: MEANS AND RANKINGS

Treat	Internal Rate of Return, %	Net Revenue $Millions	Production kg/AU/yr	Sales kg/AU/yr	Average Number of Negative Quarters per Year in the Cashflow
T1	3.0 (16)	0.51 (16)	39.8 (16)	33.7 (16)	2.3 (12)
T2	13.3 (13)	3.32 (13)	73.6 (2)	80.5 (6)	2.2 (11)
T3	14.3 (12)	3.63 (12)	70.7 (5)	85.9 (1)	2.1 (7)
T4	22.5 (4)	5.66 (7)	68.4 (7)	73.6 (9)	1.0 (3)
T5	18.8 (7)	4.37 (9)	67.2 (8)	68.4 (12)	0.8 (2)
T6	22.3 (5)	5.49 (8)	61.6 (12)	67.9 (13)	1.4 (6)
T7	12.1 (14)	2.74 (14)	68.6 (6)	60.0 (14)	2.1 (8)
T8	17.5 (8)	5.88 (5)	60.0 (13)	82.9 (4)	2.1 (9)
T9	14.5 (11)	3.94 (11)	66.2 (10)	78.7 (8)	2.6 (16)
T10	15.7 (9)	6.45 (2)	51.1 (14)	56.5 (15)	2.3 (13)
T11	21.1 (6)	6.38 (3)	50.1 (15)	68.6 (11)	2.3 (14)
T12	24.5 (2)	5.96 (4)	66.7 (9)	73.3 (10)	0.6 (1)
T13	9.6 (15)	2.27 (15)	74.3 (1)	81.0 (5)	2.1 (10)
T14	14.9 (10)	4.06 (10)	71.0 (4)	84.7 (3)	2.5 (15)
T15	23.2 (3)	5.82 (6)	71.1 (3)	79.5 (7)	1.3 (4)
T16	25.5 (1)	6.61 (1)	65.3 (11)	85.4 (2)	1.3 (5)

Consideration of Risk

All treatments were analysed using three methods with regard to the incorporation of risk: mean-variance (EV) analysis, stochastic dominance (SD) analysis, and explicit utility analysis to find the most suitable option for individuals with different levels of aversion to risk.

The advantages of EV and SD analysis derive from the fact that it is not necessary to impute a utility function to any particular individual, although there are a number of restrictions inherent in these analyses which places a limit on what can be said about how decision makers would choose between risky prospects (Table 40). Behaviourally, EV analysis implies a quadratic utility function, in addition to the non-behavioural assumption of (essentially) normally-distributed prospects. Anderson *et al.* (1977) note that this form is amenable to all sorts of algebraic manipulation, but from a theoretical viewpoint it is not ideal.

In fact, all distributions passed the Lilliefors test for normality at the 5% level (Table 41, and see Figure A2 in the Appendix for normality plots for treatment T1), a fact which is somewhat surprising in view of the ad-hoc way the 0% fractile was defined. However, with a sample size of 21, the difference between the empirical and the normal cumulative probability functions has to exceed 0.19 before the null hypothesis of normality can be rejected (Conover, 1980). EV analysis has the great virtue of simplicity and ease of applicability, even though the EV-efficient sets, i.e. that group of prospects which cannot be made any smaller by application of the ordering rule, tend to be large (Table 42).

By comparison, stochastic dominance analysis is more complex, and while no assumptions of normality are made, the restrictions which cumulatively come into force about the utility function and its derivatives may well not apply in particular circumstances. As with EV analysis, if, after the application of three successively more restrictive ordering rules, there is still more than one efficient prospect, then there is little more that can be done except to take the next step and impute some sort of utility function to the individual. As in Table 40, the first ordering rule

TABLE 40 MEAN-VARIANCE (EV) AND STOCHASTIC DOMINANCE (SD) ORDERING RULES

EV	SD
f(x) dominates g(x) if	
$E(f) >= E(g)$ and $Var(f) < Var(g)$ or $Var(f) <= Var(g)$ and $E(f) > E(g)$	FSD: $F_1(x) <= G_1(x)$ for all x with at least one strong inequality SSD: $F_2(x) <= G_2(x)$ for all x with at least one strong inequality TSD: $F_3(x) <= G_3(x)$ for all x with at least one strong inequality, and $F_2(x_{max}) <= G_2(x_{max})$
distribution of f(x)	
can be fully described by two parameters which are independent functions of the mean and variance (i.e., normal, essentially)	any
type of utility function U(x)	
quadratic	FSD: $U'(x) > 0$ SSD: $U'(x) > 0$, $U''(x) < 0$ TSD: $U'(x) > 0$, $U''(x) < 0$, $U'''(x) < 0$

Note: f(x) refers to the density function for random variable x; $F_1(.)$is the cumulative probability function, $F_2(.)$the integral of $F_1(.)$ and $F_3(.)$ the integral of F2. E(.) is the expected value, Var(.) the variance of the variable. U prime refers to respective derivatives of U(x). FSD, SSD an TSD refer to first-, second- and third-degree stochastic dominance.

TABLE 41 LILLIEFORS TEST FOR NORMALITY: THE MAXIMUM VERTICAL DISTANCE BETWEEN THE EMPIRICAL AND NORMAL CUMULATIVE PROBABILITY FUNCTION. FOR A SAMPLE SIZE OF 21, p(0.05) = 0.187

TREATMENT	OUTPUT DISTRIBUTION			
	IRR	Net Revenue	Sales kg/Au/yr	Production kg/AU/yr
T1	0.106	0.121	0.164	0.126
T2	0.128	0.084	0.100	0.062
T3	0.151	0.080	0.088	0.145
T4	0.096	0.112	0.145	0.087
T5	0.145	0.145	0.150	0.065
T6	0.120	0.127	0.092	0.110
T7	0.127	0.163	0.070	0.152
T8	0.135	0.121	0.089	0.113
T9	0.161	0.129	0.080	0.126
T10	0.127	0.061	0.150	0.059
T11	0.103	0.136	0.086	0.131
T12	0.097	0.095	0.073	0.075
T13	0.115	0.147	0.086	0.072
T14	0.082	0.135	0.118	0.168
T15	0.138	0.092	0.075	0.116
T16	0.140	0.099	0.085	0.130

TABLE 42 RISK ANALYSIS: MEMBERS OF THE MEAN-VARIANCE (EV) AND STOCHASTIC DOMINANCE (SD) EFFICIENT SETS

Treatment	Internal Rate of Return, %		Net Revenue $Millions		Production kg/AU/yr		Sales kg/AU/yr	
	EV	SD	EV	SD	EV	SD	EV	SD
T1	+		+					
T2					+	FST		
T3							+	FS
T4	+		+				+	
T5								
T6								
T7								
T8					+			
T9					+			
T10	+		+	FST	+		+	
T11	+		+	FST	+		+	
T12		F						
T13					+	FST		
T14							+	
T15					+			
T16	+	FS	+	FST				F

Note: + indicates member of the EV-efficient set.
F, S, and T denote member of the first, second and third stochastically-efficient sets.

requires that the decision maker prefers more of something to less (profit, for example), the second that the decision maker is averse to risk, and the third that decision makers are decreasingly averse to risk as wealth increases.

Figure 28 shows all cumulative probability functions for the output parameters. Efficient sets, in an EV sense, are marked in Figure 29. Stochastic Dominance analysis was carried out using the FORTRAN subroutine in Anderson et *al.* (1977). For the internal rate of return and sales criteria, it was possible to identify the utility maximising prospect by virtue of successive rules reducing the efficient set to just one member, but for net revenue and production per year, this was not possible. Note that all SD-efficient prospects are members of the EV-efficient set also, but that SD analysis is more parsimonious in including efficient prospects.

The efficiency rules can say no more about the final choice of the hypothetical decision maker among the sixteen treatments using these output criteria. To take the analysis to its logical conclusion, coefficients of risk aversion may be imputed using typical values obtained in other studies, for example, Binswanger (1980) in India, where lotteries were played for real money, and from New Zealand (Thornton, 1985), where risk attitudes were elicited using the standard card-and-counter method for a small number of producers. Most decision makers appeared to exhibit moderate-to-severe levels of risk aversion, either as subsistence farmers in India or as comparatively wealthy New Zealand cereal growers.

The sixteen treatments were analysed for various risk attitudes in the following manner. The utility function used (Binswanger, 1980) was

$$U(x) = (1-s)x^{1-s}.$$

This function implies independence of scale of the enterprise under consideration, among other things. The parameter s is the coefficient of partial risk aversion (CPRA), and is constant here. It can be shown that the certainty equivalent of any risky prospect could be calculated to be approximately

$$CE = m - 0.5 * Var[x] * (s/m) + (1/6) * M_3[x] * ((s^2+2)/m^2),$$

where m, Var[x] and $M_3[x]$ are the mean and the second and third moment about the mean (Thornton, 1985). Thus for a given value of the CPRA, the

FIGURE 28 CUMULATIVE PROBABILITY CURVES I
INTERNAL RATE OF RETURN

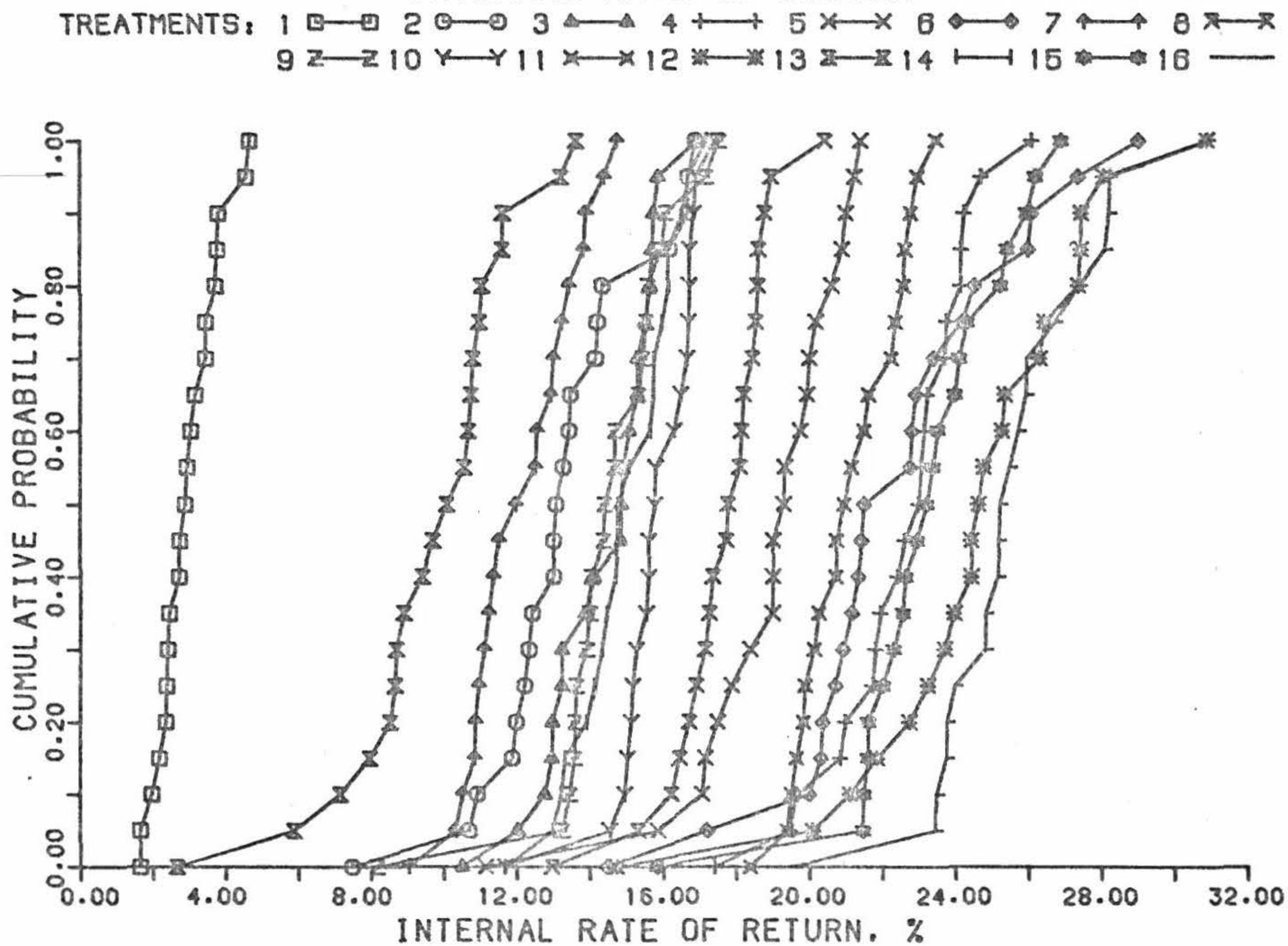


FIGURE 28 CUMULATIVE PROBABILITY CURVES II
NET REVENUE

TREATMENTS: 1 2 3 4 5 6 7 8
9 10 11 12 13 14 15 16

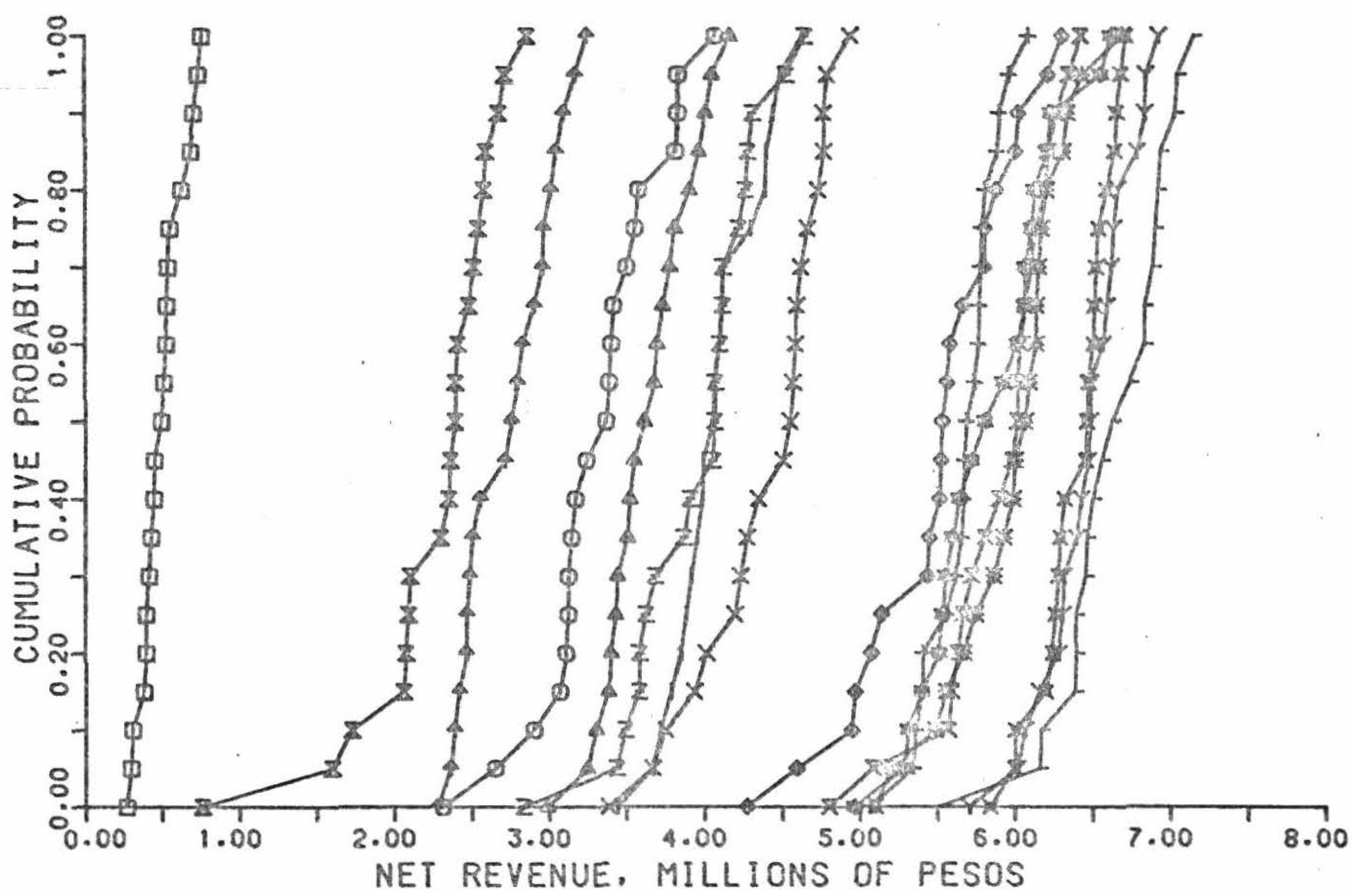


FIGURE 28 CUMULATIVE PROBABILITY CURVES III
ANIMAL PRODUCTION

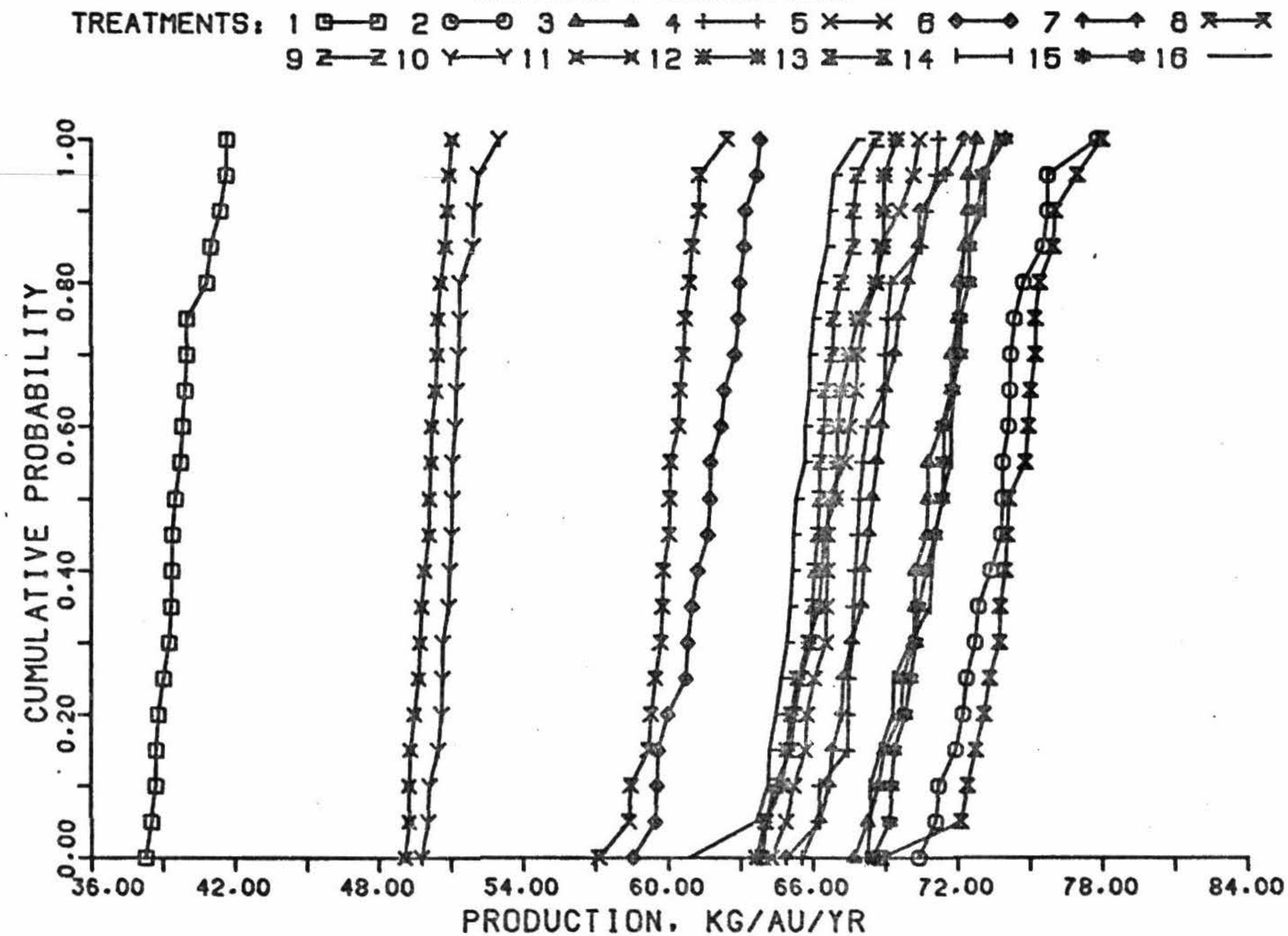


FIGURE 28 CUMULATIVE PROBABILITY CURVES IV
HERD SALES PER YEAR

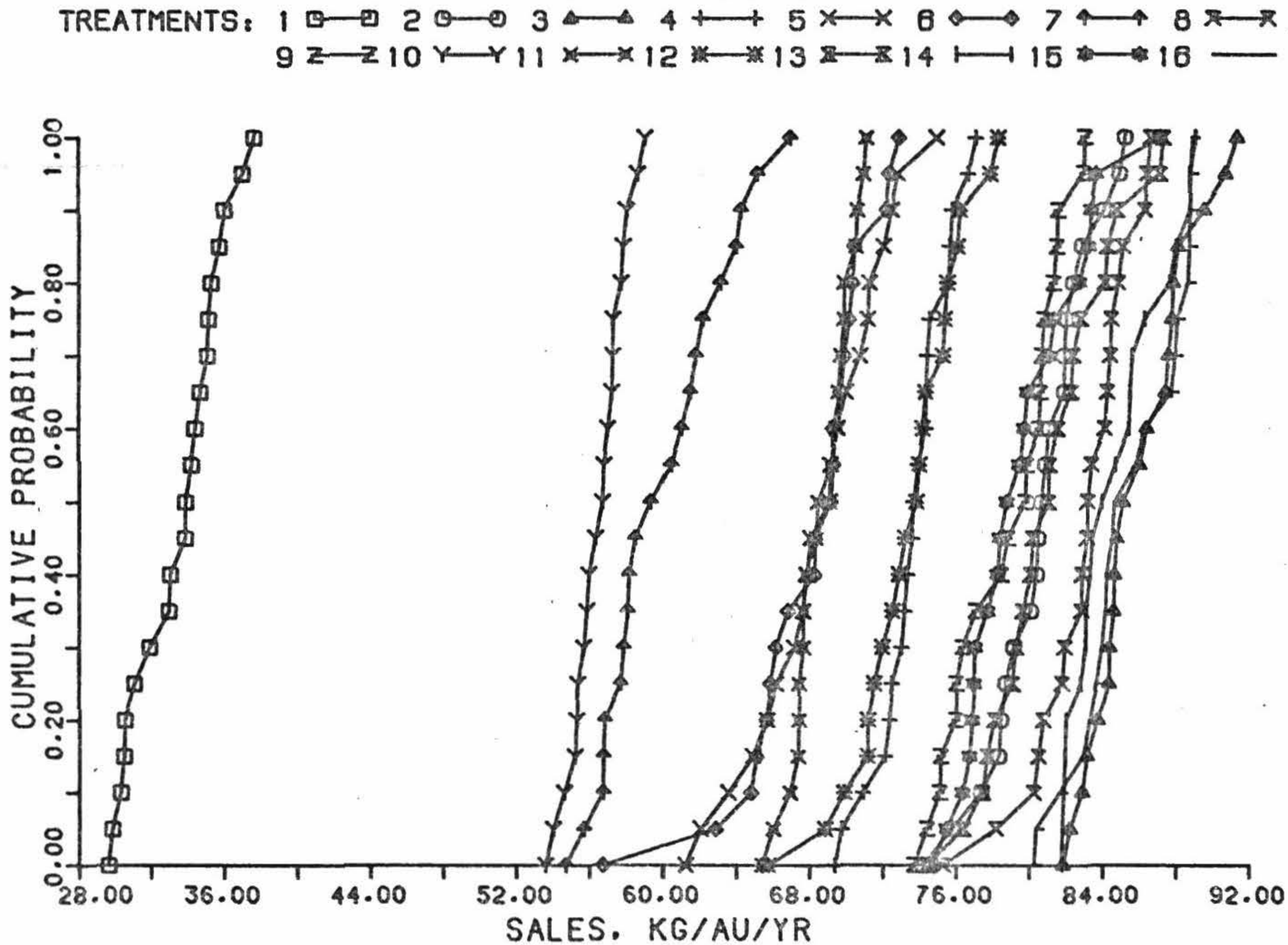
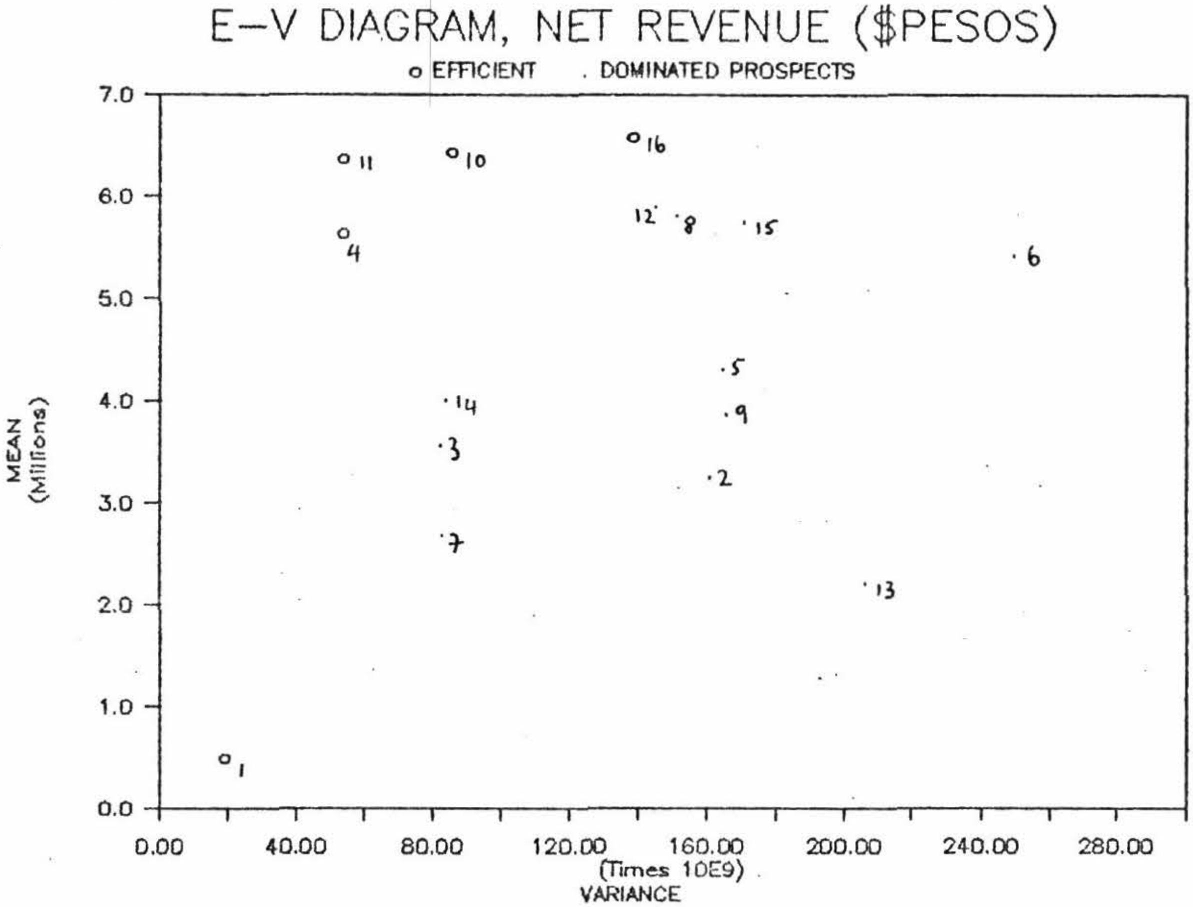
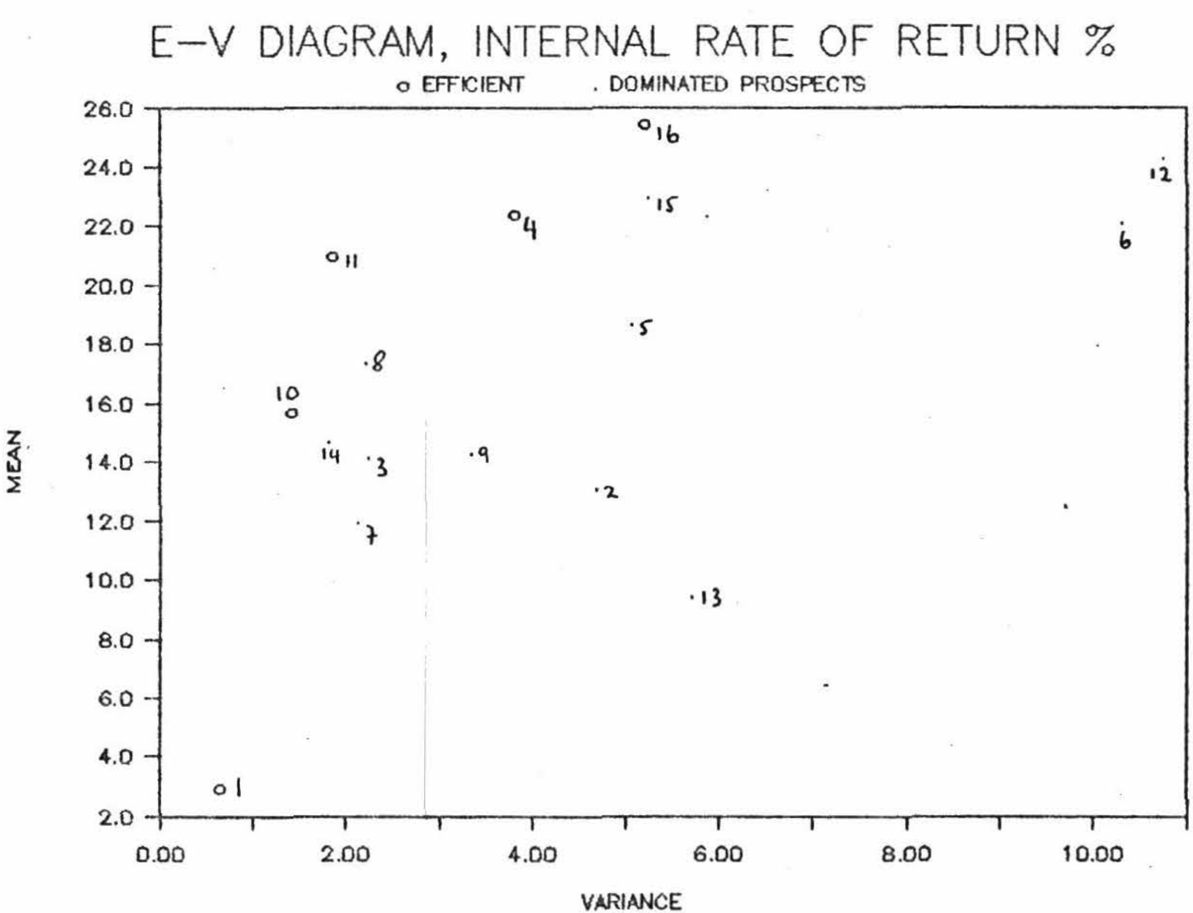
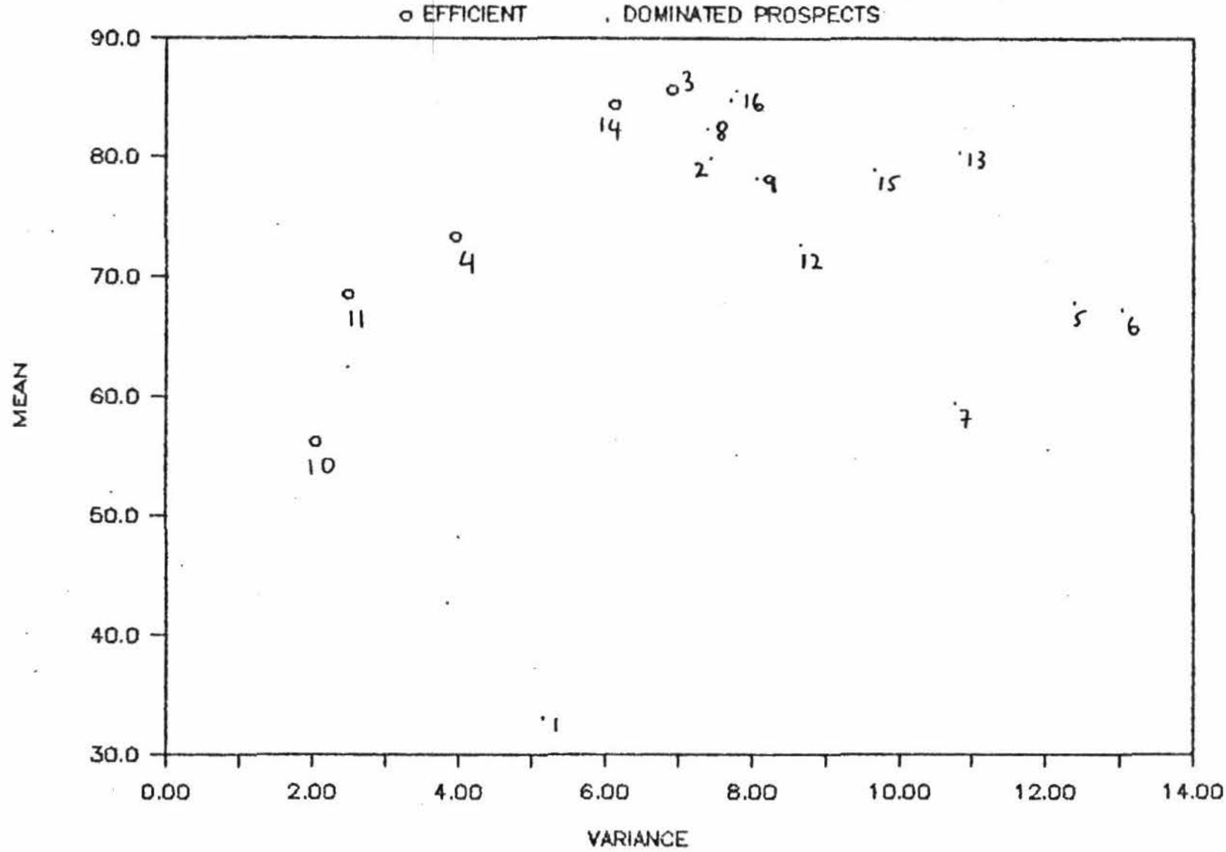


FIGURE 29

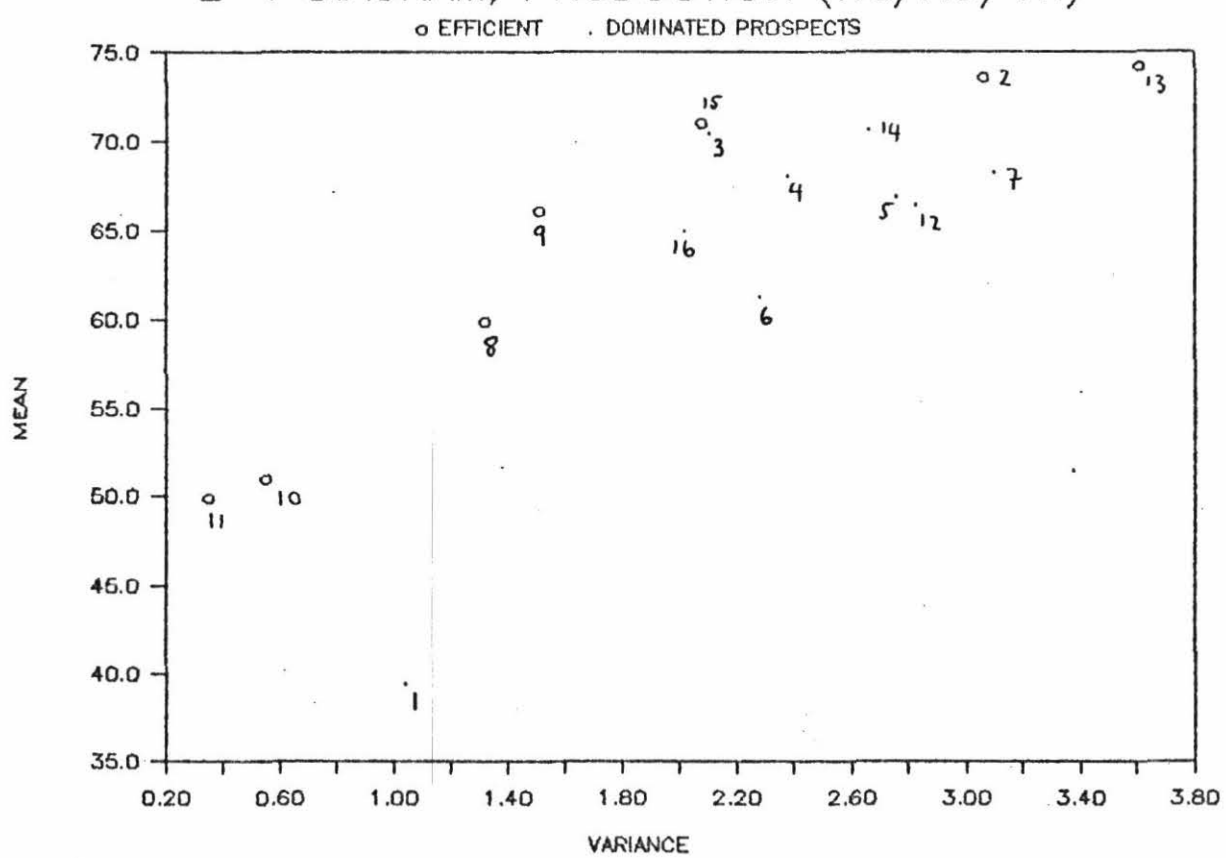

E—V DIAGRAM, NET REVENUE ($PESOS)
o EFFICIENT . DOMINATED PROSPECTS
MEAN (Millions)
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0.00
40.00
80.00
120.00
160.00
200.00
240.00
280.00
(Times 10E9)
VARIANCE
1
4
11
10
16
12
8
15
6
5
14
9
3
2
7
13


E—V DIAGRAM, INTERNAL RATE OF RETURN %
o EFFICIENT . DOMINATED PROSPECTS
MEAN
26.0
24.0
22.0
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.00
2.00
4.00
6.00
8.00
10.00
VARIANCE
16
12
15
4
6
11
5
8
10
14
3
9
2
7
13
1

E–V DIAGRAM, SALES (KG/AU/YR)



E–V DIAGRAM, PRODUCTION (KG/AU/YR)



certainty equivalent of all prospects may be calculated and these can then be ranked, since the maximisation of utility implies the maximisation of the certainty equivalent. If the prospect is riskless, then the second and third terms on the right-hand side of the equation disappear, and the certainty equivalent is equated with the expected value. If $f(x)$ is symmetrical, the third term disappears, as $M_3[x]$ is then equal to zero.

The range of values of the CPRA found by Binswanger in India varied widely, but approximately 80% of participants exhibited values in the range 0 to 1.74 (where positive values denote risk aversion and zero denotes risk neutrality). In the survey of Thornton, the range of attitudes extended from -0.70 (slight risk preference) to 4.78 (severe risk aversion, using Binswanger's classification). Prospects were analysed using a variety of values of the CPRA, and results are shown in Table 43 for two of these, a severely (CPRA = 7.5) and a mildly (CPRA = 0.6) risk-averse individual. The effect of including risk in the analysis varied from treatment to treatment (Figure 30); for a treatment which exhibited a net revenue with a large variance, such as T13, for example, the certainty equivalent changed markedly, while for other treatments, the change was small. The contribution brought about by including the third moment about the mean is not great; this was to be expected, since all prospects were normally distributed, statistically (see above), implying that all distributions are theoretically without skewness.

The results are unequivocal (Table 43); even for highly risk-averse decision makers, the utility-maximising option in each case coincides with the option which maximises the expected value of the prospect, i.e., the inclusion of risk at these levels brings about no changes in the ranking of the treatments. In fact, the ordering does not start to change until the CPRA reaches values of 15.0 or so, corresponding to extreme risk aversion. Apparently, the variability of the treatments is not great enough, and the cumulative functions do not overlap sufficiently, to bring about changes for what is presumably the vast majority of decision makers. In view of the discussion above of the variability to be expected from 18-year replicates, this is not especially surprising. It is quite possible that decision makers have a much shorter time horizon; as the variability increases with shorter time spans, so the influence of risk could reasonably be expected

FIGURE 30

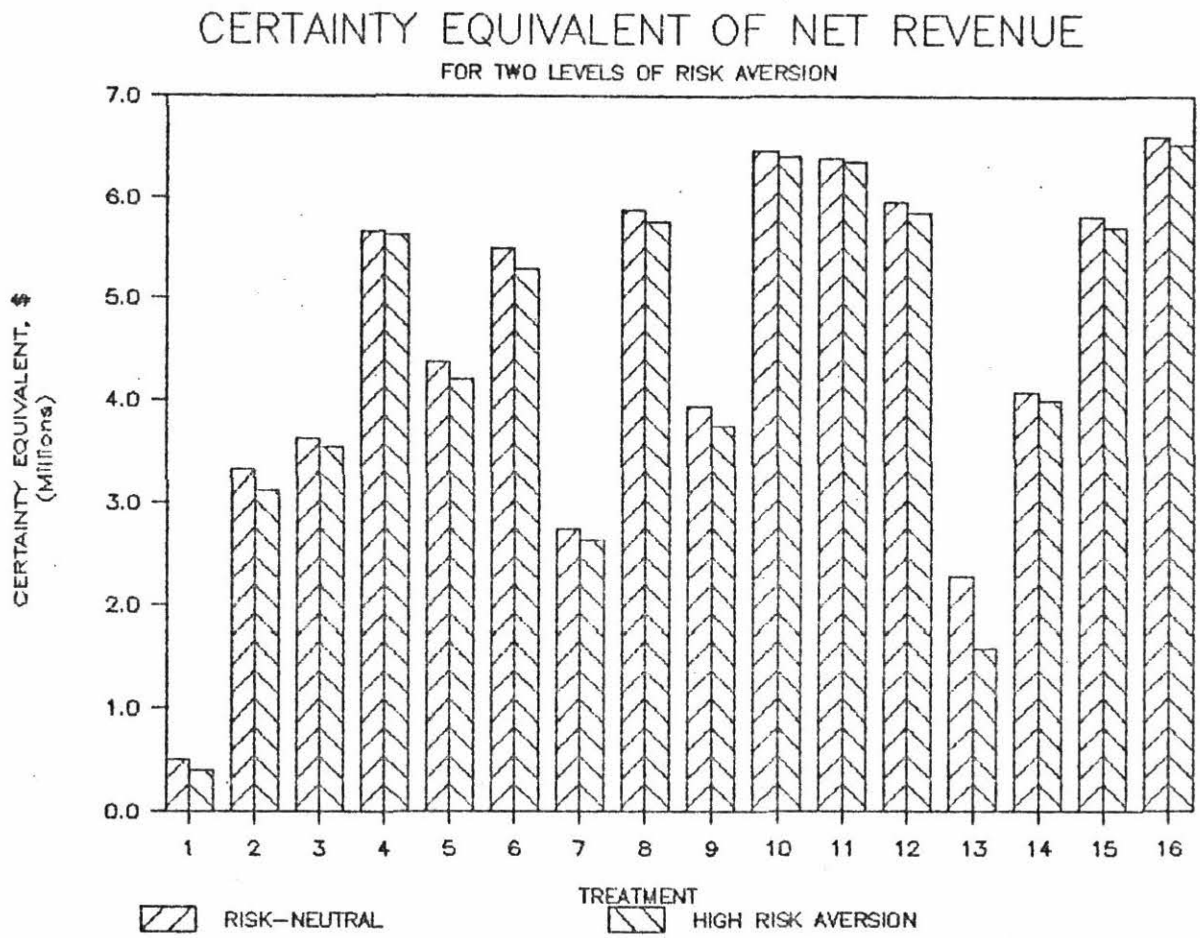

CERTAINTY EQUIVALENT OF NET REVENUE
FOR TWO LEVELS OF RISK AVERSION
CERTAINTY EQUIVALENT, $
(Millions)
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
TREATMENT
RISK-NEUTRAL
HIGH RISK AVERSION

TABLE 43 DECISION ANALYSIS : MAXIMISING OPTIONS FOR VARIOUS CRITERIA

Criteria	Treatments
Maximise Internal Rate of Return	16
- if mildly risk averse	16
- if severely risk averse	16
- EV-efficient set	1, 4, 10, 11, 16
- SD-efficient set	16
Maximise Net Revenue	16
- if mildly risk averse	16
- if severely risk averse	16
- EV-efficient set	1, 4, 10, 11, 16
- SD-efficient set	10, 11, 16
Maximise Sales per Annum	3
- if mildly risk averse	3
- if severely risk averse	3
- EV-efficient set	3, 4, 10, 11, 14
- SD-efficient set	3
Maximise Production per Annum	13
- if mildly risk averse	13
- if severely risk averse	13
- EV-efficient set	2, 8, 9, 10, 11, 13, 15
- SD-efficient set	2, 13

Mild and high levels of risk aversion correspond to values of the coefficient of partial risk aversion (CPRA) of 0.6 and 7.5, respectively.

to bring about some changes to the ordering of such prospects. The form of the utility function used is open to criticism (see Binswanger, 1981, for a critique), but it is unlikely that it is having much effect here, since exceptional levels of risk averseness are needed to produce changes in the ordering of the prospects.

Summary - Decision Analysis

1. It is noteworthy that the pure savanna system should be a member of the EV-efficient sets for the internal rate of return and net revenue criteria. There is a clear corollary to this: the observation that improved pasture technology carries with it some risk, not all of it attributable to the possibility of pasture failure. The history of agriculture, at least in Western Europe, can be interpreted as a progression whereby stability in production systems was introduced over time through the control of previously external factors; from this viewpoint the rise in yields *per se* takes a secondary role. In the tropics, the environment being generally more volatile and harsh, the importance that should be placed on attempting to dampen down damaging variability is even greater; if the model underlines anything, it is that increasing average levels of production tend to lead to increased levels of variability in the resultant system, and this brings its own dangers. It is likely, however, that at the present stage of model development, the full range of variability in all these systems is not adequately accounted for.

2. The absolute values of variance are not great, or, to put it another way, the SD-efficient sets are small. This can reasonably be attributed to the length of simulation with which the experimental program was concerned. It would be worth while to reduce the length of simulation and carry out similar analysis; it is highly likely that with only a five-year horizon, for example, system variability (and hence risk) would play a much more important part. Note that there is no contradiction between this and the previous paragraph; what is of importance is relative variability, and, ultimately, how it is perceived by the rancher. This implies some knowledge of the decision making process itself.

3. Consistently low-variability production systems are those where no

seasonal breeding or milk offtake is carried out. The <u>means</u> of such treatments (notably T10 and T11) are in all probability overestimated, for reasons already outlined. Dual-purpose systems with short breeding systems tend to carry high levels of variability. A 9-month breeding season removes some of this, and also has a beneficial effect in reducing variability when seasonal milk offtake is practised (i.e., the variance of T15 is greater than that for T16, for net revenue and sales, and these are approximately equal for the internal rate of return and production per annum criteria).

4. The influence of individual attitudes to risk is unimportant for this set of prospects. However, the following should be noted:

- the 16 treatments were not designed to be taken as a set of distinct, mutually exclusive risky prospects between which a decision maker would normally be required to choose; the spread of prospects is rather large.
- the negative results of the analysis, on the other hand, could be taken to mean that differences between treatments are, in a real sense, behaviourally as well as statistically significant.
- utility analysis does not include everything of importance in the decision making process; indeed, empirical evidence that decision makers act in such a way as to maximise their utility is conspicuous by its absence. The usual argument advanced in its defence is that it is better to include risk and variability in an explicit fashion than not at all, even if there are severe conceptual problems with the method used. It is hard not to concur with this view.

To these points can be added the problems caused by unknown levels of system variability discussed above.

5. CONCLUSIONS AND RECOMMENDATIONS

The Beef Model

Given the quantity of experimentation carried out with the beef model, it is perhaps inevitable that a number of problems should have surfaced. In retrospect, the validation work that was carried out represented the best approach in the circumstances - that of adjusting the relationships to model pure savanna systems, and then using pure improved pasture systems and adjusting parameters in a way so as not to affect simulation of the the lower energy system. It was probably not carried through far enough, in the sense that rather better quality forage should have been used.

Two problem areas in particular can be identified. First, death rates should be adjusted to take account of the (presumably) rigorous culling that must be carried out in the Llanos to preserve observed herd age distributions. Second, it is hard to resist the conclusion that the conception probability curve is rather too lenient too quickly as the animal's body condition improves. It is quite possible that the response of the model to early weaning on medium-quality diets is masked by the present conception probability functions. One further easily-rectified problem is that relating to the calculation of weaning percentages. Allowance should be made for conceptions still in progress at the end of the run, and the sometimes large numbers of orphans would presumably disappear in response to less harsh breeder death rates. Comparatively little work was done with proper fattening systems, i.e. including steers in the followers herd until weights in excess of 400kg were reached. The principal problem was that of overloading the sown pastures and operating under unrealistic stocking rates. In fact, the few runs that were carried out suggested that such systems, for the quality of forage used, yielded medium returns only. The ability of the model to cope with older male animals should probably be assessed, therefore.

The sensitivity of the model to different levels of digestibility places an unfortunate burden on the provision of accurate forage quality data. Little has been said about the effects of protein on performance; this has been due primarily to the observation that energy is the over-riding limiting resource in savanna animal production systems. The effects of protein levels of less than 6 percent could usefully be investigated (in the model, through their effect on energy intake), since such levels may exist during the dry season or in old pastures for some species. This leads directly to the consideration that the model is incapable of responding to things which do not affect the energy status of the herd in a more or less direct fashion. Such a sensitivity is not misplaced, as a first approximation. However, given current levels of modelling expertise and understanding of these systems, it is unknown if models that have to operate at rather high levels of aggregation and include other flows of importance could be made to operate satisfactorily at the present time.

Pasture Model

The pasture model constitutes an attempt to represent the animal-pasture interface in as simple a way as possible while trying to preserve its usefulness. It remains to be seen, of course, whether this formulation exhibits the virtues of satisfactory predictive power coupled with reasonable generality. The advantage of modelling tropical, as opposed to temperate, animal-pasture systems is that production is less intensive; this has ramifications for the validity of the heroic assumption that animal effects on the pasture are limited to its removal.

A number of problems can be envisioned with the present model formulation. Among the most important are the following:

- selection between species is accounted for, while selection within species is not. It may be that intra-species selection needs to be taken into consideration, perhaps by defining an ungrazeable residue, i.e., a biomass below which consumption effectively ceases (Noy-Meir, 1976). The results of the experimental program tend to support this notion.
- soils and fertility are not homogeneous in the Savannas of Colombia. The problems posed by site specificity, and hence the predictive power of the model formulation in general, remain to be investigated.

The most pressing questions relate to whether the model in its present formulation is reasonable, and whether it is complex enough to be useful, not only as an input to the beef component, but in its own right. Three such areas can be identified in which such a forage model could be expected to contribute:

- to assist in the specification of criteria relating to the collection of germplasm. The differential growth rate between grass and legume is of importance to the stability of the mixture; this suggests that a certain type of companion species will do rather better than another type, for any particular grass or legume considered. Stability analysis could be expected to provide an indication of desirable characteristics for a companion species in terms of its vigour or acceptability to animals, for example.
- to assist in the evaluation of germplasm. The potential exists to shorten the long and costly process of germplasm evaluation, particularly with regard to animal grazing trials.
- to assist in the formulation of management strategies, which can then be tested on-farm.

Recommendations and Future Work

1. Dual-purpose systems appear to be both biologically and economically feasible, although it is recognised that standard decision analysis does not take account of other benefits and disadvantages which accrue to their use, for example, the more even spread of positive cash flows and the greater management input required. Current levels of infrastructure in the Llanos imply that milk extracted from the herd has to be processed (to cheese, for instance). Model results suggest that production should be seasonal, no offtake occurring during the dry season. This is not the place to argue the merits or demerits of introducing seasonal production into extensive farming systems; suffice it to say that production appears to be seasonal to a great extent anyway (see Figure 23, showing conceptions by month), and that the benefits accruing to the cash flow from 8 months' milk income is not much inferior to those arising from year-round milk income.

2. The current quality of production systems based on improved pasture in the Llanos appears to be insufficient to support seasonal breeding, in the sense of short (3- or 6-month) traditional open seasons. Restricting the

open season to 9 months, however, appears to be energetically efficient, and has the added advantage that herd management is likely to be facilitated, in comparison with shorter breeding seasons.

3. It is possible that the benefits of early weaning in these medium productivity systems were swamped by two problems in the model (see above). Work on the beef component should include the adjustment of death rates and conception probabilities. There are many other relationships in the model which make use of no direct data from savanna production systems at all; unless there are compelling reasons for doing so, most are best left unchanged. Early weaning could then be investigated again, to see if there exist significant long-term benefits. If early weaning is not an energy effect, then the model cannot be expected to be of use; if that were the case, it would be instructive to find out to what any benefits were due.

4. It is apparent that, in the characterisation of the savanna-based systems, there are some important gaps in biological and socio-economic knowledge. These include the following:

-actual culling practices need to be characterised in order to understand death rates rather better; on what basis do farmers cull?

- milk yields need to be documented, along with the shapes of typical lactation curves.

- in view of the sensitivity of the model to energy status, the native savanna needs to be characterised rather better than has been done to date. This includes the seasonal differences due to the various types of savanna (*altillanura, bajo,* etc.). The benefits that can accrue to judicious management of different types of savanna at different times of the year needs to be understood.

- the way in which farmers perceive risk and variability, and how this affects the decisions they take, needs to be characterised. Adoption of new technology proceeds in response to many things, including what farmers perceive to be the problems and benefits of doing so. There is much to be said for the designing of technology which fits in with, rather than requiring potential users to change, their perceptions.

5. Information gleaned from the experiments in progress during 1987 in the Ecophysiology section of the Program should be analysed and

incorporated into the forage model, at which time the structure of the forage component should undergo a certain amount of testing. The ramifications of a validated pasture model are profound. What to do if the structure proves inadequate depends on the type of inadequacy. For the savanna, there are unlikely to be any data forthcoming in the foreseeable future with which to build an explicit growth model. The present tabular approach is likely to be sufficient for many purposes as long as the savanna is seen as the buffer between improved pasture and starvation.

6. Much remains to be done if the (possible) full potential of these models is to be realised; this applies particularly to the pasture model, if it can be successfully validated. Little has been said about another potential use of the system, that of a training tool, although a number of changes would be necessary, notably in the input and output of data; the first would require more extensive data input checking routines, and the quantity of output would have to be rationalised. These are not, however, difficult or fundamental changes.

7. Although extensive experimentation with comparatively detailed models is now practicable, it may be admitted that it raises a number of severe conceptual problems, particularly with regard to the levels of variability that inhere in a system over long periods of time, and how they can be estimated, if at all. A related problem is that of how to introduce such variability into what are often largely empirical (as opposed to causal) models. It is also difficult to know how to incorporate decision rules in the model for decisions which may be rather complicated in real life, and how to ensure that such rules are not having inordinate effects on model output. These, along with the perennial stumbling-blocks of validation and what constitutes a valid model for the builder's purpose, are problems which have to be faced and dealt with somehow, if the link between enormously complex agro-ecosystems and their representation as computer simulation models is to be forged strong enough to permit bio-economic experimentation with the latter to aid the producers whose job it is to battle with the former.

6. ACKNOWLEDGEMENTS

The author wishes to thank the following for their time, effort and input over the period July 1984 to April 1987:

- Dr Raul Vera, Cattle Production Systems,
- Dr Carlos Sere, Economist,
- Dr Myles Fisher, Ecophysiologist,

  all of the Tropical Pastures Program, CIAT,
- Dr Peter Jones, Agro-Climatologist of the Agroecological Unit, CIAT, and
- Dr Hava Kahn, of the Agricultural Research Organisation, Bet-Dagan, Israel, for permission to use the beef model and assistance in setting it up at CIAT.

The author takes full responsibility for any errors and omissions in this report.

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8. APPENDIX

TABLE A1 RAW OUTPUT DATA FILE, SECOND SERIES, TREATMENTS T1 TO T16

ID	Description	IRR %	Inc IRR %	Net Rev $10E6	Animal Units	Age@ Calf-1	Con Int	Prod kg/AU/yr	Con %	Wean %	Wean Wt kg	Death Adult	Death Calf %	Sales kg/AU/yr	Prod2
601	SAV ALL 18 BASE	2.95	0.00	450019.	32.58	4.04	645.72	38.74	46.37	30.24	131.47	11.09	13.16	33.87	37.92
602	SAV ALL 18 BASE	2.72	0.00	452799.	30.39	3.91	636.16	39.93	48.07	30.90	133.00	10.73	12.83	36.01	38.74
603	SAV ALL 18 BASE	2.18	0.00	380331.	33.39	4.05	603.75	39.36	46.71	31.01	132.15	11.82	13.53	30.47	38.74
604	SAV ALL 18 BASE	2.36	0.00	399696.	33.49	4.00	612.04	39.83	48.24	31.25	131.25	12.11	12.32	31.07	38.82
605	SAV ALL 18 BASE	3.73	2.20	626911.	33.61	4.07	630.83	40.86	46.86	32.35	132.85	11.18	11.90	34.69	39.72
606	SAV ALL 18 BASE	2.41	0.00	401291.	32.39	3.96	638.15	40.00	45.69	31.26	133.70	11.62	13.17	30.30	38.62
607	SAV ALL 18 BASE	1.65	0.00	299423.	31.21	3.97	653.50	41.41	45.68	32.63	132.07	12.21	6.52	31.92	39.90
608	SAV ALL 18 BASE	2.38	0.00	417493.	31.88	3.98	622.85	39.41	47.33	31.07	132.95	10.49	11.94	34.42	38.63
609	SAV ALL 18 BASE	3.16	0.00	496610.	29.77	3.93	614.14	39.39	47.54	31.25	133.77	10.04	14.89	37.66	38.96
610	SAV ALL 18 BASE	2.90	0.00	534193.	32.90	4.06	621.87	39.75	45.47	31.79	133.13	10.46	9.33	34.19	39.30
611	SAV ALL 18 BASE	3.05	0.00	519157.	33.79	4.11	611.51	38.73	45.12	30.21	132.80	11.47	11.37	30.51	37.78
612	SAV ALL 18 BASE	3.45	0.00	541301.	33.23	4.02	629.48	41.66	46.32	33.00	133.54	11.73	8.29	35.14	40.46
613	SAV ALL 18 BASE	3.81	3.21	686458.	32.39	4.00	643.52	38.30	47.87	30.22	132.92	9.53	10.71	35.28	37.90
614	SAV ALL 18 BASE	3.45	0.00	551855.	32.69	4.07	640.44	38.83	48.59	30.52	132.58	10.64	14.29	32.99	38.47
615	SAV ALL 18 BASE	2.45	0.00	431566.	33.13	4.01	625.22	38.53	48.92	29.75	133.79	10.57	14.49	29.64	37.38
616	SAV ALL 18 BASE	2.75	0.00	531964.	33.75	4.08	593.77	39.05	47.69	30.19	132.28	10.58	15.91	33.06	37.82
617	SAV ALL 18 BASE	4.57	19.23	708498.	32.48	4.03	655.25	41.68	46.20	33.26	133.82	10.88	8.16	37.02	40.71
618	SAV ALL 18 BASE	4.67	0.00	738318.	33.12	3.90	612.76	39.28	47.72	30.89	132.85	9.90	12.25	35.09	38.59
619	SAV ALL 18 BASE	1.98	0.00	270422.	28.49	4.03	606.41	39.53	47.36	30.80	133.51	10.80	16.02	33.88	38.46
620	SAV ALL 18 BASE	3.78	3.31	760572.	34.83	4.00	614.17	41.02	47.73	32.95	133.03	9.66	9.17	35.72	40.22
621	IP A 18 30 STD RA5	13.09	39.10	2904485.	40.58	3.04	393.40	70.38	81.36	56.87	147.51	8.66	6.37	75.77	67.32
622	IP A 18 30 STD RA5	16.67	0.00	3835425.	42.34	2.98	391.28	73.87	83.99	61.82	147.68	6.89	3.07	81.92	70.67
623	IP A 18 30 STD RA5	13.44	34.96	3149569.	40.35	3.00	383.62	72.74	79.96	58.60	148.37	7.37	4.11	80.47	68.41
624	IP A 18 30 STD RA5	10.72	22.41	2654888.	40.57	3.04	396.10	72.24	81.34	58.58	148.69	9.70	3.60	74.19	68.22
625	IP A 18 30 STD RA5	11.89	23.00	3129605.	41.45	3.02	393.97	75.59	84.75	62.34	147.89	8.66	2.40	80.08	71.72
626	IP A 18 30 STD RA5	14.19	33.80	3580333.	41.78	3.01	386.23	74.39	82.62	61.50	146.91	7.29	2.41	82.38	70.63
627	IP A 18 30 STD RA5	13.01	30.33	3421761.	41.26	3.07	396.16	74.12	84.24	60.79	148.37	7.13	2.39	80.64	69.98
628	IP A 18 30 STD RA5	14.31	36.37	3394905.	41.29	3.06	386.79	71.93	79.81	58.88	147.22	7.29	2.19	82.86	68.60
629	IP A 18 30 STD RA5	16.67	0.00	3835425.	42.34	2.98	391.28	73.87	83.99	61.82	147.68	6.89	3.07	81.92	70.67
630	IP A 18 30 STD RA5	14.14	36.41	3560015.	41.34	3.10	387.38	71.07	78.69	59.07	147.12	7.29	2.18	80.85	69.08
631	IP A 18 30 STD RA5	12.00	22.67	3408755.	41.98	3.03	386.64	72.87	84.76	60.59	147.92	7.06	3.12	82.01	69.65
632	IP A 18 30 STD RA5	13.47	33.00	3371423.	41.51	3.18	392.01	72.38	82.30	59.70	147.62	7.91	3.24	78.43	69.37
633	IP A 18 30 STD RA5	12.34	29.60	3173968.	41.27	3.01	398.96	75.78	84.54	61.64	147.98	9.12	3.76	78.73	71.12
634	IP A 18 30 STD RA5	12.23	26.43	3129340.	41.60	3.14	387.78	74.17	83.90	61.42	146.86	8.80	3.67	81.08	70.21
635	IP A 18 30 STD RA5	16.17	59.14	3815429.	42.68	3.03	385.34	75.78	87.55	63.57	146.70	7.43	2.52	84.02	71.78
636	IP A 18 30 STD RA5	13.28	28.97	3506771.	41.93	3.02	384.76	74.20	84.33	61.94	146.67	7.09	3.36	84.93	70.49
637	IP A 18 30 STD RA5	10.94	20.05	3071418.	41.81	3.02	382.17	74.77	86.09	62.59	147.17	8.65	3.40	79.16	71.34
638	IP A 18 30 STD RA5	13.03	32.81	3111922.	41.21	3.06	384.79	73.39	84.40	60.53	147.69	9.59	4.03	77.37	69.77
639	IP A 18 30 STD RA5	16.88	0.00	4067926.	42.53	3.04	384.05	77.84	85.61	65.79	147.05	8.04	2.01	85.23	73.97
640	IP A 18 30 STD RA5	12.43	25.58	3245065.	41.65	3.08	383.72	73.82	83.27	61.28	146.95	7.33	2.41	80.40	70.29
641	IP A 18 30 RA5 RESOW 2	7.49	10.92	2315745.	40.58	3.13	389.78	71.22	81.97	58.06	147.64	8.54	3.08	78.33	68.20
642	IP A 18 30 RA5 RESOW 10	9.77	18.66	2601864.	41.24	3.03	400.20	70.76	80.19	58.13	146.99	6.54	4.95	81.97	67.30
643	IP A 18 30 RA5 SO2,10	6.76	10.68	1802442.	40.53	3.18	411.36	70.16	79.17	57.41	145.39	7.69	3.95	74.48	66.80
651	IP A 18 30 RA5 CUL 8+4	14.09	30.73	3618675.	41.00	3.05	397.56	70.18	83.99	57.63	147.27	5.27	1.89	84.64	67.33
652	IP A 18 30 RA5 CUL 8+4	16.92	49.44	4050566.	41.79	3.00	388.83	72.35	83.65	60.15	147.54	4.70	2.84	89.52	69.12
653	IP A 18 30 RA5 CUL 8+4	15.29	45.45	3685478.	41.43	3.04	395.62	70.25	83.99	57.73	147.33	5.59	3.17	86.41	67.56
654	IP A 18 30 RA5 CUL 8+4	15.07	38.15	3783199.	41.24	3.02	392.05	71.75	85.05	58.69	147.51	4.67	3.48	87.44	68.30
655	IP A 18 30 RA5 CUL 8+4	13.25	31.10	3403415.	40.23	3.00	398.11	68.27	82.08	54.91	147.25	5.47	3.95	84.75	65.46
656	IP A 18 30 RA5 CUL 8+4	15.69	35.78	4163242.	42.05	3.03	389.95	72.84	86.89	60.30	148.13	3.93	1.03	90.72	69.70

657 IP A 18 30 RA5 CUL 8+4	15.85	46.86	3962171.	41.70	2.97	397.59	72.47	84.99	60.41	147.28	5.25	2.63	87.59	69.71
658 IP A 18 30 RA5 CUL 8+4	15.62	37.04	4010151.	41.33	3.06	394.38	71.75	85.12	59.13	149.13	4.14	1.09	91.34	68.95
659 IP A 18 30 RA5 CUL 8+4	14.86	46.04	3526798.	40.80	3.10	403.56	68.75	84.56	56.12	147.79	4.71	2.73	82.88	66.17
660 IP A 18 30 RA5 CUL 8+4	15.29	43.42	3704124.	41.46	3.01	386.43	71.36	85.55	58.72	147.44	6.94	4.63	84.35	68.74
661 IP A 18 30 RA5 CUL 8+4	12.99	27.31	3553562.	40.95	3.01	393.22	72.05	85.12	58.95	147.71	6.59	2.12	85.09	68.64
662 IP A 18 30 RA5 CUL 8+4	15.73	46.34	3739170.	41.25	3.09	398.10	72.07	85.50	58.95	147.96	4.71	2.12	87.84	68.17
663 IP A 18 30 RA5 CUL 8+4	15.49	43.11	3811842.	41.41	3.02	399.87	69.74	83.61	56.80	147.26	4.66	2.68	87.78	66.51
664 IP A 18 30 RA5 CUL 8+4	12.98	27.64	3387149.	41.22	3.03	395.79	72.48	86.68	58.91	147.11	5.63	3.43	84.60	68.63
665 IP A 18 30 RA5 CUL 8+4	14.90	44.69	3512388.	40.86	3.02	395.72	70.80	85.90	57.71	147.71	6.20	5.01	83.70	67.22
666 IP A 18 30 RA5 CUL 8+4	12.79	26.48	3448398.	41.14	3.02	396.63	67.71	81.94	55.31	147.23	5.03	4.34	83.13	65.55
667 IP A 18 30 RA5 CUL 8+4	14.85	39.00	3904955.	41.15	3.03	390.14	70.25	83.80	57.17	148.69	4.84	2.45	88.11	67.49
668 IP A 18 30 RA5 CUL 8+4	13.25	28.77	3437951.	40.81	3.07	402.28	70.74	82.84	57.09	148.42	4.85	2.71	85.99	66.93
669 IP A 18 30 RA5 CUL 8+4	13.89	42.94	3252160.	39.91	3.08	398.11	68.98	82.51	55.89	146.98	6.27	2.55	81.84	66.31
670 IP A 18 30 RA5 CUL 8+4	12.05	25.05	3306854.	41.29	3.05	394.88	69.68	84.14	57.28	146.57	7.09	2.13	82.22	66.79
671 IP A 18 30 RA5 CUL 8+4	10.51	18.78	2994189.	41.29	3.13	397.15	70.78	82.67	58.38	146.01	6.03	2.47	84.38	68.04
672 IP A 18 30 RA5 CUL 8+4	12.76	33.60	2899548.	40.42	3.11	413.15	68.01	81.17	54.99	147.18	3.77	2.54	84.88	64.97
673 IP A 18 30 RA5 CUL 8+4	6.03	8.79	1628845.	39.65	3.07	421.26	64.92	78.42	51.78	144.63	7.32	4.72	74.19	62.11
681 IP A 30 18 DP.333 ME6	24.12	79.97	5737338.	40.52	3.13	387.21	67.47	79.78	54.49	125.77	7.87	8.22	73.63	62.51
682 IP A 30 18 DP.333 ME6	23.70	77.73	5673024.	40.64	3.10	382.78	68.29	82.30	55.56	125.91	8.85	10.48	73.56	63.50
683 IP A 30 18 DP.333 ME6	21.94	55.62	5559070.	40.57	3.19	384.97	69.02	83.86	56.10	125.26	9.19	8.42	72.09	63.64
684 IP A 30 18 DP.333 ME6	19.46	43.30	5898907.	41.15	3.11	377.26	69.29	83.36	57.57	125.10	9.35	9.02	74.34	64.89
685 IP A 30 18 DP.333 ME6	26.07	105.61	5767897.	40.95	3.17	377.24	68.09	85.32	55.58	125.48	8.36	8.88	70.88	63.06
686 IP A 30 18 DP.333 ME6	20.98	49.30	5803053.	40.88	3.08	388.58	70.75	83.77	57.46	125.60	8.77	10.76	74.41	64.96
687 IP A 30 18 DP.333 ME6	24.22	88.53	5960212.	40.20	3.30	378.82	70.53	85.28	57.36	126.83	7.84	10.37	76.68	65.13
688 IP A 30 18 DP.333 ME6	22.40	70.83	5686184.	40.18	3.24	389.99	67.78	78.80	53.85	127.05	7.88	8.78	75.56	62.06
689 IP A 30 18 DP.333 ME6	19.66	43.91	5405877.	40.44	3.16	383.58	67.71	81.73	55.56	125.77	9.23	10.08	72.32	63.49
690 IP A 30 18 DP.333 ME6	23.22	83.09	5657805.	40.31	3.10	380.32	66.21	81.09	53.56	125.13	7.30	10.00	73.31	61.85
691 IP A 30 18 DP.333 ME6	23.74	79.23	6081924.	41.25	3.16	386.89	71.19	84.51	58.21	125.98	7.84	9.40	75.63	65.27
692 IP A 30 18 DP.333 ME6	23.14	97.37	5360428.	39.74	3.10	385.76	67.65	83.62	54.48	125.76	8.19	9.55	73.01	62.56
693 IP A 30 18 DP.333 ME6	24.69	71.57	5777250.	40.98	3.17	386.31	67.95	83.93	55.14	126.49	7.10	10.67	74.32	62.98
694 IP A 30 18 DP.333 ME6	21.73	48.53	5616127.	40.26	3.17	383.59	66.31	84.06	53.89	125.37	6.07	10.14	75.76	62.00
695 IP A 30 18 DP.333 ME6	23.06	66.90	5783838.	40.55	3.13	387.32	71.27	83.90	58.14	126.32	8.90	9.07	77.11	65.70
696 IP A 30 18 DP.333 ME6	20.85	50.47	5400847.	40.21	3.16	384.64	67.88	80.08	54.70	126.22	8.27	9.66	73.16	62.88
697 IP A 30 18 DP.333 ME6	23.00	59.55	5879977.	40.82	3.18	381.99	69.15	80.94	57.36	125.21	8.49	8.33	73.87	64.30
698 IP A 30 18 DP.333 ME6	24.15	73.01	5764740.	40.60	3.18	380.50	67.48	83.33	54.68	125.45	6.93	10.84	74.53	62.59
699 IP A 30 18 DP.333 ME6	21.81	60.67	5665390.	40.48	3.17	385.01	67.51	81.16	54.66	125.95	7.65	9.78	72.48	62.68
700 IP A 30 18 DP.333 ME6	22.61	87.29	5344098.	40.25	3.10	389.55	68.99	82.49	55.74	126.06	10.36	9.16	69.73	63.31
701 IP A 30 18 DP.333 ME6	17.41	36.07	5072880.	39.95	3.18	393.26	65.54	80.80	54.18	124.17	8.56	10.83	69.36	61.93
702 IP A 30 18 DP.333 ME6	18.73	50.42	4466786.	40.16	3.19	396.40	66.38	79.85	53.73	125.10	10.26	9.86	66.46	61.37
703 IP A 30 18 DP.333 ME6	11.82	21.04	3577223.	39.39	3.30	407.82	62.92	76.82	50.09	124.71	9.35	10.85	63.39	58.47
711 IP A 30 18 DP.333 ME3	17.88	51.61	4013753.	38.07	3.24	427.08	67.81	72.71	49.72	127.70	10.28	10.67	62.05	58.30
712 IP A 30 18 DP.333 ME3	20.58	93.80	4549057.	37.97	3.17	419.11	66.08	72.07	48.23	129.09	5.77	12.88	70.74	56.69
713 IP A 30 18 DP.333 ME3	20.15	64.54	4618693.	38.48	3.20	413.50	68.70	75.56	51.12	128.54	8.58	10.26	67.84	58.93
714 IP A 30 18 DP.333 ME3	20.98	61.35	4659372.	38.46	3.23	409.85	67.53	73.97	50.75	128.33	7.87	7.60	69.49	59.14
715 IP A 30 18 DP.333 ME3	19.98	63.25	4197745.	37.30	3.20	432.80	67.37	68.29	48.41	128.21	8.26	8.06	69.08	57.36
716 IP A 30 18 DP.333 ME3	15.86	43.12	3755591.	36.48	3.33	423.14	65.77	65.97	46.31	127.97	8.88	9.09	64.88	55.63
717 IP A 30 18 DP.333 ME3	18.98	61.68	4584529.	38.13	3.26	408.68	66.62	73.64	48.97	128.26	7.85	9.85	68.02	57.50
718 IP A 30 18 DP.333 ME3	18.99	61.90	4348339.	37.40	3.26	414.28	68.15	71.59	49.24	129.03	8.14	9.46	71.15	57.80
719 IP A 30 18 DP.333 ME3	20.88	64.66	4787894.	38.73	3.24	414.33	66.67	75.47	50.00	128.19	6.37	9.04	72.01	58.02
720 IP A 30 18 DP.333 ME3	19.32	57.89	4502923.	38.36	3.20	419.86	66.58	71.96	49.53	128.80	8.04	9.45	67.61	57.95
721 IP A 30 18 DP.333 ME3	18.38	43.70	4569289.	38.70	3.29	423.27	66.56	71.61	49.17	128.85	6.49	7.10	72.81	57.84
722 IP A 30 18 DP.333 ME3	19.92	54.90	4762645.	38.74	3.25	409.13	70.21	78.03	52.14	128.10	7.64	7.69	71.23	59.77
723 IP A 30 18 DP.333 ME3	19.74	54.78	4592057.	39.14	3.34	416.74	66.63	75.61	51.02	127.65	9.12	9.68	66.18	58.86
724 IP A 30 18 DP.333 ME3	17.50	65.60	3671653.	36.76	3.17	432.74	64.86	72.00	46.67	128.44	9.90	12.10	61.22	55.92
725 IP A 30 18 DP.333 ME3	21.38	74.36	4765351.	38.58	3.29	418.84	69.64	73.42	51.67	128.06	7.99	8.01	72.45	59.47

726 IP A 30 18 DP.333 ME3	17.08	43.10	4232271.	37.94	3.17	417.83	65.23	72.52	48.04	127.57	8.41	10.19	67.16	56.92
727 IP A 30 18 DP.333 ME3	19.01	43.95	4937143.	38.90	3.37	416.09	70.46	73.18	52.89	128.38	6.70	6.59	74.94	60.40
728 IP A 30 18 DP.333 ME3	21.22	75.39	4725945.	38.79	3.25	412.30	68.82	76.64	51.40	128.86	8.79	10.14	69.96	59.47
729 IP A 30 18 DP.333 ME3	17.16	41.68	4274792.	37.83	3.30	417.62	67.88	71.54	49.44	129.29	8.05	8.86	69.07	58.03
730 IP A 30 18 DP.333 ME3	19.29	73.89	3933701.	37.37	3.23	426.76	64.26	70.90	46.46	127.98	7.84	11.46	63.56	55.39
731 IP A 30 18 DP.333 ME3	11.15	18.82	3388387.	37.43	3.43	426.29	65.70	72.01	47.01	128.29	8.40	12.34	65.65	55.73
732 IP A 30 18 DP.333 ME3	18.73	59.23	4008018.	38.02	3.35	440.54	66.71	74.15	49.62	128.50	7.17	7.86	71.23	57.59
733 IP A 30 18 DP.333 ME3	10.63	20.78	2688215.	36.91	3.40	455.70	60.89	67.80	44.26	126.94	7.72	10.47	61.59	52.99
741 IP A 30 18 DP.333 ME3B	22.91	64.23	5581006.	39.86	3.27	403.22	61.25	75.34	53.03	123.77	8.02	7.85	69.68	63.00
742 IP A 30 18 DP.333 ME3B	24.16	86.75	5514104.	40.01	3.25	409.37	60.83	75.58	52.33	122.97	8.33	6.29	69.12	62.49
743 IP A 30 18 DP.333 ME3B	25.98	88.54	5802445.	40.39	3.27	407.24	62.78	78.49	54.65	124.06	8.91	7.39	68.29	64.56
744 IP A 30 18 DP.333 ME3B	21.43	50.46	5800216.	40.46	3.27	401.48	62.21	76.78	53.74	124.66	7.49	7.47	69.25	63.81
745 IP A 30 18 DP.333 ME3B	22.80	67.58	5141479.	40.15	3.20	407.48	61.00	75.91	52.20	123.77	8.80	8.43	65.62	62.26
746 IP A 30 18 DP.333 ME3B	21.33	61.99	5663295.	40.13	3.19	398.79	63.20	78.08	54.79	123.99	8.61	8.24	70.40	64.73
747 IP A 30 18 DP.333 ME3B	24.50	75.41	5873616.	40.72	3.18	408.39	63.73	75.77	55.58	124.67	9.04	6.59	68.26	65.25
748 IP A 30 18 DP.333 ME3B	28.99	0.00	6207950.	40.90	3.27	398.20	62.34	77.14	53.71	124.73	5.90	9.09	72.15	63.66
749 IP A 30 18 DP.333 ME3B	26.07	108.55	6297576.	41.14	3.19	409.99	63.86	76.10	55.83	124.64	7.27	5.63	72.33	65.44
750 IP A 30 18 DP.333 ME3B	20.36	52.60	4948065.	39.05	3.35	410.48	58.53	74.42	48.64	124.30	7.56	9.01	65.08	59.99
751 IP A 30 18 DP.333 ME3B	17.21	43.03	4274475.	38.62	3.26	425.70	59.44	72.21	50.10	124.34	11.94	9.75	56.74	60.99
752 IP A 30 18 DP.333 ME3B	21.16	48.82	5446703.	40.11	3.20	402.83	60.75	76.69	52.02	123.90	7.13	8.99	69.26	62.21
753 IP A 30 18 DP.333 ME3B	20.92	53.21	5529747.	40.25	3.19	403.62	63.01	78.88	54.46	125.49	9.50	8.00	66.16	64.60
754 IP A 30 18 DP.333 ME3B	20.00	50.12	5436418.	40.44	3.24	403.50	59.60	77.76	50.76	124.01	7.60	13.02	65.87	60.97
755 IP A 30 18 DP.333 ME3B	27.34	105.84	6019003.	40.97	3.29	408.03	63.25	78.74	55.36	123.68	8.24	7.48	69.89	64.78
756 IP A 30 18 DP.333 ME3B	20.71	52.23	5561026.	40.25	3.26	407.97	61.66	75.97	52.91	123.88	7.56	9.51	70.32	63.00
757 IP A 30 18 DP.333 ME3B	21.50	49.69	5522153.	40.34	3.18	406.56	61.77	77.33	53.29	123.74	6.59	7.43	72.87	63.12
758 IP A 30 18 DP.333 ME3B	20.32	55.85	5071911.	39.64	3.21	407.93	61.75	76.80	53.22	122.95	9.94	7.42	64.79	63.13
759 IP A 30 18 DP.333 ME3B	23.39	64.14	5997051.	40.92	3.21	397.04	62.96	77.59	54.79	123.72	7.28	8.68	70.12	64.47
760 IP A 30 18 DP.333 ME3B	22.76	102.33	4968411.	38.42	3.20	410.98	60.00	72.91	51.00	123.63	8.96	8.95	66.81	61.49
761 IP A 30 18 DP.333 ME3B	14.45	27.19	4592330.	39.58	3.32	410.62	59.55	74.52	50.38	121.88	9.00	9.31	62.86	60.85
762 IP A 30 18 DP.333 ME3B	19.73	65.16	4235163.	39.37	3.32	419.56	57.61	73.41	48.94	122.03	9.06	10.94	60.25	59.17
763 IP A 30 18 DP.333 ME3B	12.67	25.07	3377278.	38.82	3.44	416.62	58.90	74.32	50.00	120.85	10.31	12.50	59.34	59.96
771 IP A 18 9/150 RA10 BH	10.88	29.46	2490683.	41.69	3.10	367.68	64.87	88.07	61.17	131.76	19.70	4.16	55.70	63.94
772 IP A 18 9/150 RA10 BH	13.23	43.86	2908887.	42.25	3.05	378.58	70.43	88.10	65.61	132.36	18.03	3.20	61.49	67.26
773 IP A 18 9/150 RA10 BH	12.94	36.30	3097961.	41.81	3.10	372.74	68.34	86.87	63.23	133.44	15.01	2.29	63.95	65.88
774 IP A 18 9/150 RA10 BH	13.42	54.08	3011732.	42.85	3.07	365.97	69.02	88.43	65.11	130.34	19.59	2.49	62.15	66.40
775 IP A 18 9/150 RA10 BH	13.84	46.42	3172090.	42.30	3.09	372.56	67.28	85.23	63.36	130.53	15.89	1.53	64.21	65.48
776 IP A 18 9/150 RA10 BH	11.53	29.13	2831801.	41.87	3.11	374.94	69.59	84.73	64.43	131.30	16.20	2.32	61.01	67.04
777 IP A 18 9/150 RA10 BH	10.97	26.63	2757259.	41.67	3.05	367.68	66.27	84.89	60.26	130.77	17.72	2.64	60.42	63.68
778 IP A 18 9/150 RA10 BH	11.12	33.72	2418916.	40.86	3.05	375.63	66.83	85.55	60.60	132.14	18.39	3.17	56.75	63.69
779 IP A 18 9/150 RA10 BH	11.36	33.19	2556638.	42.38	3.08	368.25	68.68	87.71	65.03	130.90	20.79	2.54	57.88	66.59
780 IP A 18 9/150 RA10 BH	13.89	41.19	3244855.	42.74	3.06	367.33	69.41	89.33	65.54	130.23	15.73	2.72	66.94	67.10
781 IP A 18 9/150 RA10 BH	12.52	50.39	2717948.	42.13	3.03	372.63	68.50	84.76	64.13	132.09	20.63	2.31	57.72	66.49
782 IP A 18 9/150 RA10 BH	13.00	52.00	2966030.	41.48	3.12	371.73	68.04	87.92	63.21	133.03	17.17	3.08	61.77	65.91
783 IP A 18 9/150 RA10 BH	10.34	25.77	2389499.	41.69	3.05	366.85	67.22	82.18	62.29	131.18	21.39	3.35	58.10	64.87
784 IP A 18 9/150 RA10 BH	10.53	34.33	2469682.	41.07	3.10	373.72	66.69	84.12	61.25	131.35	19.66	2.65	56.75	64.27
785 IP A 18 9/150 RA10 BH	14.36	57.53	3044048.	41.51	3.09	370.72	70.49	87.29	64.90	133.09	17.65	1.82	65.15	67.14
786 IP A 18 9/150 RA10 BH	10.86	32.87	2365242.	41.25	3.06	370.34	69.99	83.49	63.23	132.50	20.64	2.37	58.50	66.73
787 IP A 18 9/150 RA10 BH	11.99	49.08	2472743.	41.94	3.11	375.60	67.63	89.35	63.18	132.37	20.56	2.80	54.71	65.56
788 IP A 18 9/150 RA10 BH	12.56	57.88	2801104.	42.19	3.10	370.57	72.33	90.67	68.10	131.65	21.08	1.96	59.33	68.73
789 IP A 18 9/150 RA10 BH	11.24	30.62	2506515.	41.64	3.10	376.45	68.13	85.79	62.62	132.33	21.31	2.32	58.17	65.21
790 IP A 18 9/150 RA10 BH	14.72	56.95	2961702.	42.07	2.99	371.22	71.56	88.27	65.36	133.56	18.99	1.98	63.10	67.01
791 IP A 18 9/150 RA10 BH	9.05	18.55	2284509.	41.79	3.07	375.90	68.88	86.94	62.69	132.80	20.15	2.85	56.82	65.26
792 IP A 18 9/150 RA10 BH	11.77	46.95	2641728.	41.38	3.07	393.92	66.88	84.62	61.35	132.71	17.45	2.12	60.00	64.33
801 IP A30 FH200 C4+B	16.72	29.06	5719092.	55.79	3.04	386.23	61.03	93.49	64.87	147.11	6.13	3.54	84.48	73.48
802 IP A30 FH200 C4+B	17.74	31.46	6258992.	57.14	3.12	386.98	60.06	95.00	65.00	147.67	5.93	1.18	84.13	73.08

B03 IP A30 FH200 C4+B	16.46	28.53	5806002.	55.05	3.06	398.21	59.19	94.04	62.94	148.72	5.96	2.73	83.18	72.50
B04 IP A30 FH200 C4+B	18.10	34.18	6099217.	56.70	3.12	394.22	59.48	93.69	64.38	147.34	6.12	2.62	81.81	72.25
B05 IP A30 FH200 C4+B	17.36	33.77	5569904.	54.57	3.02	386.66	60.63	93.69	63.82	148.60	7.98	2.63	80.24	72.86
B06 IP A30 FH200 C4+B	18.94	39.56	6343408.	55.43	3.11	389.30	60.92	93.48	64.99	150.05	5.77	3.37	84.27	74.67
B07 IP A30 FH200 C4+B	16.23	29.17	5665177.	55.77	3.11	391.15	60.10	93.85	64.25	149.12	7.26	3.34	80.49	72.40
B08 IP A30 FH200 C4+B	17.79	33.52	6012438.	55.31	3.03	394.71	60.08	91.21	64.30	149.06	5.61	3.16	83.15	73.22
B09 IP A30 FH200 C4+B	16.91	31.10	5897611.	55.35	3.04	388.10	62.48	95.00	65.37	147.61	7.22	3.31	84.43	74.53
B10 IP A30 FH200 C4+B	20.41	49.85	6033855.	54.89	3.07	396.53	58.46	91.26	61.71	147.74	4.83	2.44	83.37	70.79
B11 IP A30 FH200 C4+B	18.57	35.58	6189435.	55.67	3.06	388.24	61.32	96.46	65.55	148.38	6.33	2.81	84.85	74.12
B12 IP A30 FH200 C4+B	18.77	36.55	6204634.	55.97	3.08	384.73	59.70	94.62	63.82	147.71	4.45	3.83	86.29	72.44
B13 IP A30 FH200 C4+B	17.27	33.51	5589156.	55.30	3.08	390.22	59.30	93.51	62.71	147.16	7.61	2.89	80.75	71.35
B14 IP A30 FH200 C4+B	18.43	36.29	5979542.	56.10	2.99	397.45	61.33	92.19	65.99	148.37	7.25	2.43	82.87	75.06
B15 IP A30 FH200 C4+B	18.61	37.03	6014307.	56.35	3.06	388.74	59.78	92.01	64.13	148.03	6.51	2.18	82.85	72.51
B16 IP A30 FH200 C4+B	17.16	31.39	5630360.	54.94	3.08	388.06	60.44	94.21	63.55	147.44	7.48	2.88	86.46	72.38
B17 IP A30 FH200 C4+B	15.32	27.93	5083298.	54.73	3.08	393.16	58.35	92.78	62.04	146.70	10.00	3.99	75.28	71.10
B18 IP A30 FH200 C4+B	18.20	33.25	6417834.	56.06	3.08	390.11	60.74	95.18	64.75	149.00	5.75	2.61	86.66	73.55
B19 IP A30 FH200 C4+B	18.14	34.65	6125986.	56.38	3.06	390.78	59.80	90.74	64.63	147.61	6.30	3.34	81.96	72.60
B20 IP A30 FH200 C4+B	18.52	37.80	6066627.	55.01	3.09	384.08	60.50	90.91	63.64	147.57	6.12	1.73	85.10	72.55
B21 IP A30 FH200 C4+B	12.97	20.64	4802379.	53.59	3.14	396.80	57.14	90.50	59.59	146.79	7.26	4.26	78.19	69.63
B22 IP A30 FH200 C4+B	14.89	29.79	4462290.	53.43	3.10	408.49	58.34	91.23	60.63	147.62	9.33	2.01	75.17	70.13
B23 IP A30 FH200 C4+B	10.65	15.92	3983641.	54.82	3.11	401.94	56.92	93.68	60.59	146.71	7.81	4.24	76.06	68.82
B31 IP A 18 30 EW210 FH150	14.37	34.78	3494751.	43.85	3.05	389.24	66.23	82.71	62.97	129.69	8.83	1.62	76.36	69.31
B32 IP A 18 30 EW210 FH150	15.33	34.63	4218428.	45.98	3.04	384.43	67.72	86.78	66.67	131.11	8.19	2.53	80.79	71.77
B33 IP A 18 30 EW210 FH150	13.47	28.99	3439211.	44.31	3.04	380.42	64.43	84.42	61.04	131.38	8.91	4.05	73.69	68.17
B34 IP A 18 30 EW210 FH150	16.08	37.37	4310489.	46.22	3.00	375.33	66.82	85.93	65.93	131.14	7.41	2.73	80.60	71.49
B35 IP A 18 30 EW210 FH150	17.52	46.13	4523842.	45.61	3.02	387.53	66.51	86.36	64.86	130.96	6.36	2.99	81.53	70.94
B36 IP A 18 30 EW210 FH150	14.68	32.51	4070372.	45.30	3.01	384.61	65.24	86.85	62.22	130.36	6.48	3.11	81.30	68.98
B37 IP A 18 30 EW210 FH150	15.95	40.22	4117721.	45.29	3.05	386.29	66.52	85.00	63.89	130.28	6.67	3.60	79.75	69.85
B38 IP A 18 30 EW210 FH150	15.58	33.76	4099982.	45.66	3.08	377.98	66.90	85.29	65.55	130.21	7.82	2.76	81.47	70.68
B39 IP A 18 30 EW210 FH150	15.44	35.35	4260228.	44.95	3.09	384.26	66.09	85.53	63.82	131.27	6.86	4.34	80.66	70.18
B40 IP A 18 30 EW210 FH150	13.62	31.22	3628983.	45.14	3.08	386.32	67.23	85.90	64.94	130.12	9.28	2.08	75.09	70.97
B41 IP A 18 30 EW210 FH150	14.40	34.61	3583251.	43.92	3.04	391.11	63.91	81.56	60.15	131.14	8.19	3.80	74.40	67.75
B42 IP A 18 30 EW210 FH150	14.00	27.38	4053564.	45.54	3.07	381.18	67.90	87.36	65.80	130.26	7.99	2.53	79.82	71.29
B43 IP A 18 30 EW210 FH150	13.65	28.60	3907672.	45.08	3.10	383.27	65.52	87.69	63.43	131.10	8.21	2.35	75.95	69.20
B44 IP A 18 30 EW210 FH150	13.27	26.90	3584677.	43.91	3.09	391.79	65.11	83.02	60.82	130.35	7.46	3.52	77.08	68.47
B45 IP A 18 30 EW210 FH150	13.60	27.61	3871186.	45.12	3.04	385.74	65.96	86.03	63.50	130.69	7.26	2.58	78.46	69.74
B46 IP A 18 30 EW210 FH150	13.92	27.03	4119367.	45.23	3.05	389.62	66.32	86.54	64.11	130.17	5.98	2.34	82.97	70.19
B47 IP A 18 30 EW210 FH150	17.16	41.97	4640668.	46.78	3.05	378.64	67.73	88.70	67.22	130.24	5.93	2.44	83.02	72.27
B48 IP A 18 30 EW210 FH150	15.53	34.90	4275476.	45.95	3.00	385.07	68.70	87.34	67.23	130.77	8.19	1.27	80.52	72.48
B49 IP A 18 30 EW210 FH150	14.67	34.68	4063595.	45.10	3.10	383.71	66.00	85.50	63.57	130.77	7.81	3.60	78.81	69.60
B50 IP A 18 30 EW210 FH150	14.04	33.09	3688686.	44.19	3.02	386.09	66.30	83.61	62.94	130.17	8.75	2.92	75.14	69.83
B51 IP A 18 30 EW210 FH150	8.17	11.57	2837150.	43.09	3.11	390.67	64.02	78.62	58.74	128.57	7.99	4.18	76.02	66.00
B52 IP A 18 30 EW210 FH150	12.72	30.53	3014560.	44.73	3.08	403.03	65.19	85.63	62.87	129.84	9.33	2.62	73.34	68.99
B53 IP A 18 30 EW210 FH150	7.74	12.32	2182423.	44.56	3.14	389.61	64.27	84.57	61.52	130.13	11.34	3.72	71.34	67.89
B61 IPBH 30 FH250 CB+4 RA10	14.54	22.82	6015036.	87.85	4.01	391.08	51.06	94.76	62.92	150.44	8.61	2.44	54.04	41.06
B62 IPBH 30 FH250 CB+4 RA10	15.02	24.05	6153898.	89.35	3.98	388.94	51.94	93.10	64.18	150.01	9.70	2.16	53.62	41.29
B63 IPBH 30 FH250 CB+4 RA10	17.40	31.33	6917408.	89.74	4.03	386.79	51.31	96.65	63.94	149.15	5.76	2.34	58.06	41.22
B64 IPBH 30 FH250 CB+4 RA10	16.48	27.40	6564319.	90.17	3.99	387.11	52.18	95.72	64.25	149.95	7.45	2.36	56.34	41.35
B65 IPBH 30 FH250 CB+4 RA10	16.64	28.58	6776905.	89.39	3.95	386.03	51.41	96.47	63.57	149.16	6.69	2.09	57.74	41.22
B66 IPBH 30 FH250 CB+4 RA10	16.83	29.41	6616402.	89.17	3.92	385.69	51.18	94.24	63.75	149.28	7.43	0.72	59.08	41.25
B67 IPBH 30 FH250 CB+4 RA10	15.61	26.16	6425399.	89.12	4.04	388.73	51.04	97.96	63.45	148.92	8.72	3.08	55.87	41.08
B68 IPBH 30 FH250 CB+4 RA10	16.29	27.36	6653423.	87.27	4.02	390.56	51.07	94.05	62.83	149.90	6.69	2.66	58.68	41.53
B69 IPBH 30 FH250 CB+4 RA10	15.77	25.85	6394272.	88.15	3.98	386.95	50.12	96.10	62.45	148.38	7.62	3.37	56.71	41.04
B70 IPBH 30 FH250 CB+4 RA10	16.89	28.53	6829735.	90.84	3.98	380.40	53.03	96.65	65.61	149.43	7.99	2.58	57.03	41.78
B71 IPBH 30 FH250 CB+4 RA10	16.68	28.73	6469089.	87.73	4.04	387.12	49.77	95.90	61.27	149.69	6.70	4.09	57.29	40.56

872 IPBH 30 FH250 CB+4 RA10	15.16	24.12	6312625.	89.24	3.98	383.41	51.40	96.09	64.25	149.06	8.38	2.83	55.71	41.51
873 IPBH 30 FH250 CB+4 RA10	16.72	29.16	6480812.	87.59	3.98	387.84	50.96	96.46	62.94	150.07	7.82	2.12	57.25	41.63
874 IPBH 30 FH250 CB+4 RA10	15.53	24.29	6588576.	90.42	4.04	377.98	51.23	98.51	64.06	148.67	6.33	3.04	57.31	41.16
875 IPBH 30 FH250 CB+4 RA10	15.12	23.67	6274804.	88.33	3.90	385.02	51.99	97.39	64.55	149.67	8.02	2.13	54.63	42.19
876 IPBH 30 FH250 CB+4 RA10	15.59	25.21	6307062.	88.85	4.00	388.94	50.67	96.82	62.62	150.02	6.92	2.18	55.98	40.87
877 IPBH 30 FH250 CB+4 RA10	14.95	24.29	6063853.	86.78	3.89	383.71	50.03	95.72	62.08	149.45	7.81	3.33	55.29	41.06
878 IPBH 30 FH250 CB+4 RA10	15.26	24.79	6485363.	88.41	4.02	385.59	50.66	97.01	62.69	150.49	6.72	3.29	55.21	40.96
879 IPBH 30 FH250 CB+4 RA10	15.79	25.06	6836341.	88.45	3.95	386.10	50.62	95.36	62.34	150.32	6.31	2.88	57.85	40.87
880 IPBH 30 FH250 CB+4 RA10	16.71	28.94	6629419.	88.39	4.00	385.12	50.47	96.65	62.45	149.82	6.69	1.92	56.78	40.91
881 IPBH 30 FH250 CB+4 RA10	11.68	16.03	5707355.	87.34	4.03	386.47	50.91	94.24	62.64	148.24	8.55	2.17	55.38	40.89
882 IPBH 30 FH250 CB+4 RA10	17.31	0.00	6003204.	87.16	4.08	402.89	48.77	95.35	60.78	148.26	5.58	3.45	57.26	40.60
883 IPBH 30 FH250 CB+4 RA10	10.78	14.80	4961183.	83.89	3.95	400.45	47.89	93.10	59.70	145.57	7.65	3.27	54.99	40.66
891 IP 9 DF WB CB+4 RA10	21.49	73.64	6458537.	60.12	3.43	395.66	49.66	87.94	59.55	141.88	5.01	1.81	69.16	58.90
892 IP 9 DF WB CB+4 RA10	22.33	0.00	6001202.	60.24	3.47	404.18	50.11	86.54	60.00	142.77	7.85	3.07	66.04	59.22
893 IP 9 DF WB CB+4 RA10	20.95	50.31	6288169.	60.24	3.41	400.93	49.48	90.19	58.70	142.89	6.11	2.77	68.34	58.56
894 IP 9 DF WB CB+4 RA10	20.13	47.96	6260234.	61.45	3.47	399.43	50.18	89.59	60.78	141.70	6.13	2.51	67.78	59.32
895 IP 9 DF WB CB+4 RA10	20.25	43.77	6582710.	61.94	3.50	397.63	50.60	91.47	61.22	142.20	4.27	2.95	69.57	59.39
896 IP 9 DF WB CB+4 RA10	21.61	68.46	5998344.	59.47	3.43	403.08	50.10	87.17	59.29	142.29	6.69	3.13	67.40	59.01
897 IP 9 DF WB CB+4 RA10	22.76	70.17	6453465.	60.23	3.44	392.54	49.32	88.29	58.36	142.19	5.02	5.01	70.97	58.26
898 IP 9 DF WB CB+4 RA10	22.55	70.04	6674306.	61.11	3.47	397.17	50.43	92.57	60.97	143.50	5.76	1.98	69.56	59.64
899 IP 9 DF WB CB+4 RA10	19.84	43.60	6508717.	62.60	3.46	403.85	51.08	88.13	62.71	142.14	6.49	0.99	67.67	60.02
900 IP 9 DF WB CB+4 RA10	19.40	47.41	5839835.	59.93	3.47	400.27	49.08	90.33	58.18	141.60	6.51	2.31	65.41	57.75
901 IP 9 DF WB CB+4 RA10	19.51	42.40	6277705.	61.15	3.43	389.87	49.79	90.93	60.00	142.31	5.93	3.69	67.67	58.90
902 IP 9 DF WB CB+4 RA10	20.71	53.58	6235164.	60.59	3.43	395.67	49.72	89.78	59.48	141.92	6.13	2.04	67.36	58.85
903 IP 9 DF WB CB+4 RA10	22.22	62.94	6632492.	61.44	3.42	399.38	50.89	89.24	61.60	142.15	5.38	2.21	69.70	60.23
904 IP 9 DF WB CB+4 RA10	22.94	0.00	6703776.	62.03	3.45	397.34	50.95	91.48	61.67	143.04	5.74	2.72	69.08	59.64
905 IP 9 DF WB CB+4 RA10	23.45	0.00	6503976.	60.81	3.46	393.19	50.37	89.98	60.67	142.94	6.12	2.97	66.93	59.61
906 IP 9 DF WB CB+4 RA10	20.75	48.27	6467531.	61.01	3.39	403.83	50.20	88.66	60.04	143.07	5.20	2.53	71.12	59.32
907 IP 9 DF WB CB+4 RA10	19.88	43.50	6518550.	60.94	3.42	398.60	49.91	88.83	59.78	142.95	5.03	3.26	70.59	58.95
908 IP 9 DF WB CB+4 RA10	19.65	41.41	6645505.	61.25	3.48	391.38	49.27	89.98	59.37	141.46	4.64	3.19	70.51	58.70
909 IP 9 DF WB CB+4 RA10	22.61	73.09	6531618.	61.23	3.37	395.03	50.80	90.32	61.08	142.41	5.59	2.71	69.89	59.66
910 IP 9 DF WB CB+4 RA10	21.15	78.77	6315499.	59.99	3.40	394.16	50.49	89.37	60.45	143.08	6.90	1.82	68.44	59.78
911 IP 9 DF WB CB+4 RA10	18.38	40.49	6194498.	59.85	3.51	403.96	49.25	87.36	58.36	140.61	5.58	3.35	67.44	58.18
912 IP 9 DF WB CB+4 RA10	22.23	0.00	5638857.	57.99	3.43	422.28	47.79	84.57	55.20	140.94	5.95	3.59	65.03	56.93
913 IP 9 DF WB CB+4 RA10	16.87	33.36	5714069.	59.00	3.48	411.17	48.23	84.79	56.59	140.26	5.38	3.83	66.62	56.80
921 IP A 30 DP.333	21.85	56.82	5554512.	39.26	3.03	384.54	65.10	85.19	53.46	129.67	8.08	13.78	72.51	62.91
922 IP A 30 DP.333	26.29	81.86	5984795.	39.88	3.04	383.68	69.02	85.74	56.27	129.59	7.22	12.89	76.19	64.95
923 IP A 30 DP.333	21.11	47.98	5748202.	40.21	3.06	384.71	67.20	83.24	54.38	129.96	7.08	13.76	73.19	64.40
924 IP A 30 DP.333	24.43	70.00	6195664.	40.42	3.10	383.04	65.37	81.24	54.60	128.16	6.57	10.51	75.27	63.49
925 IP A 30 DP.333	22.73	59.62	6087553.	40.84	3.03	380.63	66.27	85.15	55.45	127.21	8.46	12.85	72.86	64.28
926 IP A 30 DP.333	20.10	58.66	5100254.	39.31	3.01	376.95	63.65	85.55	51.59	128.05	9.01	17.02	65.74	61.33
927 IP A 30 DP.333	24.63	65.89	6329709.	40.53	3.14	379.47	68.66	83.08	56.58	129.07	7.14	10.82	78.33	65.39
928 IP A 30 DP.333	27.34	110.58	5925965.	40.35	3.08	380.57	68.99	85.85	56.05	130.47	7.82	11.84	73.94	65.12
929 IP A 30 DP.333	30.86	159.12	6684864.	41.08	3.05	379.54	69.51	89.01	57.54	129.12	6.33	12.81	77.90	66.12
930 IP A 30 DP.333	24.42	82.41	6164878.	40.30	3.01	385.08	66.97	82.93	54.22	129.69	6.38	13.70	76.05	63.81
931 IP A 30 DP.333	23.25	70.10	5665547.	39.84	3.03	385.83	66.42	83.93	53.83	129.52	8.22	13.16	69.88	63.86
932 IP A 30 DP.333	23.96	87.12	5486936.	39.98	3.13	379.35	64.92	85.50	52.97	128.70	8.18	14.06	68.83	62.45
933 IP A 30 DP.333	25.35	65.98	6429724.	41.77	3.03	378.48	68.97	88.31	58.44	127.10	7.42	12.01	75.36	66.36
934 IP A 30 DP.333	27.43	0.00	6134690.	40.87	3.05	381.81	67.04	87.45	55.99	127.29	8.43	13.01	71.14	64.44
935 IP A 30 DP.333	27.43	0.00	6134690.	40.87	3.05	381.81	67.04	87.45	55.99	127.29	8.43	13.01	71.14	64.44
936 IP A 30 DP.333	28.04	0.00	6299488.	40.44	3.04	379.00	67.88	84.17	55.12	130.48	7.45	14.90	71.96	64.38
937 IP A 30 DP.333	23.70	67.26	6060581.	40.46	3.01	384.28	65.85	85.05	54.21	128.83	6.54	14.21	73.80	63.28
938 IP A 30 DP.333	24.77	91.47	5997885.	40.08	3.05	383.38	67.53	84.28	55.30	127.79	7.39	13.00	75.50	64.52
939 IP A 30 DP.333	26.42	92.42	6148457.	40.59	3.05	383.03	66.46	85.47	55.28	128.53	6.42	15.38	74.17	64.24
940 IP A 30 DP.333	25.27	89.79	5863561.	40.05	3.08	382.98	64.00	80.38	52.26	128.04	6.98	11.73	74.32	61.70

941 IP A 30 DP.333	14.72	23.81	5207489.	40.01	3.12	380.40	64.74	82.74	52.91	126.52	7.32	15.82	71.52	62.97
942 IP A 30 DP.333	25.40	114.65	5062800.	40.01	3.13	390.16	62.44	84.62	51.22	126.71	6.00	15.47	70.65	60.45
943 IP A 30 DP.333	12.24	21.06	3736221.	38.54	3.22	400.13	59.89	78.94	47.82	125.23	6.64	17.38	67.70	57.22
c1 IP A 30 ME V-VII PURE	10.57	27.63	2400445.	38.45	3.40	433.07	72.43	72.66	51.12	147.99	6.74	4.09	80.18	62.83
c2 IP A 30 ME V-VII PURE	10.68	27.28	2592189.	39.15	3.16	414.51	76.10	75.19	54.66	146.88	8.21	2.70	80.07	65.50
c3 IP A 30 ME V-VII PURE	13.20	58.04	2679444.	37.75	3.20	447.31	73.12	68.63	51.52	147.42	6.27	3.28	84.77	63.21
c4 IP A 30 ME V-VII PURE	11.61	33.42	2579404.	38.35	3.21	430.81	77.02	71.56	54.43	148.64	7.53	1.57	84.24	65.64
c5 IP A 30 ME V-VII PURE	10.97	31.44	2414818.	38.30	3.14	435.68	75.25	70.38	53.21	148.15	7.74	1.25	82.38	64.53
c6 IP A 30 ME V-VII PURE	8.91	16.70	2301039.	38.64	3.20	428.77	76.04	72.43	55.13	148.06	7.98	1.87	79.08	66.05
c7 IP A 30 ME V-VII PURE	9.41	18.23	2393457.	38.86	3.25	425.80	74.83	74.30	53.28	148.09	6.94	3.95	82.29	64.52
c8 IP A 30 ME V-VII PURE	10.80	25.83	2485660.	38.84	3.27	422.95	73.34	72.21	53.12	147.06	6.81	4.01	81.06	64.02
c9 IP A 30 ME V-VII PURE	11.04	33.32	2364974.	38.46	3.20	423.75	74.00	74.25	52.82	147.24	7.14	3.40	81.55	63.37
c10 IP A 30 ME V-VII PURE	7.97	14.02	2075386.	38.41	3.28	433.54	75.05	71.99	52.69	148.08	8.72	1.86	76.38	64.12
c11 IP A 30 ME V-VII PURE	9.71	19.97	2353582.	38.36	3.53	422.89	74.96	73.46	52.15	148.42	6.17	1.57	82.79	63.70
c12 IP A 30 ME V-VII PURE	11.62	26.89	2720086.	39.52	3.23	418.65	75.46	73.74	54.19	147.25	6.15	3.92	87.15	64.86
c13 IP A 30 ME V-VII PURE	8.53	16.40	2104924.	38.47	3.19	430.71	73.76	68.79	52.52	147.43	8.22	1.91	78.07	63.85
c14 IP A 30 ME V-VII PURE	5.89	7.94	1727571.	38.36	3.24	447.24	72.77	69.22	51.49	146.09	7.09	1.62	79.64	62.24
c15 IP A 30 ME V-VII PURE	7.16	15.15	1601238.	38.92	3.30	436.99	73.79	71.72	53.56	146.36	8.24	2.49	77.68	64.08
c16 IP A 30 ME V-VII PURE	2.66	1.29	759886.	37.34	3.48	461.71	68.83	65.42	47.85	145.85	6.92	2.11	74.39	58.82
c17 IP A 30 ME V-VII PURE	13.62	55.52	2860748.	39.26	3.20	433.01	78.05	73.56	55.31	148.79	6.52	2.65	87.32	66.28
c18 IP A 30 ME V-VII PURE	10.75	23.03	2544140.	38.82	3.20	424.74	74.07	70.28	52.52	147.69	6.36	3.13	84.13	63.92
c19 IP A 30 ME V-VII PURE	8.67	18.55	2095075.	38.03	3.26	427.39	74.15	71.05	52.07	148.14	7.52	3.75	79.26	63.29
c20 IP A 30 ME V-VII PURE	10.09	20.69	2515817.	38.92	3.26	418.94	75.27	72.83	54.72	146.52	7.74	1.57	81.03	65.78
c21 IP A 30 ME V-VII PURE	8.70	18.14	2059111.	38.44	3.18	436.28	72.13	69.46	51.02	148.33	7.82	2.24	77.43	62.05
c22 IP A 30 ME V-VII PURE	9.30	20.06	2264174.	39.01	3.24	419.11	75.73	72.36	53.62	147.41	8.16	2.46	79.74	64.90
c23 IP A 30 ME V-VII PURE	10.18	24.41	2314722.	38.87	3.21	431.01	71.78	73.47	51.21	146.65	6.86	5.31	78.84	62.50
d1 IP A 18 30 ME6-2	15.72	32.73	4487663.	43.89	3.14	385.02	73.17	87.69	63.64	143.84	6.63	2.54	88.78	73.09
d2 IP A 18 30 ME6-2	14.32	31.56	3917694.	41.87	3.14	384.76	68.37	80.57	56.95	144.53	7.24	3.89	83.07	68.28
d3 IP A 18 30 ME6-2	13.34	27.28	3671694.	42.78	3.18	390.05	70.87	85.12	60.83	143.86	8.85	2.91	81.76	70.76
d4 IP A 18 30 ME6-2	13.01	25.03	3848551.	42.32	3.09	393.38	71.75	82.39	60.42	144.66	7.95	3.49	81.81	71.19
d5 IP A 18 30 ME6-2	14.45	30.64	3791268.	42.55	3.11	380.73	69.38	85.69	59.35	142.42	7.82	5.05	81.99	69.32
d6 IP A 18 30 ME6-2	13.24	26.22	3722034.	42.07	3.15	386.91	68.40	84.60	57.98	144.16	6.46	3.93	83.31	68.75
d7 IP A 18 30 ME6-2	15.64	37.44	4054027.	42.41	3.08	390.99	70.08	83.21	60.50	143.69	7.44	2.16	82.82	70.39
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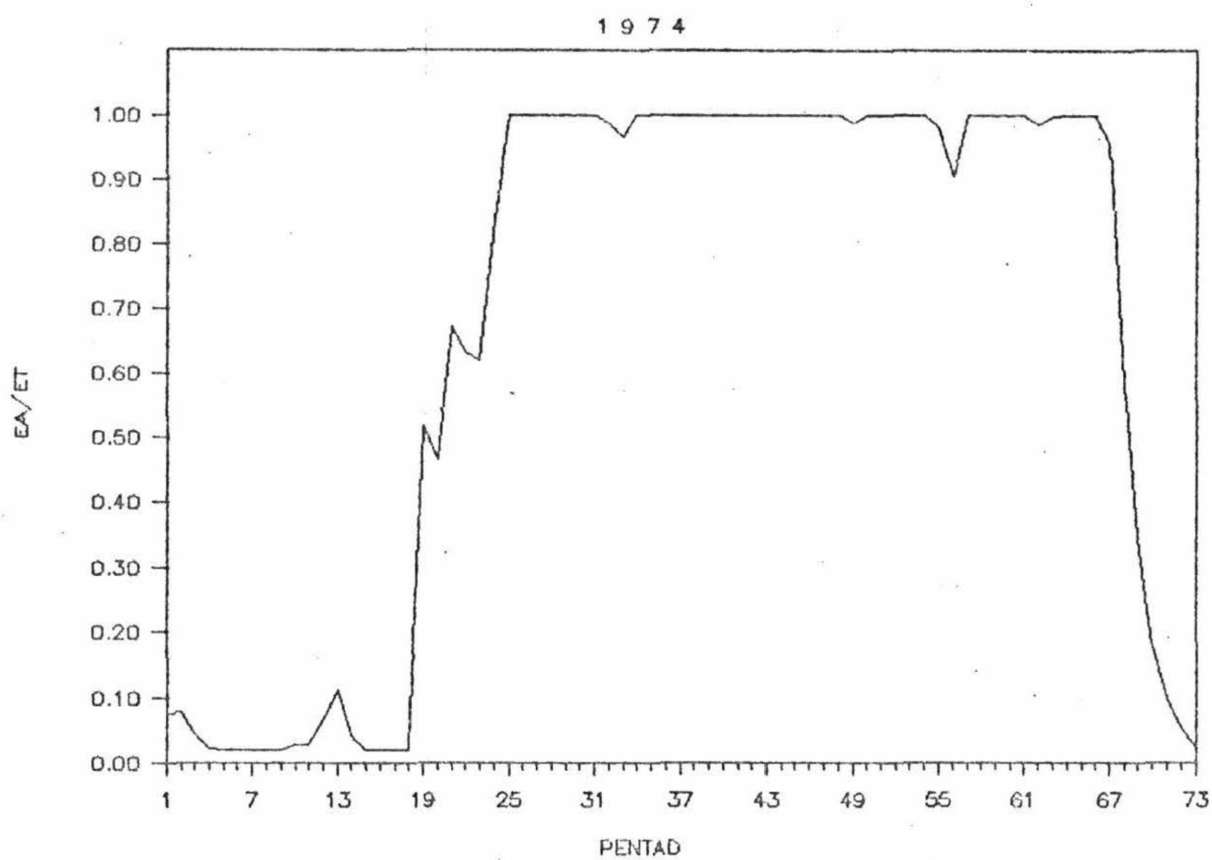
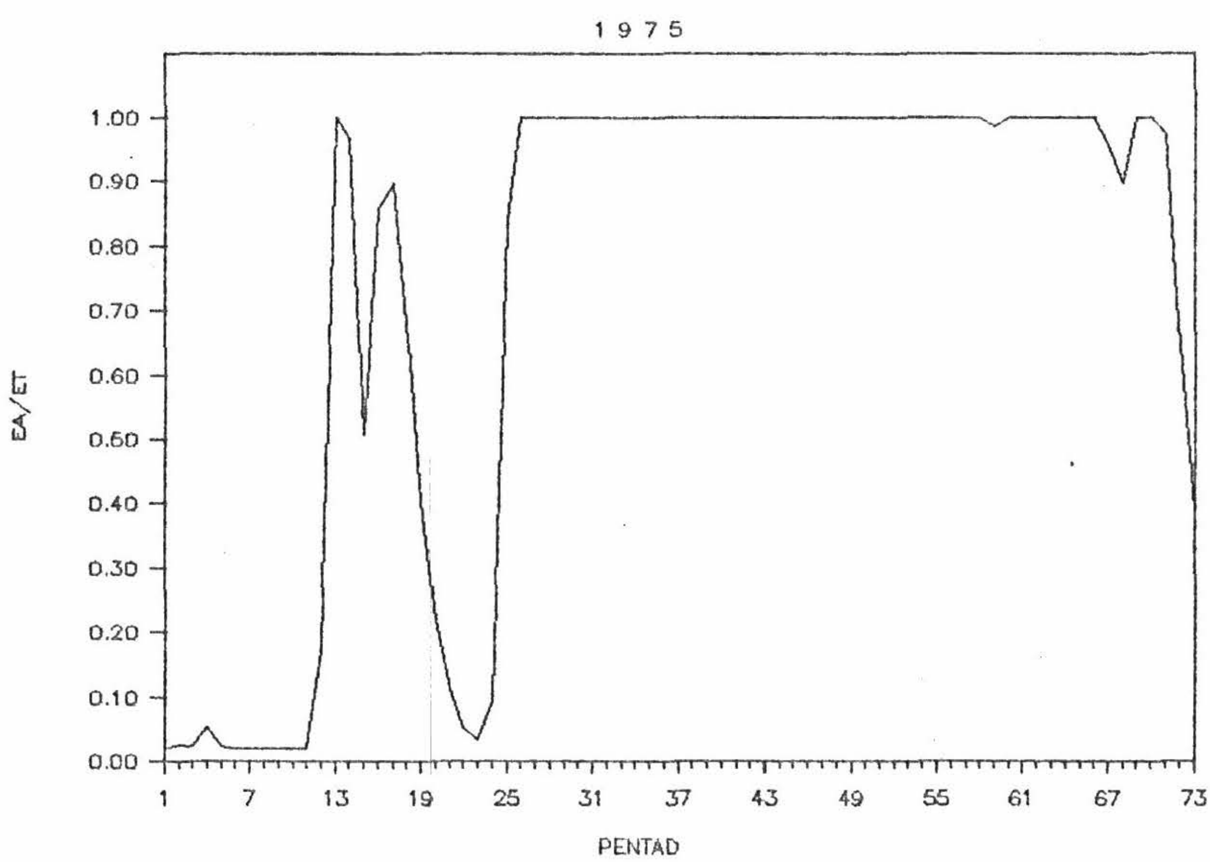
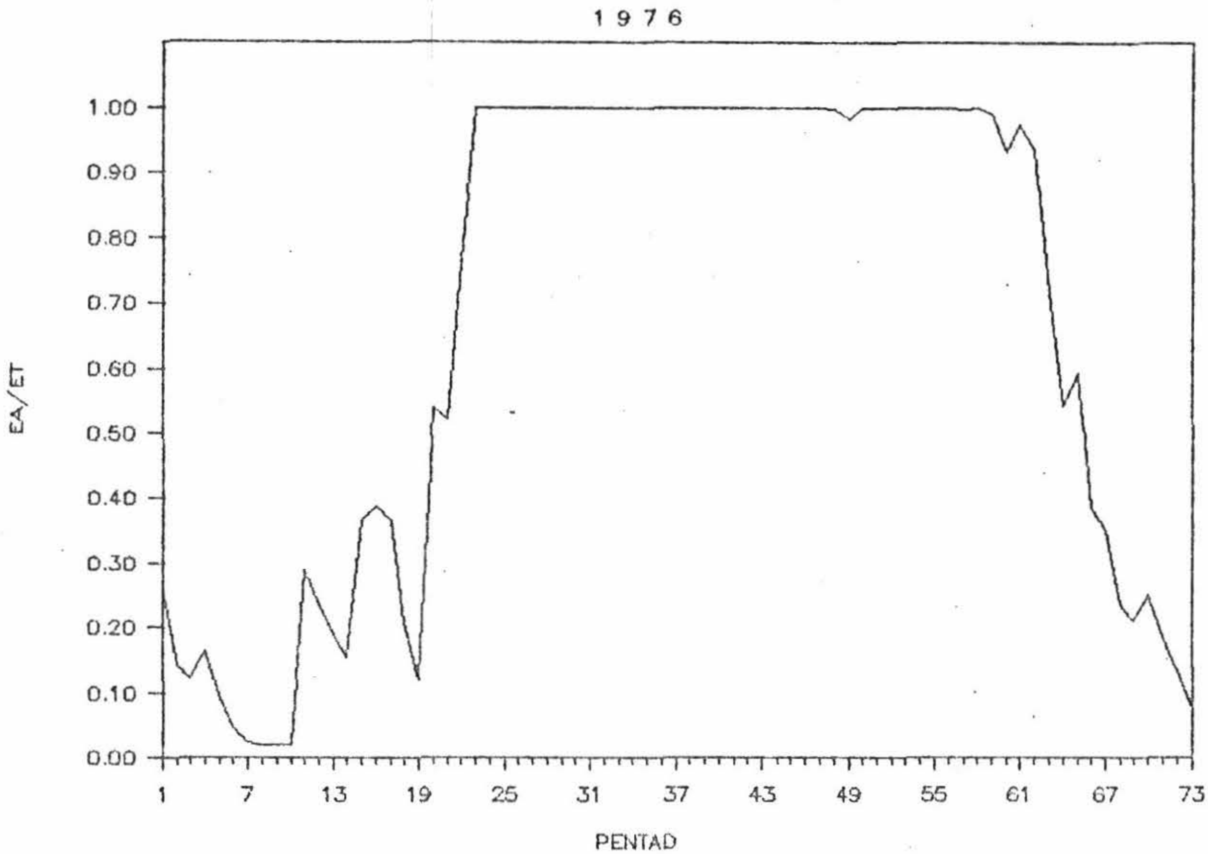
d9 IP A 18 30 ME6-2	14.14	30.45	3954471.	43.39	3.20	389.77	71.94	86.68	61.73	142.41	7.88	1.05	81.87	71.59
d10 IP A 18 30 ME6-2	13.93	26.08	4109580.	43.05	3.15	385.66	72.33	87.71	61.81	144.71	5.67	2.60	87.65	71.91
d11 IP A 18 30 ME6-2	15.74	42.71	4121221.	42.42	3.15	381.99	69.33	81.52	58.48	143.17	6.29	3.32	86.30	69.05
d12 IP A 18 30 ME6-2	14.75	32.79	4059125.	42.20	3.13	391.19	71.75	85.55	60.46	145.90	7.22	2.23	84.67	71.55
d13 IP A 18 30 ME6-2	17.17	41.65	4395289.	42.60	3.17	391.13	71.39	83.02	60.69	145.33	5.73	1.62	88.76	71.52
d14 IP A 18 30 ME6-2	16.13	36.28	4388500.	43.33	3.14	387.77	72.01	82.30	61.77	143.08	7.16	2.66	85.51	71.53
d15 IP A 18 30 ME6-2	15.07	35.89	3886255.	42.40	3.13	396.55	71.87	83.68	61.29	143.69	7.59	2.43	81.95	71.25
d16 IP A 18 30 ME6-2	14.69	32.62	4097932.	42.10	3.11	388.66	68.82	79.92	57.95	144.11	5.87	3.04	85.44	68.65
d17 IP A 18 30 ME6-2	16.13	36.04	4625978.	43.90	3.13	389.26	72.21	82.36	62.85	143.68	6.19	1.82	89.09	72.34
d18 IP A 18 30 ME6-2	16.53	41.68	4298127.	43.29	3.14	386.99	70.95	81.80	60.60	143.03	6.57	2.12	85.62	70.82
d19 IP A 18 30 ME6-2	15.96	42.99	3993088.	42.95	3.15	387.36	73.19	86.58	62.76	145.21	7.75	3.13	83.94	72.77
d20 IP A 18 30 ME6-2	16.68	43.24	4443929.	43.03	3.14	387.28	73.64	85.25	63.41	144.53	6.90	2.35	87.99	73.24
d21 IP A 18 30 ME6-2	11.69	21.45	3448986.	41.82	3.18	397.65	68.25	79.73	56.82	142.34	6.06	4.25	83.43	67.64
d22 IP A 18 30 ME6-2	13.22	39.54	2965331.	41.25	3.21	415.69	68.00	80.19	57.31	141.71	7.31	2.34	79.80	67.55
d23 IP A 18 30 ME6-2	6.61	9.36	1983674.	41.03	3.22	410.84	66.56	77.65	55.87	142.59	9.09	3.47	73.37	66.32
e1 IP A 30 DF.333 W+W	24.10	67.74	6121908.	41.40	3.03	387.49	70.07	84.18	58.95	133.40	6.78	5.28	79.42	67.64
e2 IP A 30 DF.333 W+W	21.62	56.10	6018697.	41.52	3.10	388.43	69.28	85.39	58.61	132.85	6.55	6.01	78.75	66.98
e3 IP A 30 DF.333 W+W	25.21	85.11	6200107.	40.85	3.06	383.92	72.54	84.82	59.96	132.34	5.88	5.38	83.22	68.75
e4 IP A 30 DF.333 W+W	21.62	57.60	5555129.	40.10	3.03	382.89	69.39	82.04	56.14	133.59	7.18	8.70	77.04	66.04
e5 IP A 30 DF.333 W+W	25.95	77.72	6613737.	41.78	3.09	382.38	69.86	82.80	58.50	133.62	5.42	6.04	83.64	67.72
e6 IP A.30 DF.333 W+W	23.39	59.34	6547900.	41.74	3.07	395.46	73.09	85.88	61.83	132.76	4.77	2.95	87.16	70.53

e7	IP A 30 DF.333 W+W	21.47	55.86	5289161.	40.79	3.04	386.98	71.44	84.53	58.30	133.74	9.81	7.33	74.68	67.54
e8	IP A 30 DF.333 W+W	21.50	55.43	5509330.	40.99	3.06	388.06	70.29	81.50	58.13	133.91	7.85	6.74	78.39	67.23
e9	IP A 30 DF.333 W+W	26.18	91.81	5922151.	40.77	3.14	385.54	72.90	85.77	59.96	133.19	7.40	7.65	81.09	69.22
e10	IP A 30 DF.333 W+W	22.31	75.35	5536240.	40.17	3.06	388.89	71.08	79.21	57.47	133.09	7.94	7.02	79.74	67.36
e11	IP A 30 DF.333 W+W	22.01	61.51	5600393.	41.14	3.02	392.03	72.14	84.02	59.77	132.79	8.46	5.29	76.35	68.61
e12	IP A 30 DF.333 W+W	23.98	65.75	6064780.	41.29	3.10	385.29	71.46	85.96	59.36	131.39	7.30	4.99	79.90	67.74
e13	IP A 30 DF.333 W+W	23.52	80.73	5641953.	40.63	3.09	386.81	69.18	80.71	56.74	135.59	7.68	6.67	76.73	66.41
e14	IP A 30 DF.333 W+W	22.96	65.59	5312503.	40.36	3.05	391.03	71.82	83.11	58.16	135.29	7.88	6.99	76.86	67.69
e15	IP A 30 DF.333 W+W	23.22	77.29	5805089.	41.15	3.06	381.79	72.17	84.64	59.55	132.01	7.68	7.39	78.26	68.06
e16	IP A 30 DF.333 W+W	26.88	0.00	6061873.	40.81	3.01	391.24	70.71	81.27	57.87	133.56	6.18	6.79	81.34	67.49
e17	IP A 30 DF.333 W+W	22.56	65.10	5401926.	40.50	3.10	392.38	72.53	81.46	58.61	135.60	7.87	5.46	77.72	68.56
e18	IP A 30 DF.333 W+W	25.42	80.63	6227584.	41.39	3.07	380.14	74.03	88.17	62.79	132.84	7.82	5.19	82.70	70.75
e19	IP A 30 DF.333 W+W	22.62	69.55	5719436.	40.34	3.14	390.16	71.39	84.31	58.79	132.16	7.94	5.46	75.47	67.68
e20	IP A 30 DF.333 W+W	24.30	80.42	6106263.	41.05	3.02	389.82	70.41	81.77	58.27	134.46	5.64	6.45	83.35	68.12
e21	IP A 30 DF.333 W+W	15.83	29.22	4968386.	40.18	3.10	396.82	68.48	82.89	56.46	133.16	7.03	8.97	76.99	65.17
e22	IP A 30 DF.333 W+W	22.51	83.22	4282977.	38.79	3.03	399.83	69.91	82.17	56.59	132.80	8.33	9.09	73.29	65.41
e23	IP A 30 DF.333 W+W	9.59	16.37	2882197.	38.21	3.27	408.78	65.49	80.31	51.93	130.53	9.85	12.36	63.51	61.62
f1	IP A ME6-2 0.333W+W	28.21	104.50	6623269.	41.38	3.14	385.52	65.21	84.36	56.37	130.26	5.60	5.68	86.28	65.81
f2	IP A ME6-2 0.333W+W	24.82	80.39	6168507.	40.66	3.12	398.79	64.21	81.89	53.76	130.56	3.47	6.86	87.96	63.92
f3	IP A ME6-2 0.333W+W	25.23	71.57	6390479.	41.67	3.13	395.89	66.08	84.89	57.36	131.30	6.12	3.29	83.95	66.52
f4	IP A ME6-2 0.333W+W	23.44	54.11	6385661.	41.78	3.11	386.79	64.48	84.63	55.60	130.08	4.74	7.45	85.78	64.85
f5	IP A ME6-2 0.333W+W	23.76	73.86	6501421.	41.95	3.15	390.46	65.17	84.21	56.02	129.95	6.77	5.05	80.36	65.02
f6	IP A ME6-2 0.333W+W	25.16	80.77	6159000.	40.44	3.10	386.45	64.94	85.80	55.06	132.07	6.23	8.22	81.66	65.35
f7	IP A ME6-2 0.333W+W	28.09	75.18	6898501.	42.19	3.16	386.66	65.07	85.63	55.58	129.78	3.40	6.35	88.73	64.94
f8	IP A ME6-2 0.333W+W	25.20	65.69	6465661.	41.34	3.10	390.02	64.15	84.22	54.56	130.54	4.75	6.27	82.92	64.28
f9	IP A ME6-2 0.333W+W	27.38	106.38	6557944.	41.58	3.10	390.01	65.88	83.65	56.84	130.48	6.65	5.68	84.15	66.04
f10	IP A ME6-2 0.333W+W	25.95	66.16	7144805.	42.38	3.12	389.37	65.90	85.44	56.71	129.91	4.35	5.19	88.82	65.93
f11	IP A ME6-2 0.333W+W	25.93	64.92	7041438.	42.64	3.17	386.09	65.70	89.79	57.09	129.96	4.35	4.94	88.64	66.02
f12	IP A ME6-2 0.333W+W	28.19	82.92	6929149.	41.30	3.07	394.90	66.33	84.81	57.12	131.43	3.85	5.16	88.71	66.39
f13	IP A ME6-2 0.333W+W	24.83	74.52	6734378.	41.74	3.15	389.22	65.69	85.80	56.25	130.95	4.92	5.38	83.66	65.78
f14	IP A ME6-2 0.333W+W	23.99	58.68	6456389.	41.56	3.13	386.90	63.64	82.45	54.53	129.23	4.53	5.22	94.50	63.70
f15	IP A ME6-2 0.333W+W	25.72	77.27	6832728.	41.97	3.11	395.69	66.77	83.90	57.77	130.80	4.92	4.02	87.74	66.90
f16	IP A ME6-2 0.333W+W	25.49	67.50	6833099.	42.24	3.07	388.25	67.90	86.36	58.71	131.09	6.63	5.47	84.62	68.14
f17	IP A ME6-2 0.333W+W	23.50	50.47	6882885.	42.40	3.14	381.44	64.70	85.66	56.04	129.00	3.96	5.26	88.06	64.73
f18	IP A ME6-2 0.333W+W	26.71	67.82	7026966.	41.84	3.10	395.68	65.32	84.12	56.33	131.81	3.40	4.08	88.90	65.69
f19	IP A ME6-2 0.333W+W	30.90	0.00	6915452.	42.34	3.09	385.53	66.65	87.48	58.25	130.95	6.64	3.42	83.28	67.16
f20	IP A ME6-2 0.333W+W	23.78	58.53	6392896.	41.37	3.11	389.82	66.93	84.89	57.55	131.37	5.54	5.65	84.20	66.79
f21	IP A ME6-2 0.333W+W	19.53	0.00	5514847.	40.15	3.14	404.97	60.87	81.66	50.77	129.48	5.02	8.36	80.25	61.26
f22	IP A ME6-2 0.333W+W	25.43	84.70	5647461.	41.40	3.12	411.90	61.57	81.02	52.26	129.59	3.76	8.49	81.17	61.85
f23	IP A ME6-2 0.333W+W	13.70	23.13	4457513.	40.52	3.24	412.42	58.01	80.34	48.20	128.69	3.97	10.06	78.03	58.55

FIGURE A1 EVAPOTRANSPIRATION RATIO AT CARIMAGUA



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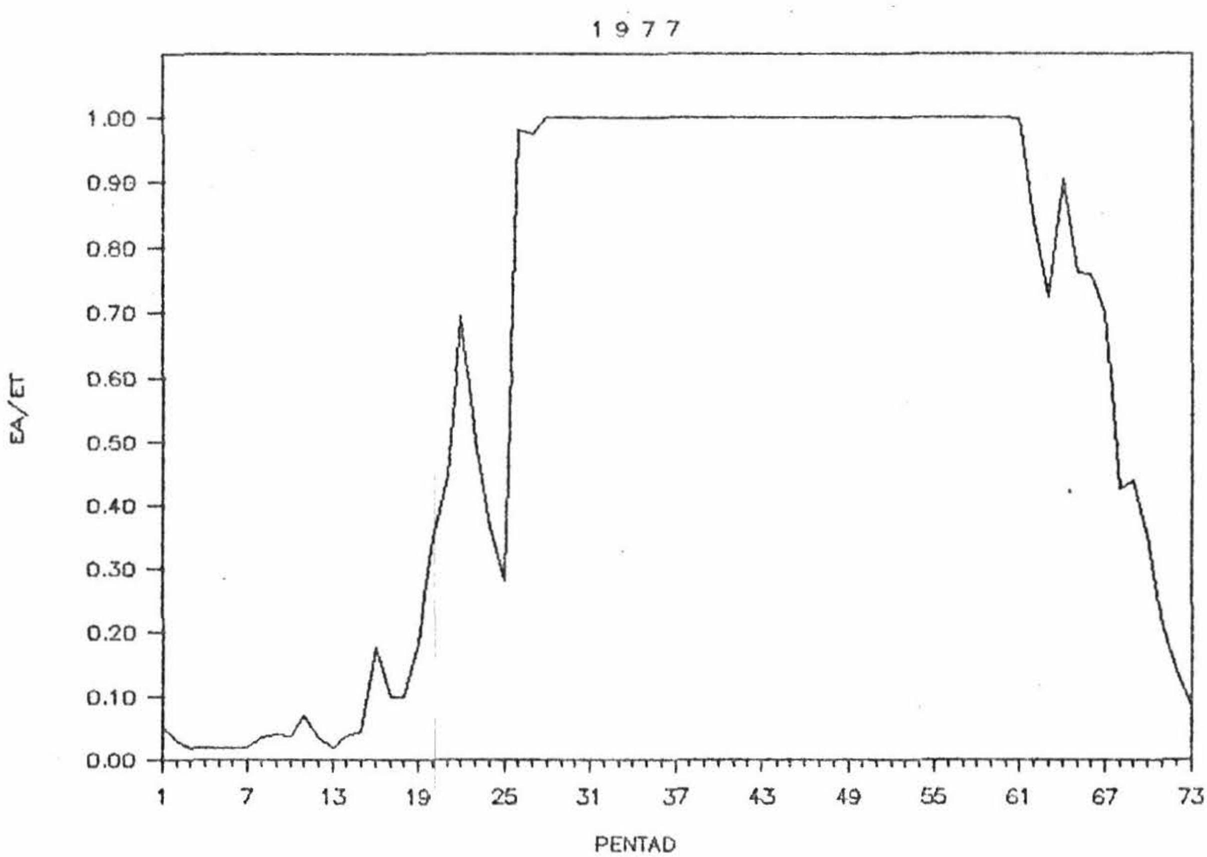
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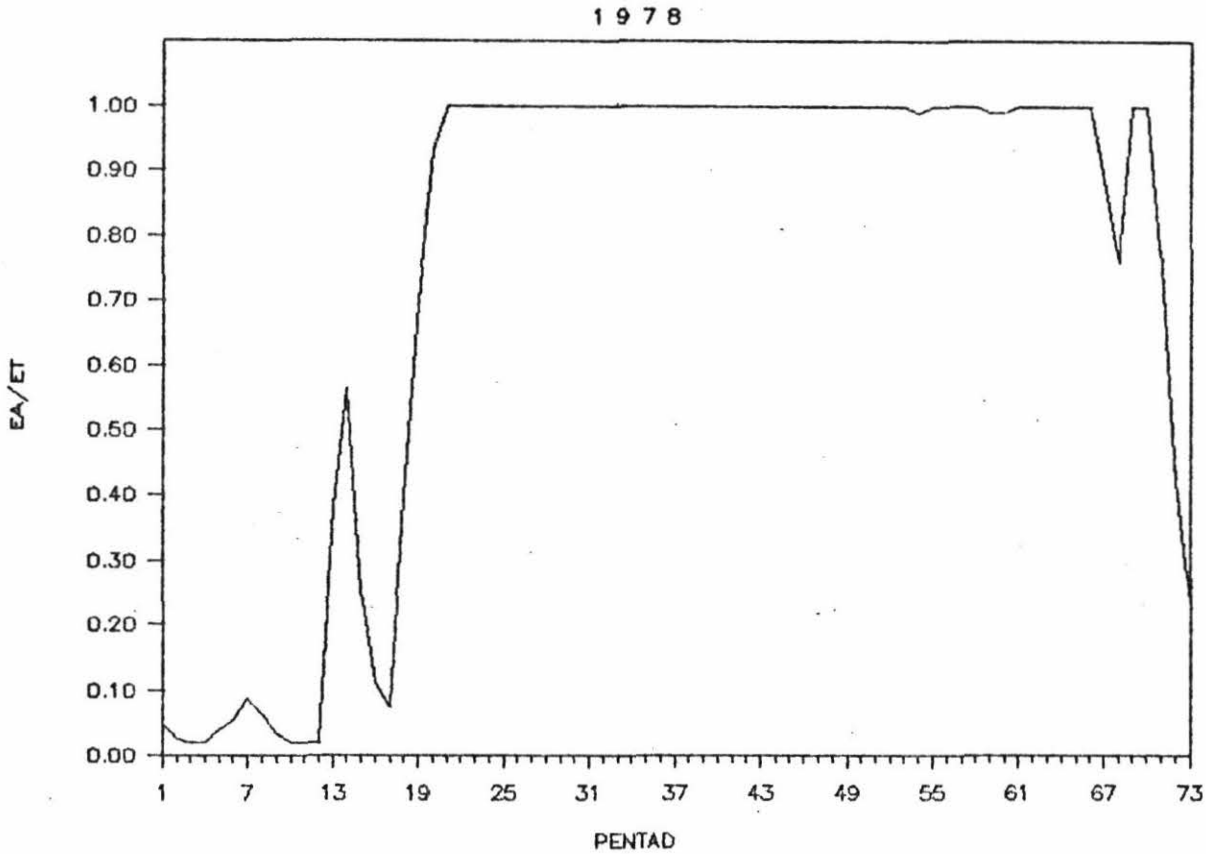
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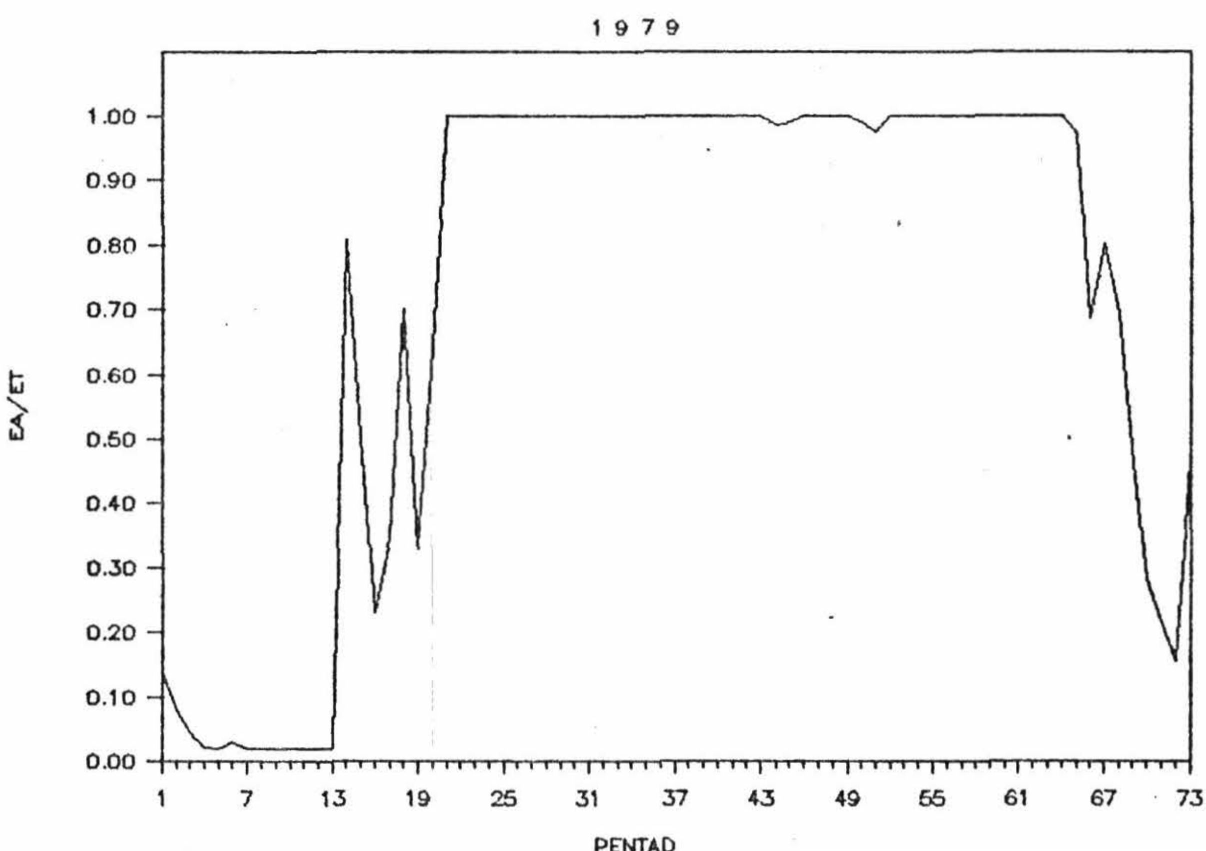
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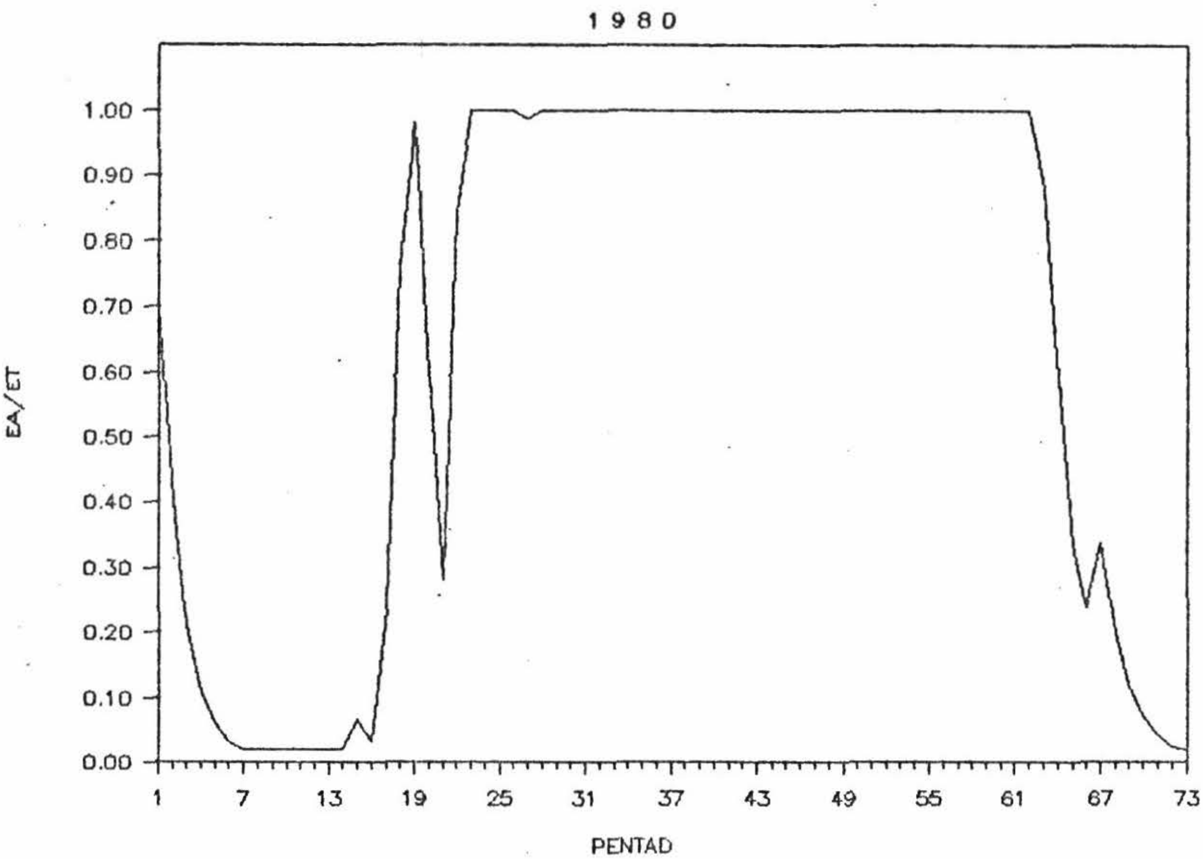
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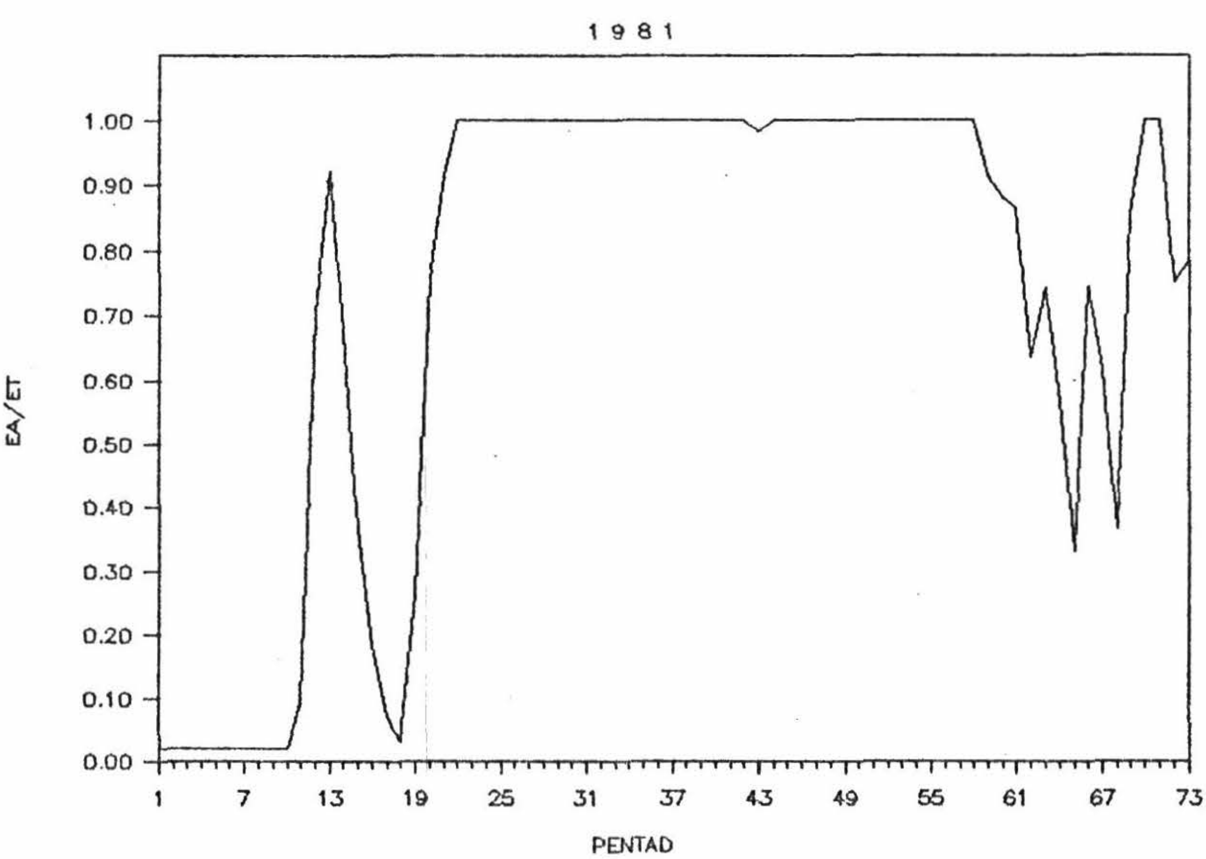
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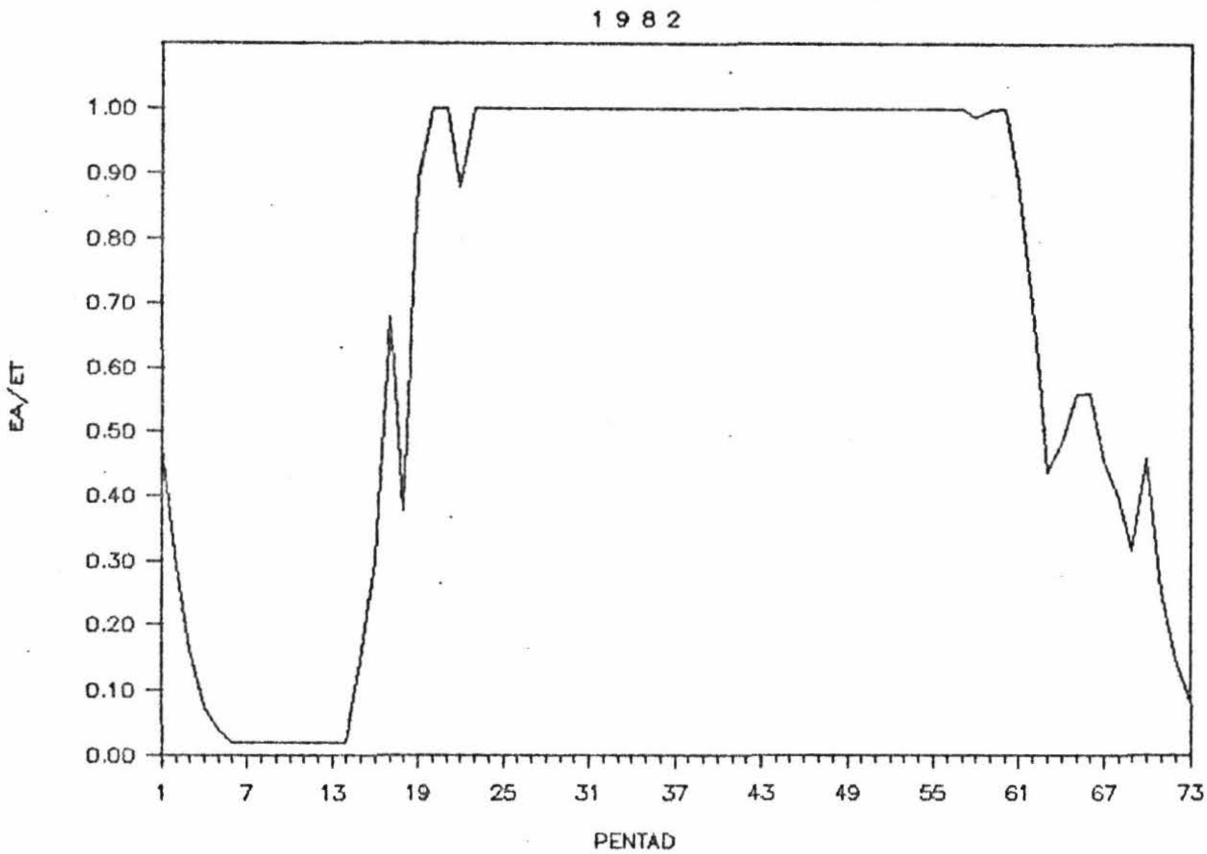
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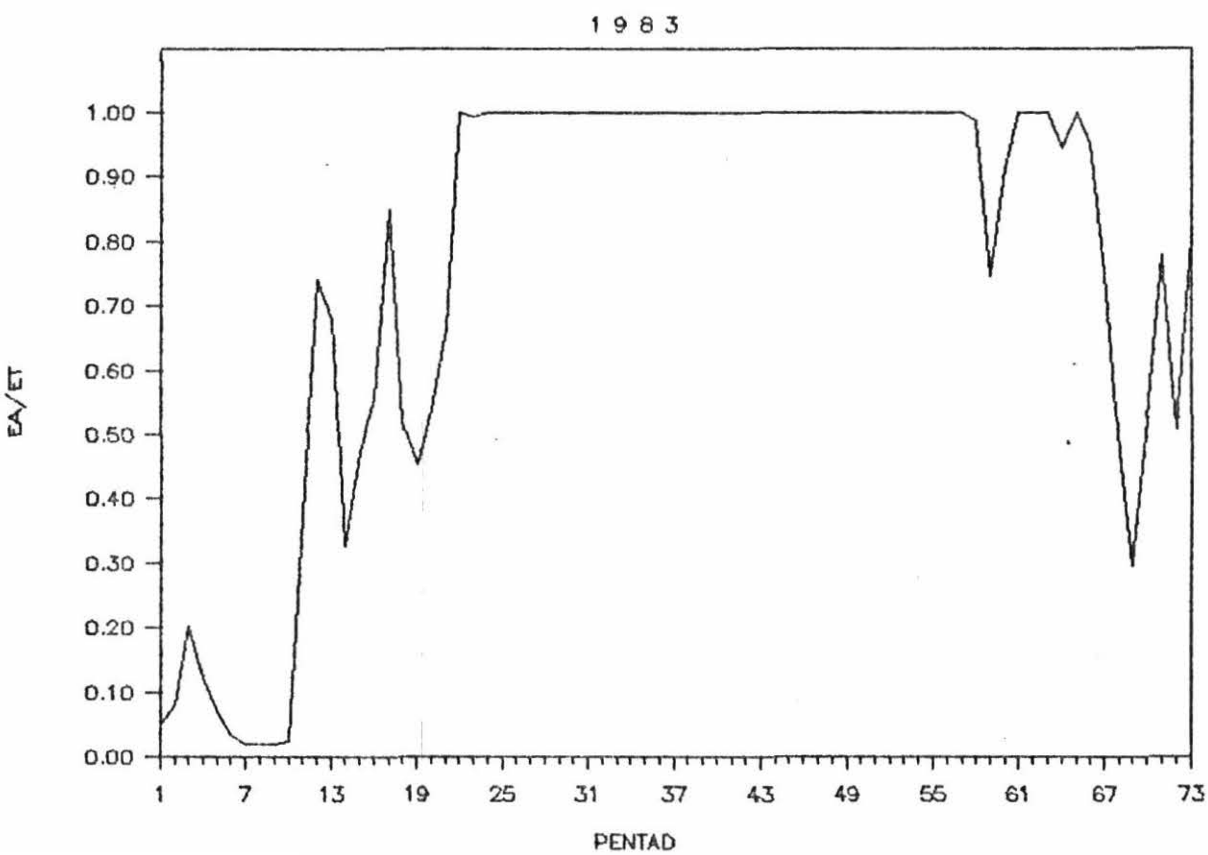
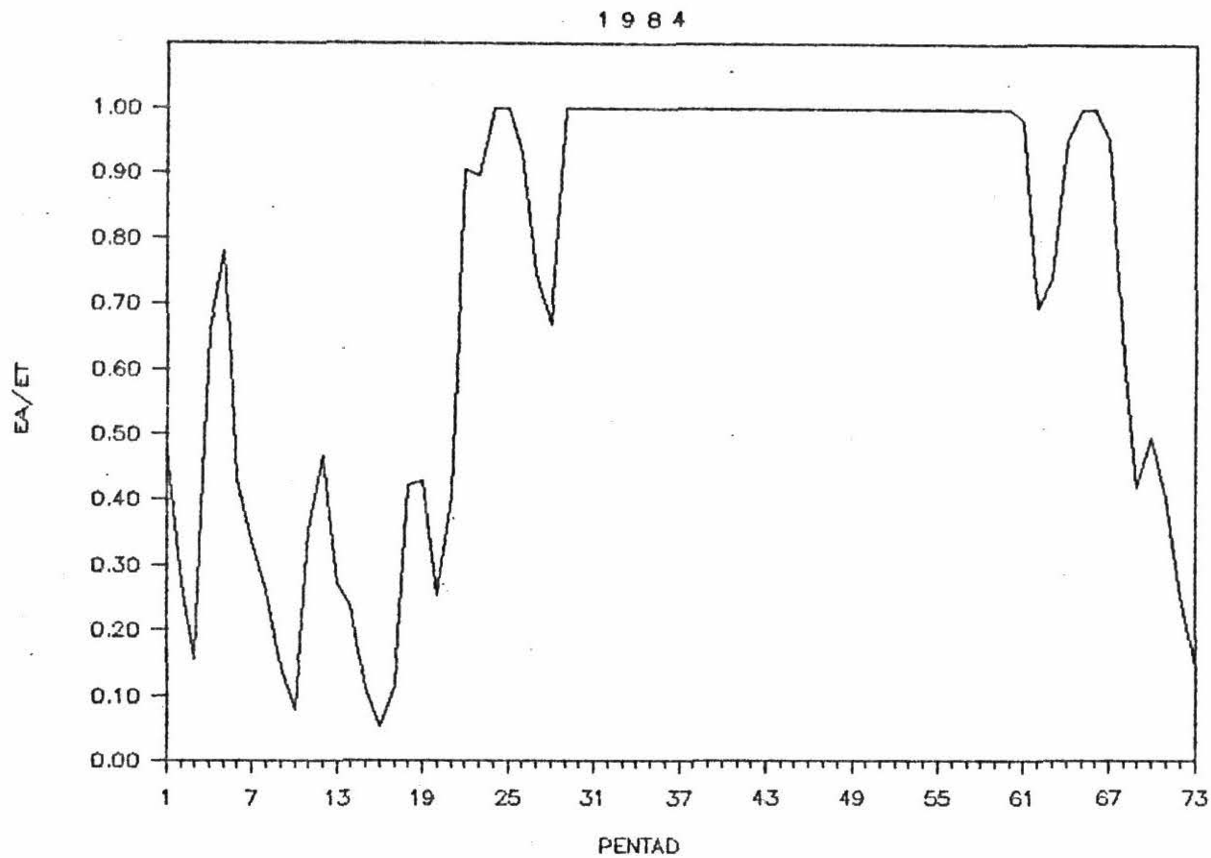
0.50
0.40
0.30
0.20
0.10
0.00
EA/ET
1 7 13 19 25 31 37 43 49 55 61 67 73
PENTAD


1 9 8 3
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
EA/ET
1 7 13 19 25 31 37 43 49 55 61 67 73
PENTAD


1 9 8 4
EA/ET
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
1 7 13 19 25 31 37 43 49 55 61 67 73
PENTAD

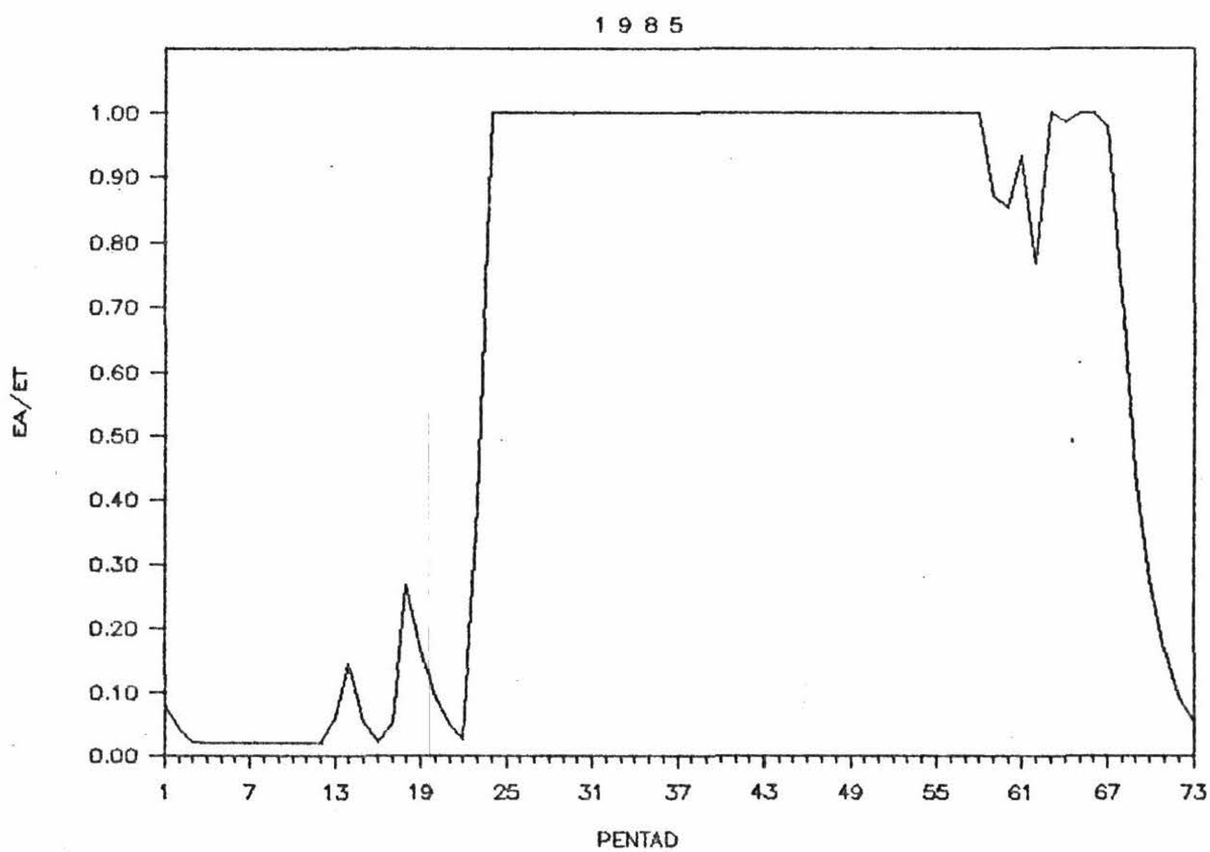
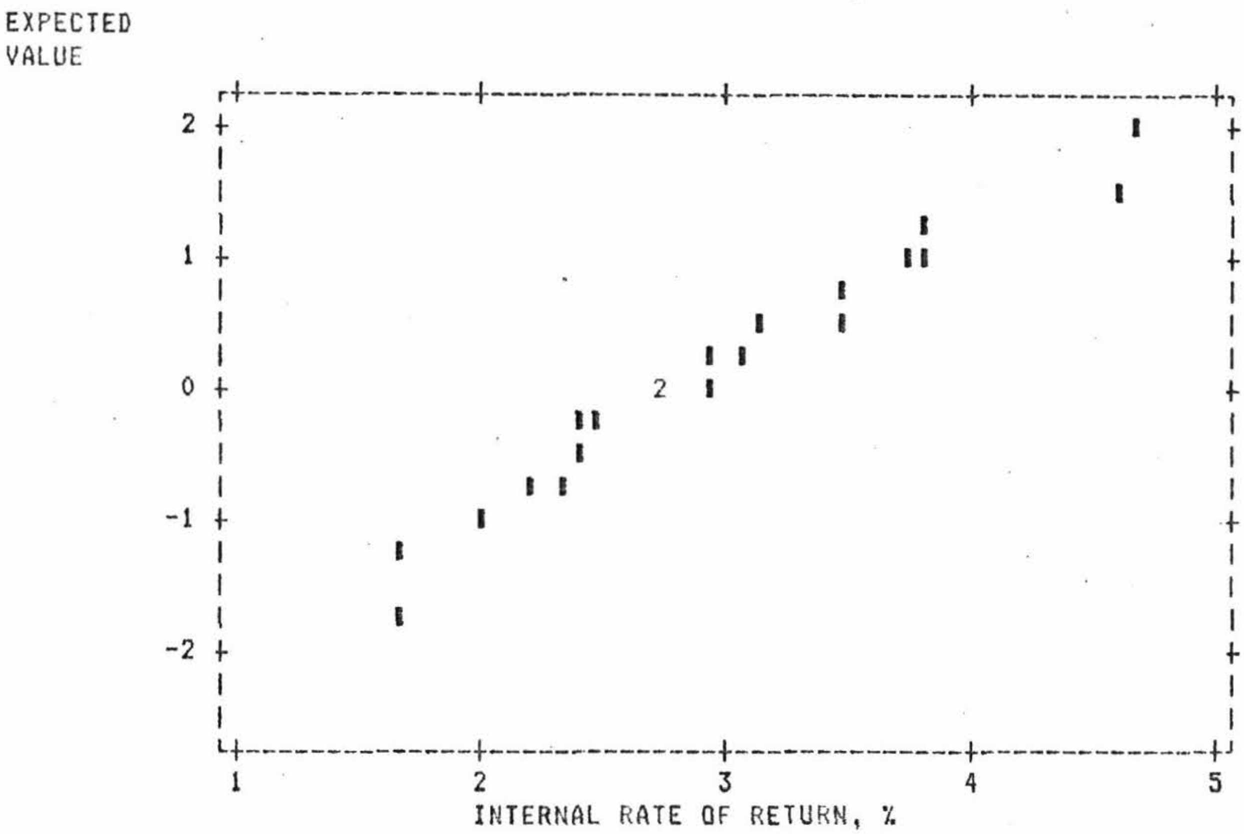
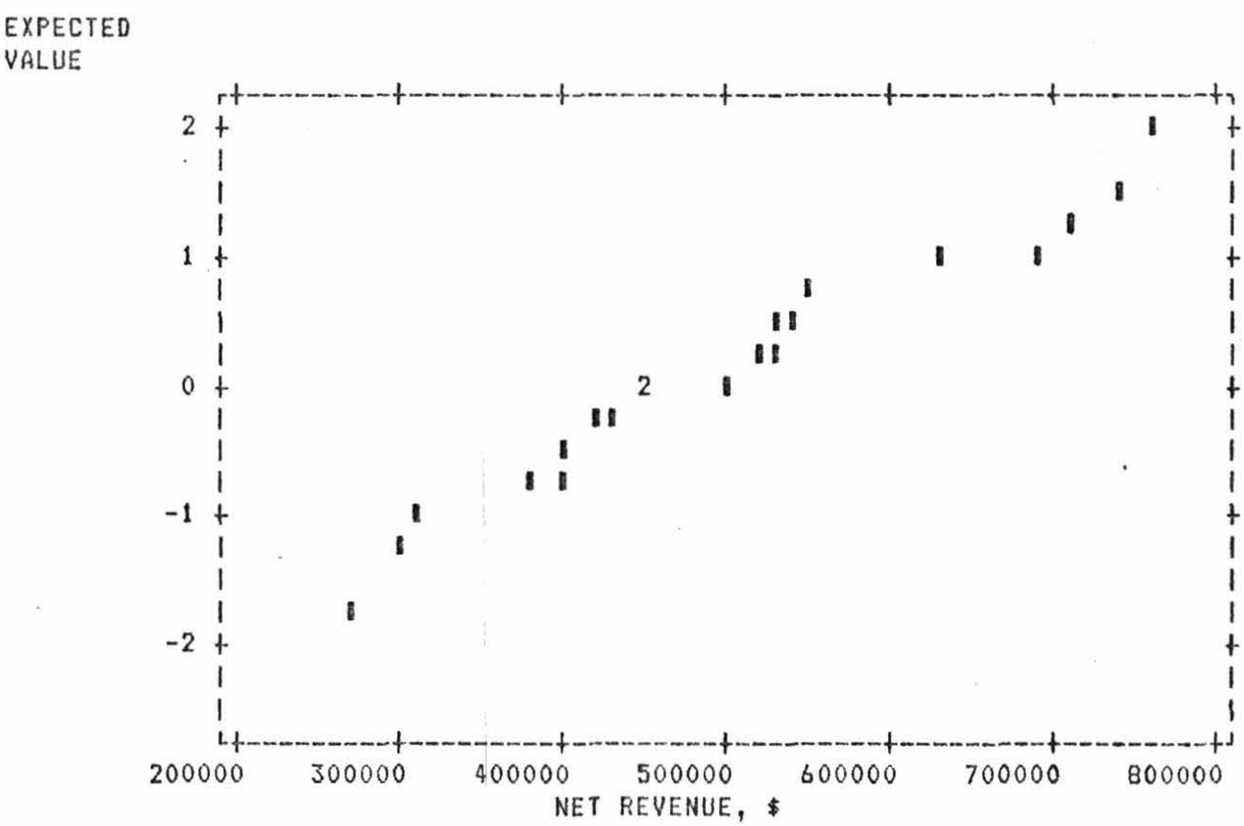
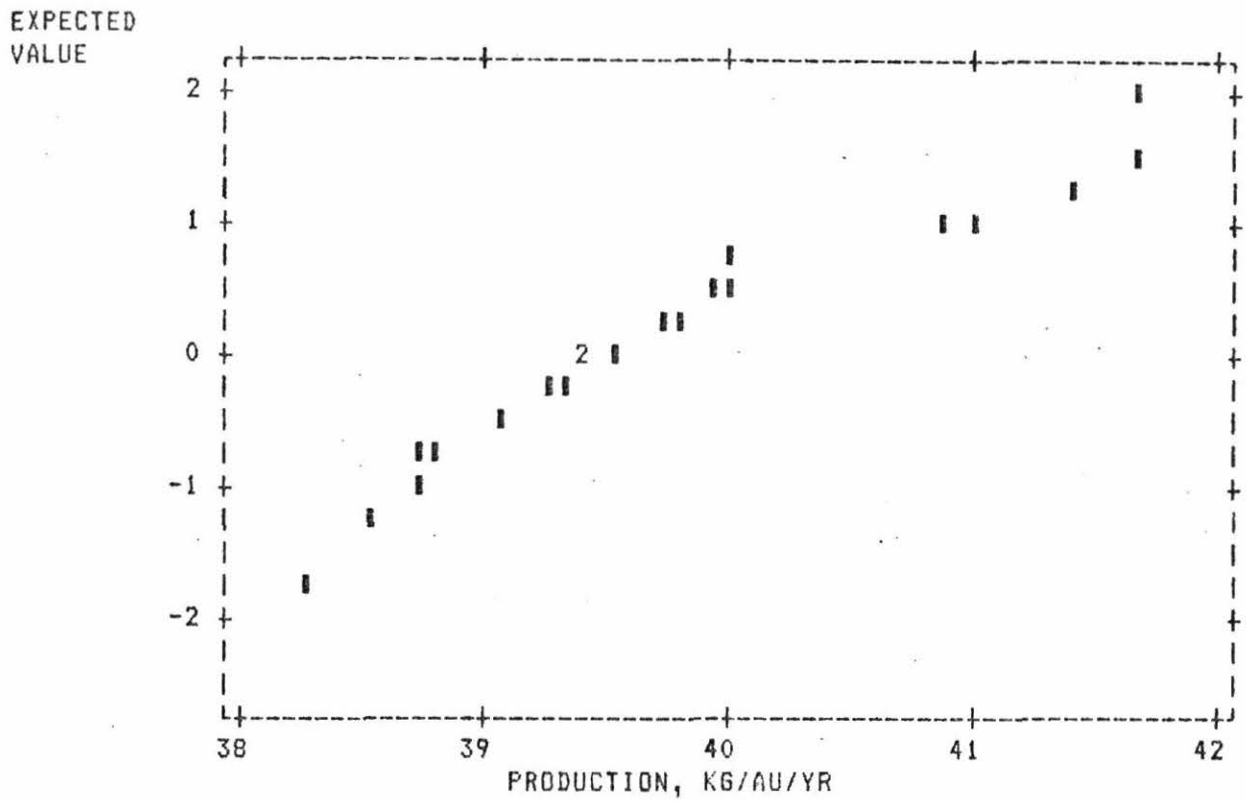

1 9 8 5
EA/ET
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
1 7 13 19 25 31 37 43 49 55 61 67 73
PENTAD

FIGURE A3 NORMAL PROBABILITY PLOTS, TREATMENT T1






EXPECTED
VALUE
2
1
0
-1
-2
38
39
40
41
42
PRODUCTION, KG/AU/YR

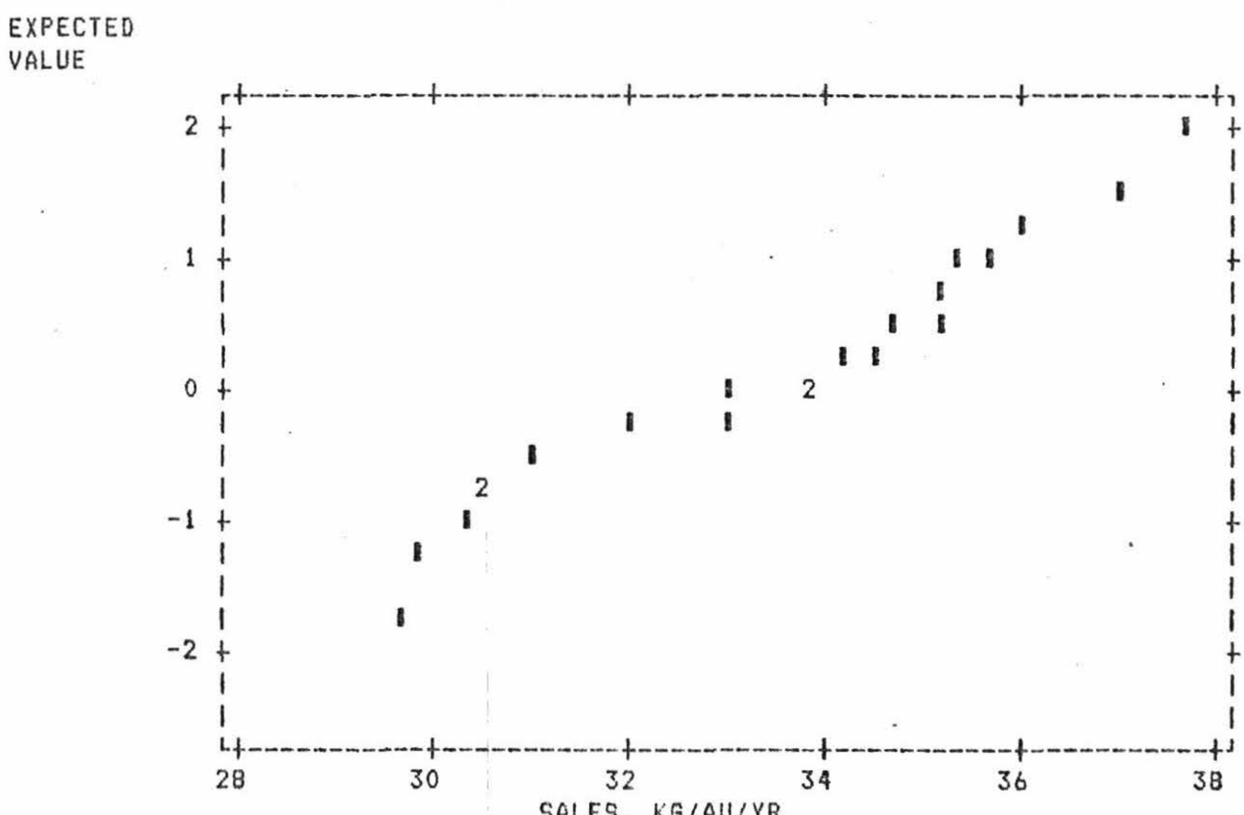
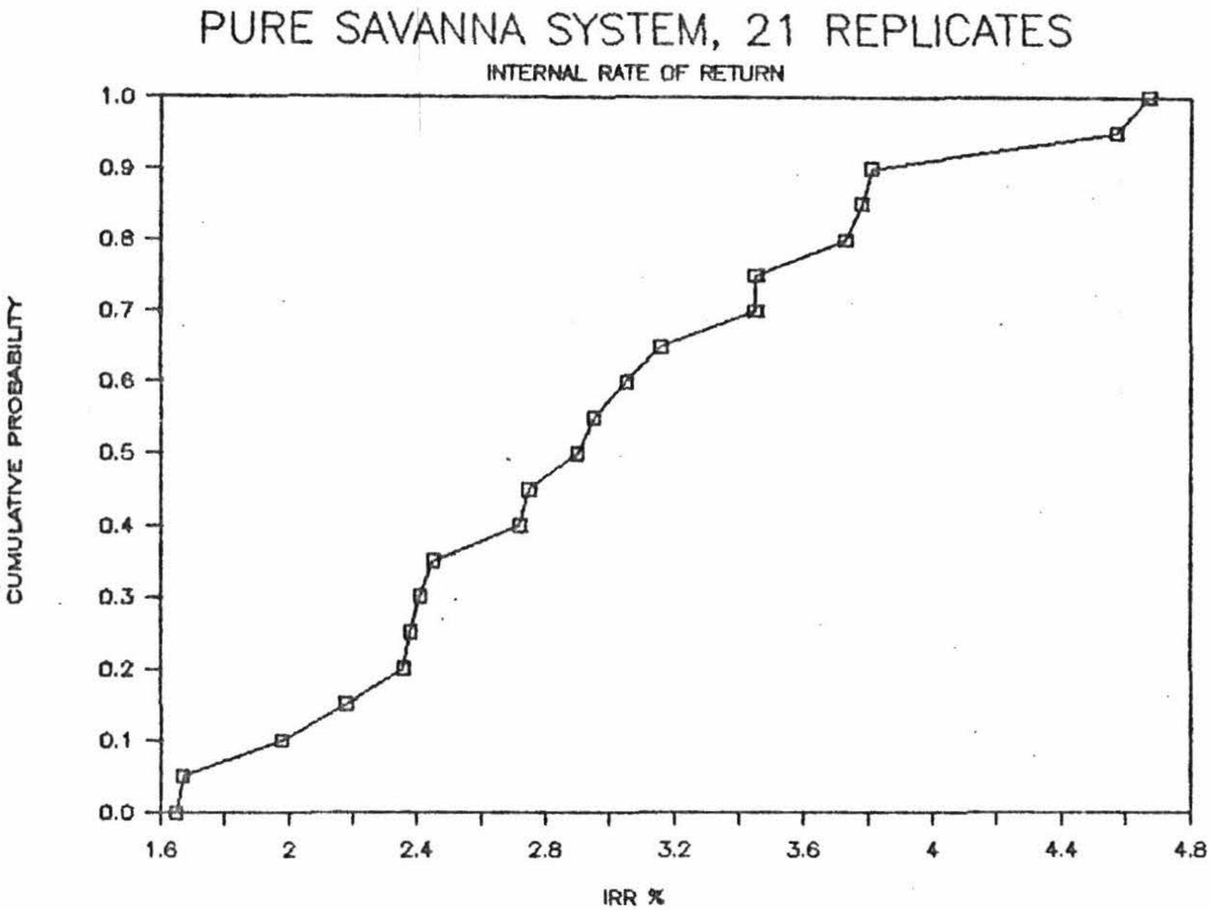
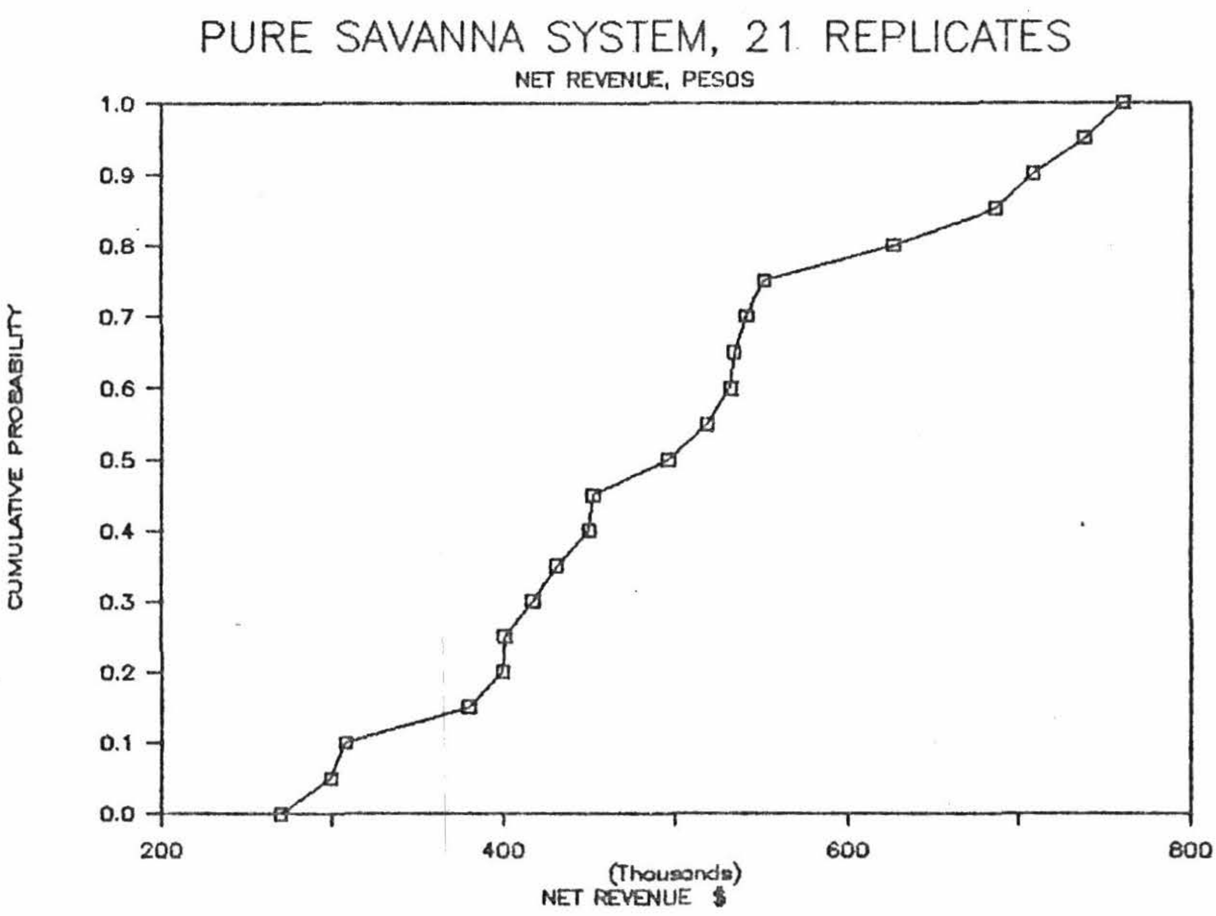
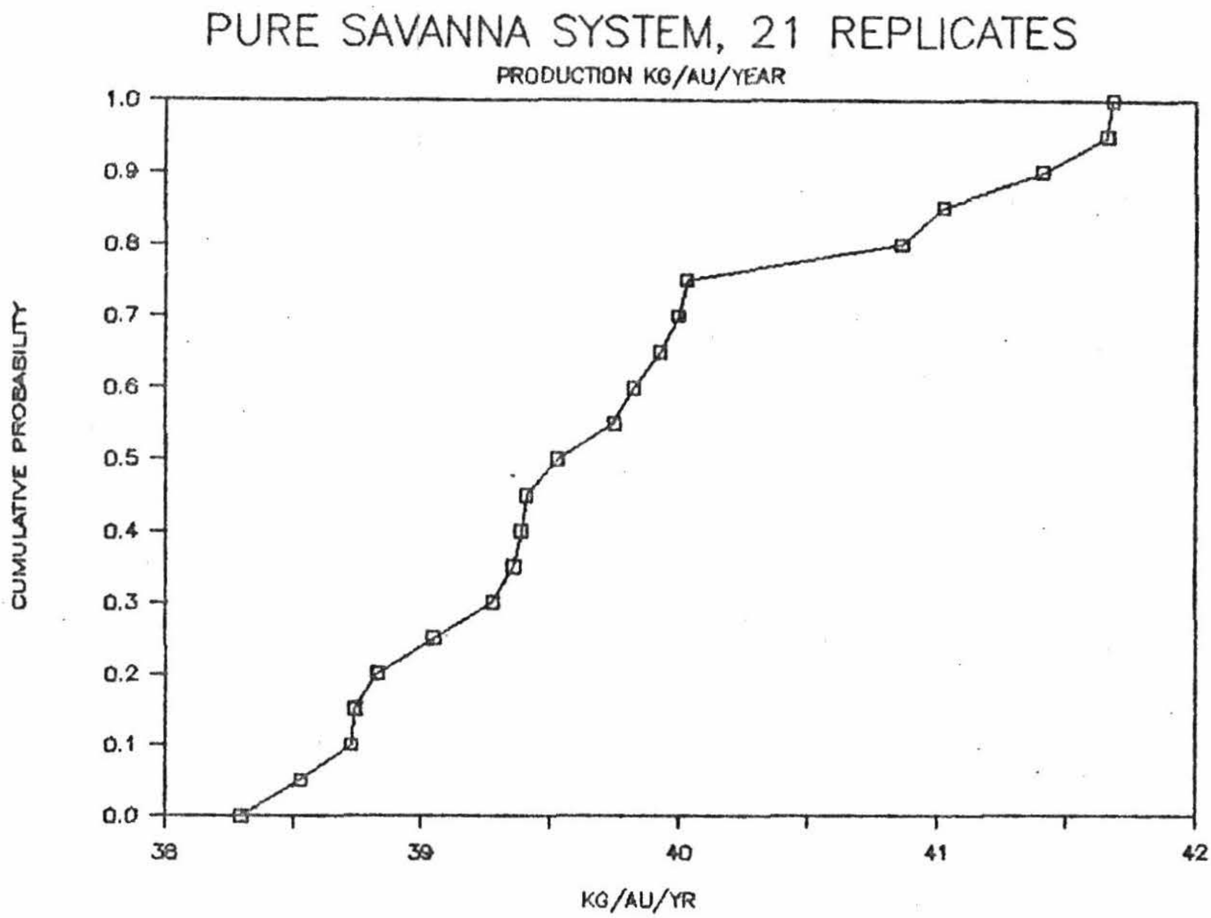

EXPECTED
VALUE
2
1
0
-1
-2
28
30
32
34
36
38
SALES, KG/AU/YR

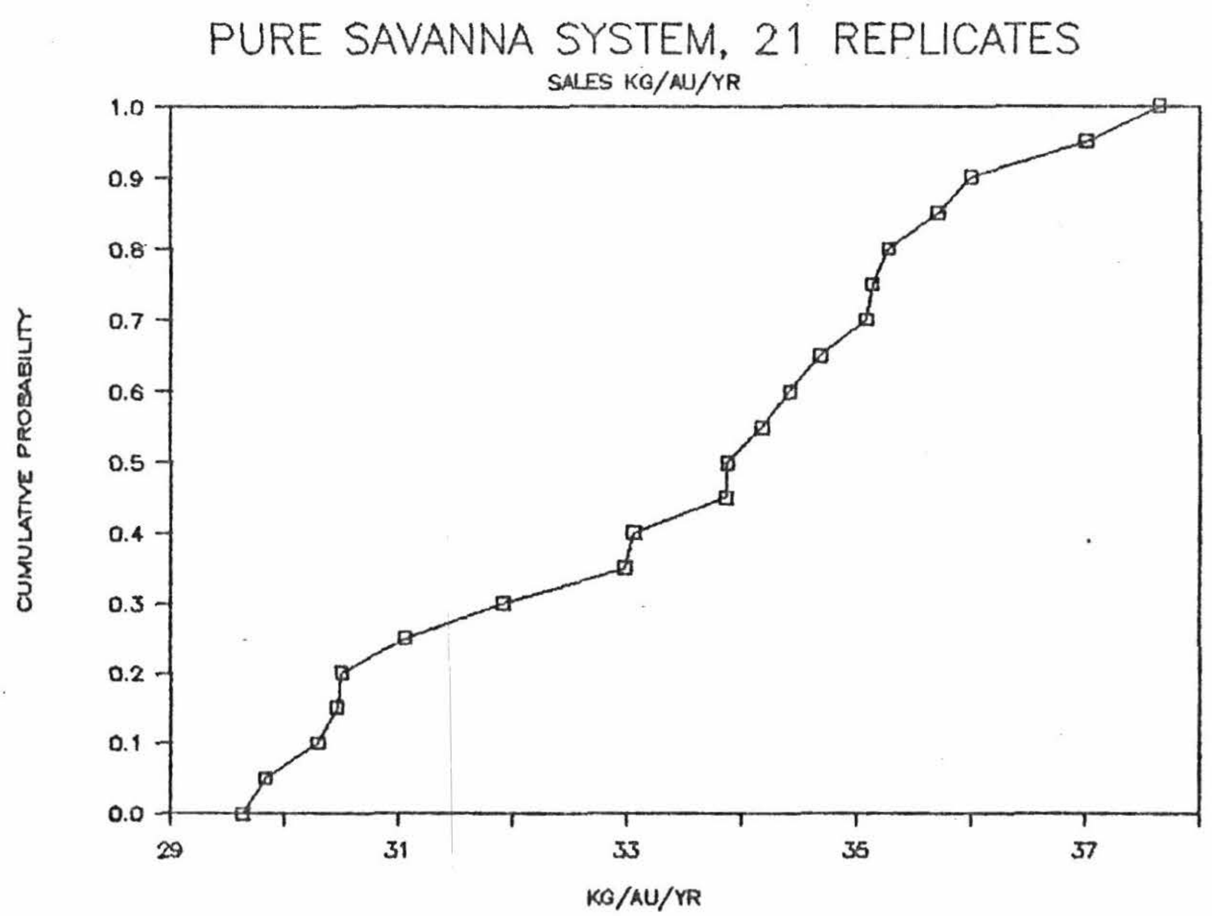
FIGURE A3


PURE SAVANNA SYSTEM, 21 REPLICATES
INTERNAL RATE OF RETURN
CUMULATIVE PROBABILITY
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1.6
2
2.4
2.8
3.2
3.6
4
4.4
4.8
IRR %


PURE SAVANNA SYSTEM, 21 REPLICATES
NET REVENUE, PESOS
CUMULATIVE PROBABILITY
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
200
400
600
800
(Thousands)
NET REVENUE $



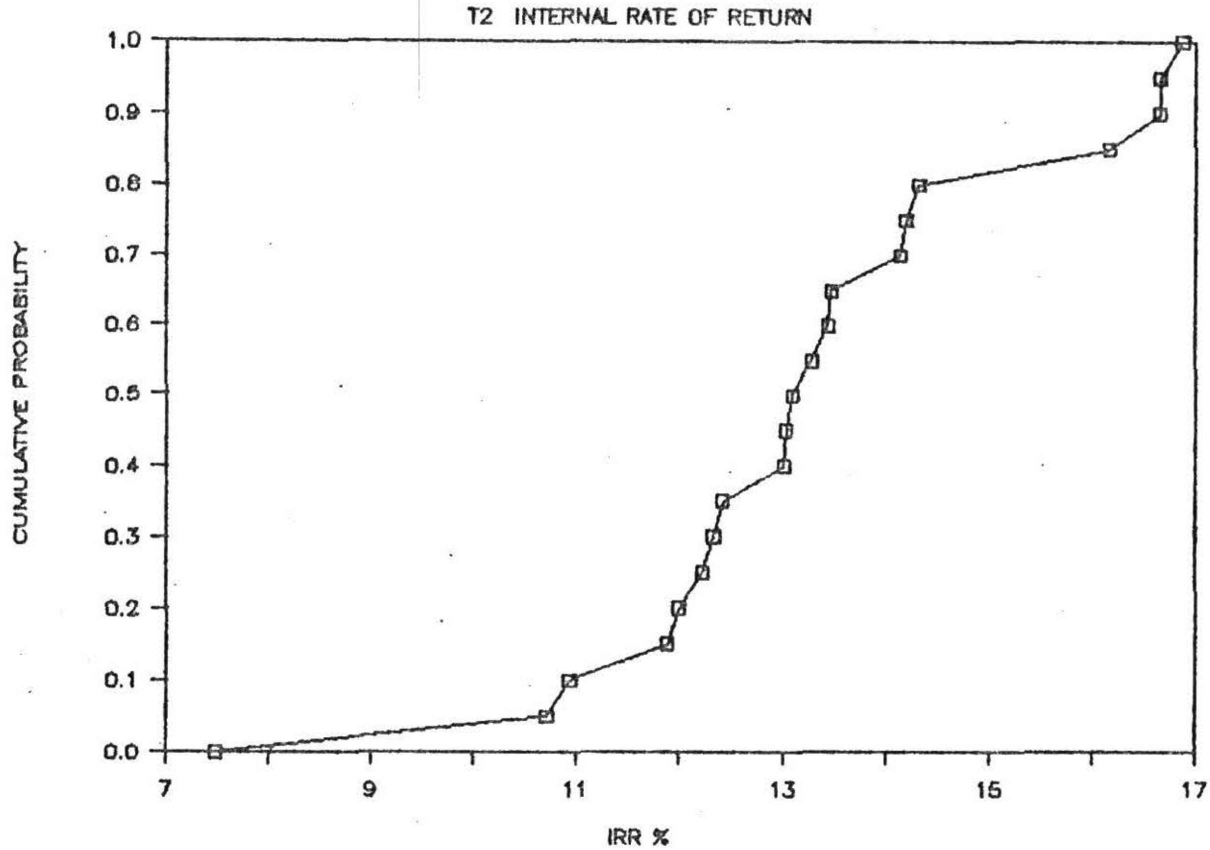
PURE SAVANNA SYSTEM, 21 REPLICATES
PRODUCTION KG/AU/YEAR
CUMULATIVE PROBABILITY
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
38
39
40
41
42
KG/AU/YR



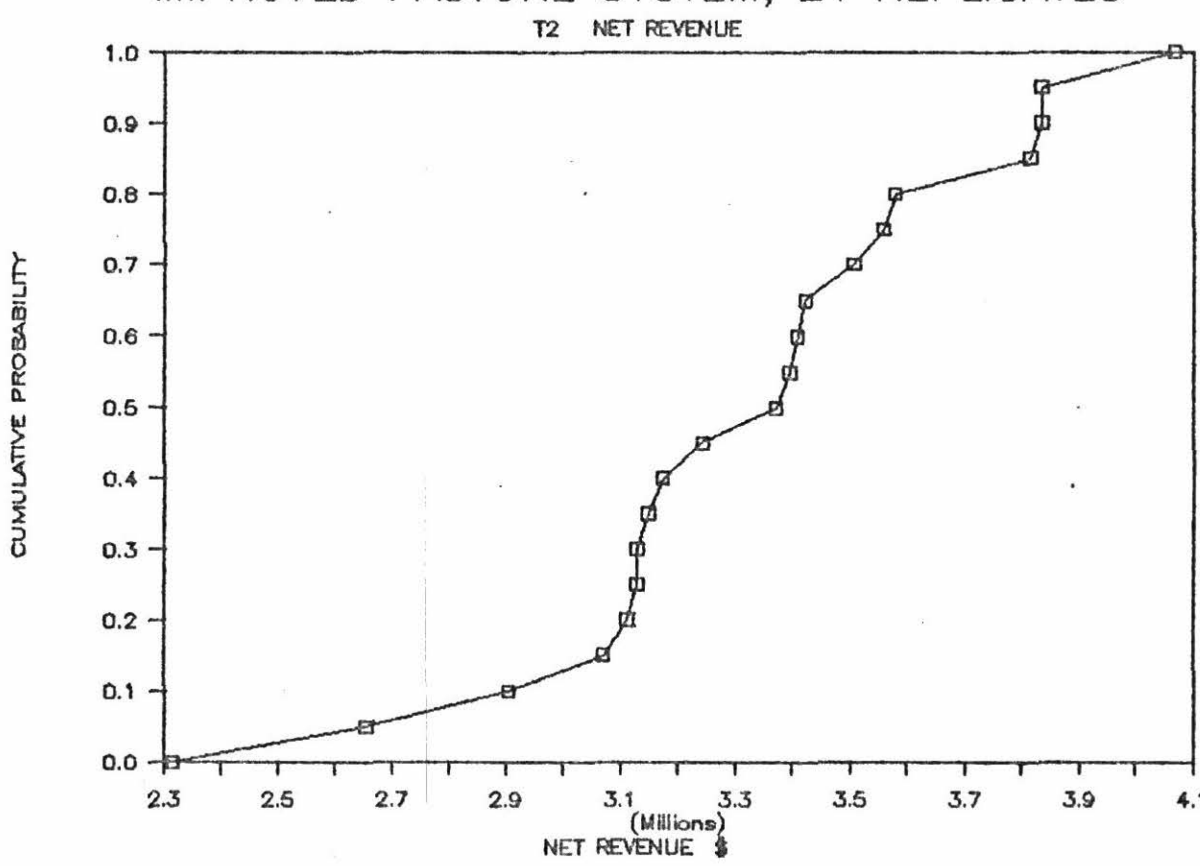
PURE SAVANNA SYSTEM, 21 REPLICATES
SALES KG/AU/YR
CUMULATIVE PROBABILITY
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
29
31
33
35
37
KG/AU/YR

FIGURE A4

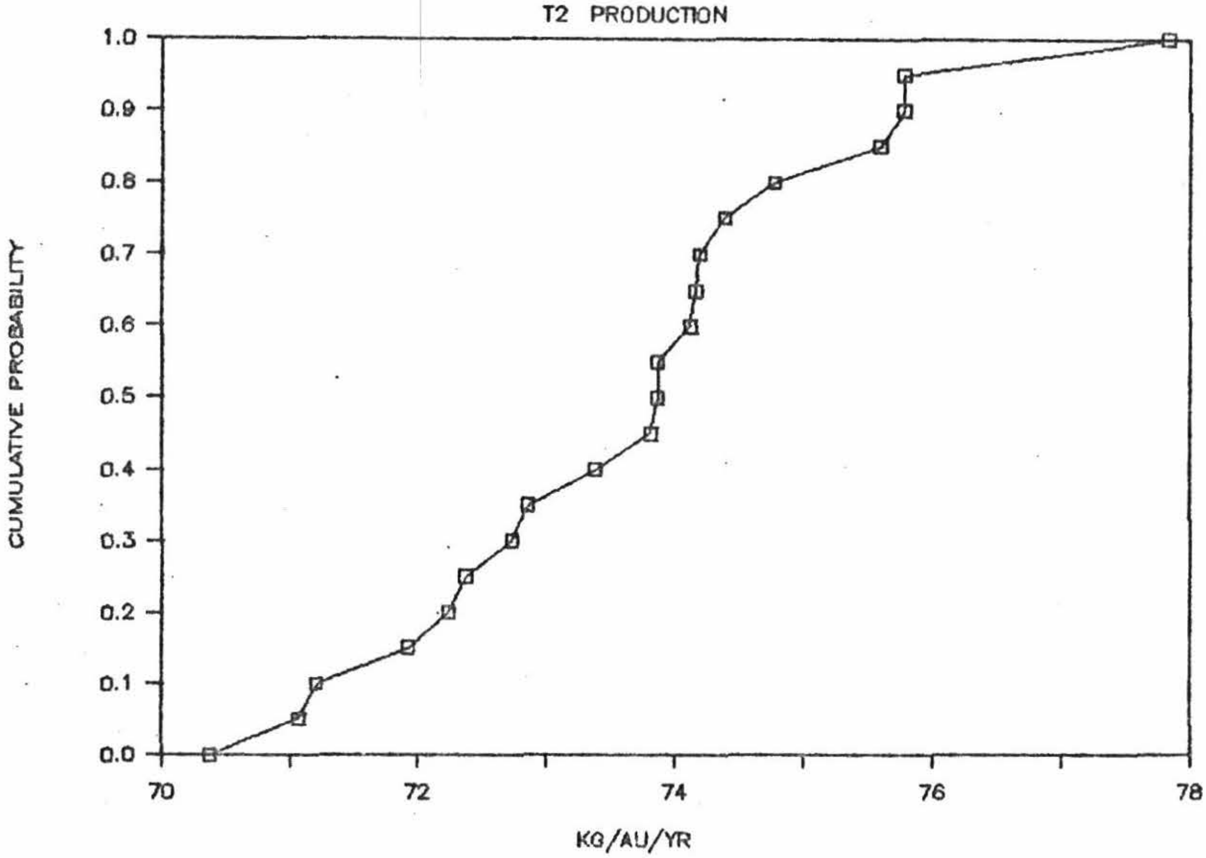
IMPROVED PASTURE SYSTEM, 21 REPLICATES



IMPROVED PASTURE SYSTEM, 21 REPLICATES



IMPROVED PASTURE SYSTEM, 21 REPLICATES



IMPROVED PASTURE SYSTEM, 21 REPLICATES

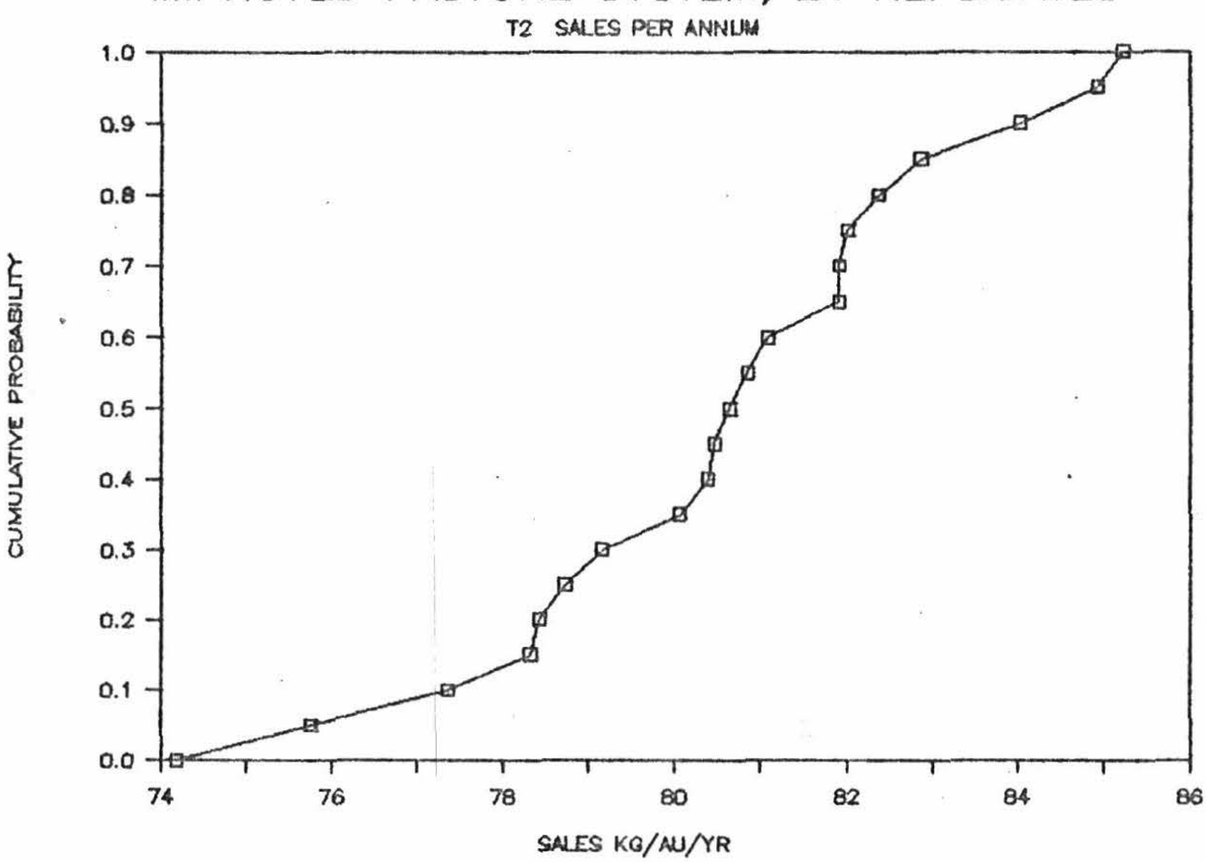
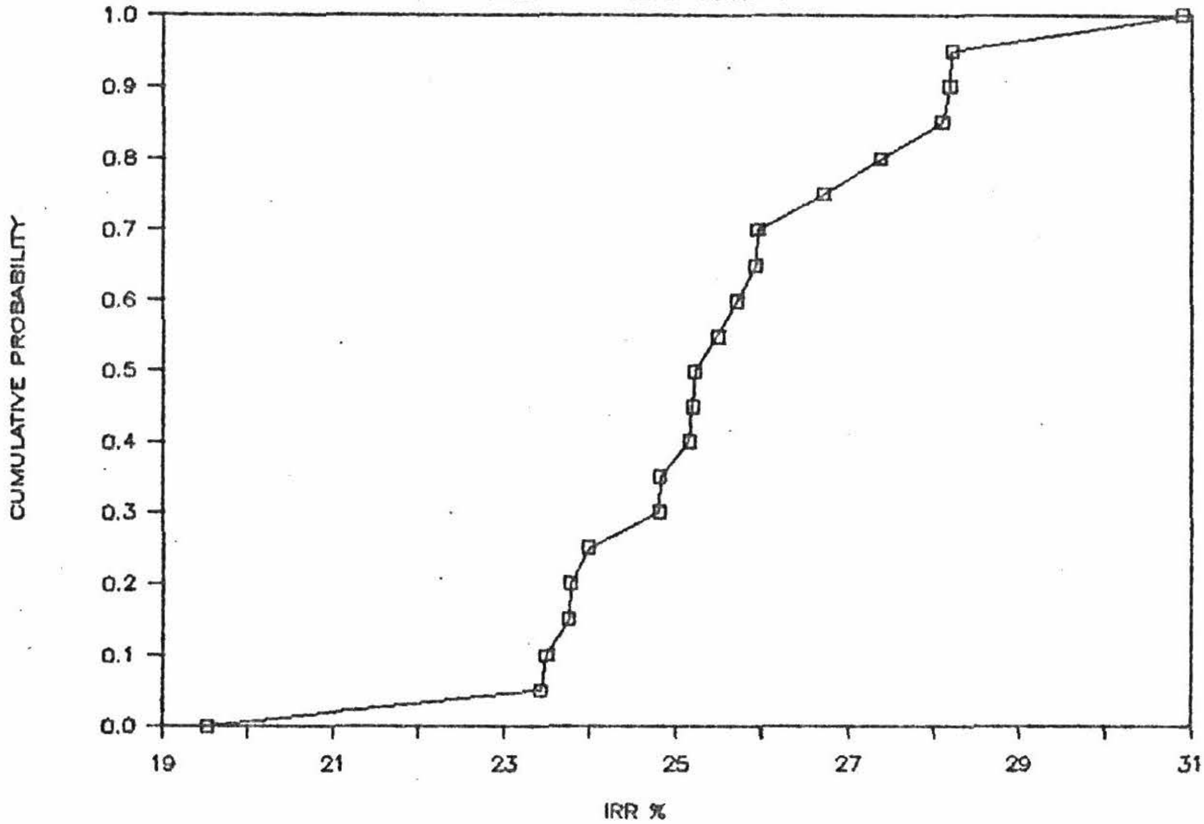


FIGURE A6

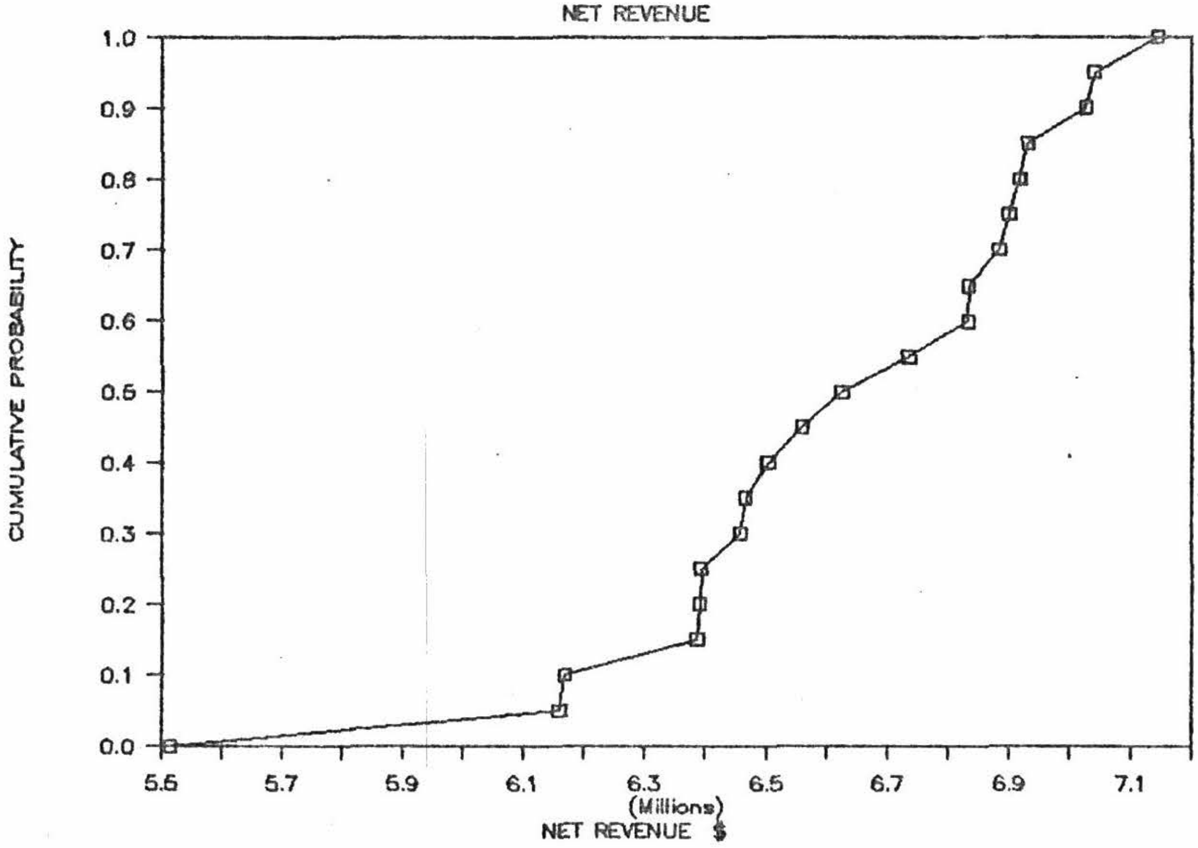
TREATMENT T16, 21 REPLICATES

INTERNAL RATE OF RETURN



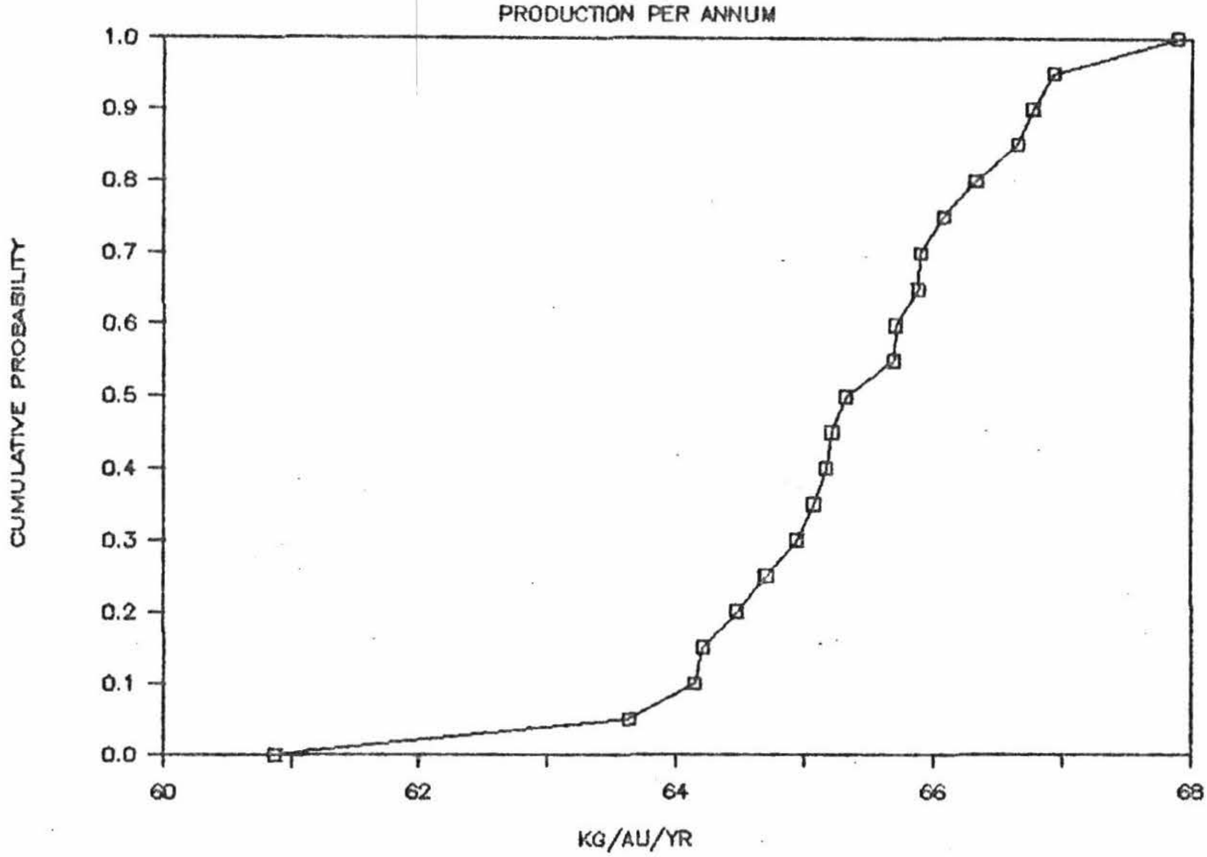
TREATMENT T16, 21 REPLICATES

NET REVENUE



TREATMENT T16, 21 REPLICATES

PRODUCTION PER ANNUM



TREATMENT T16, 21 REPLICATES

SALES PER ANNUM

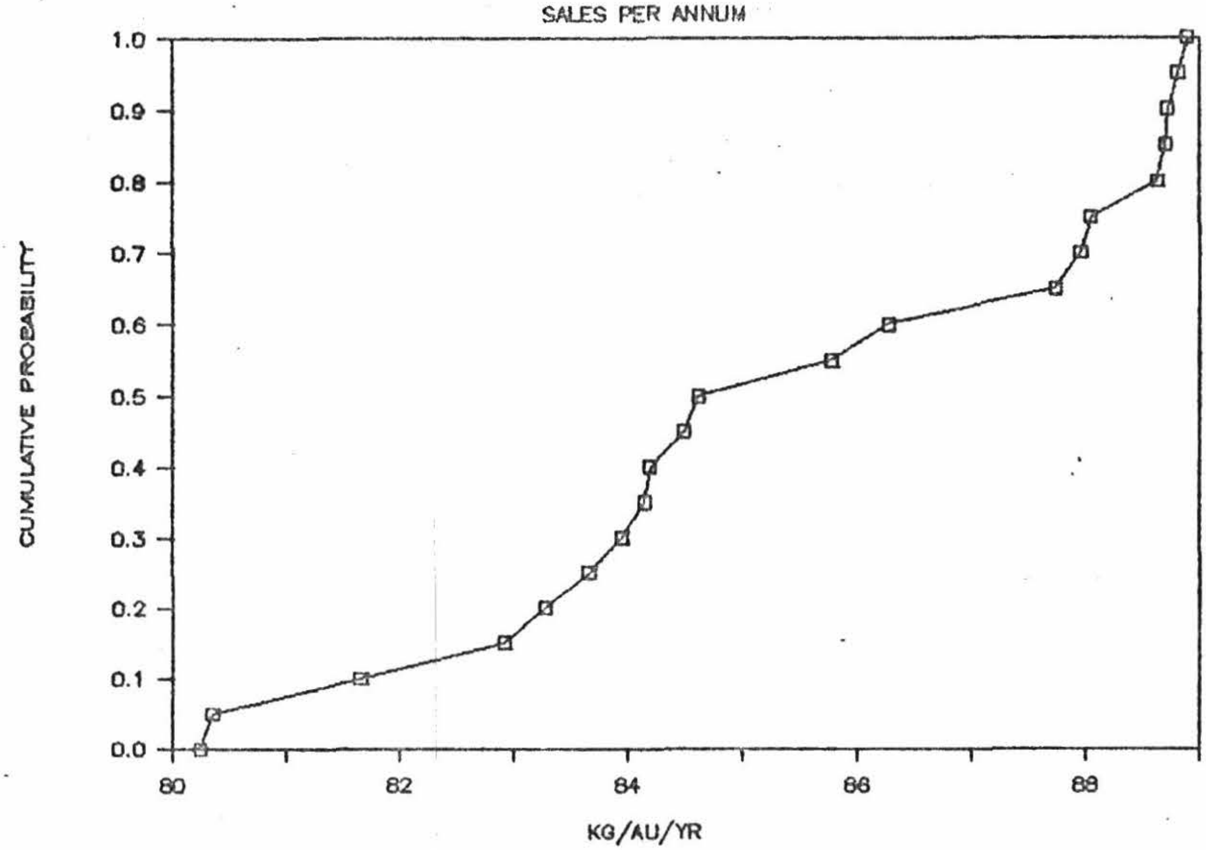
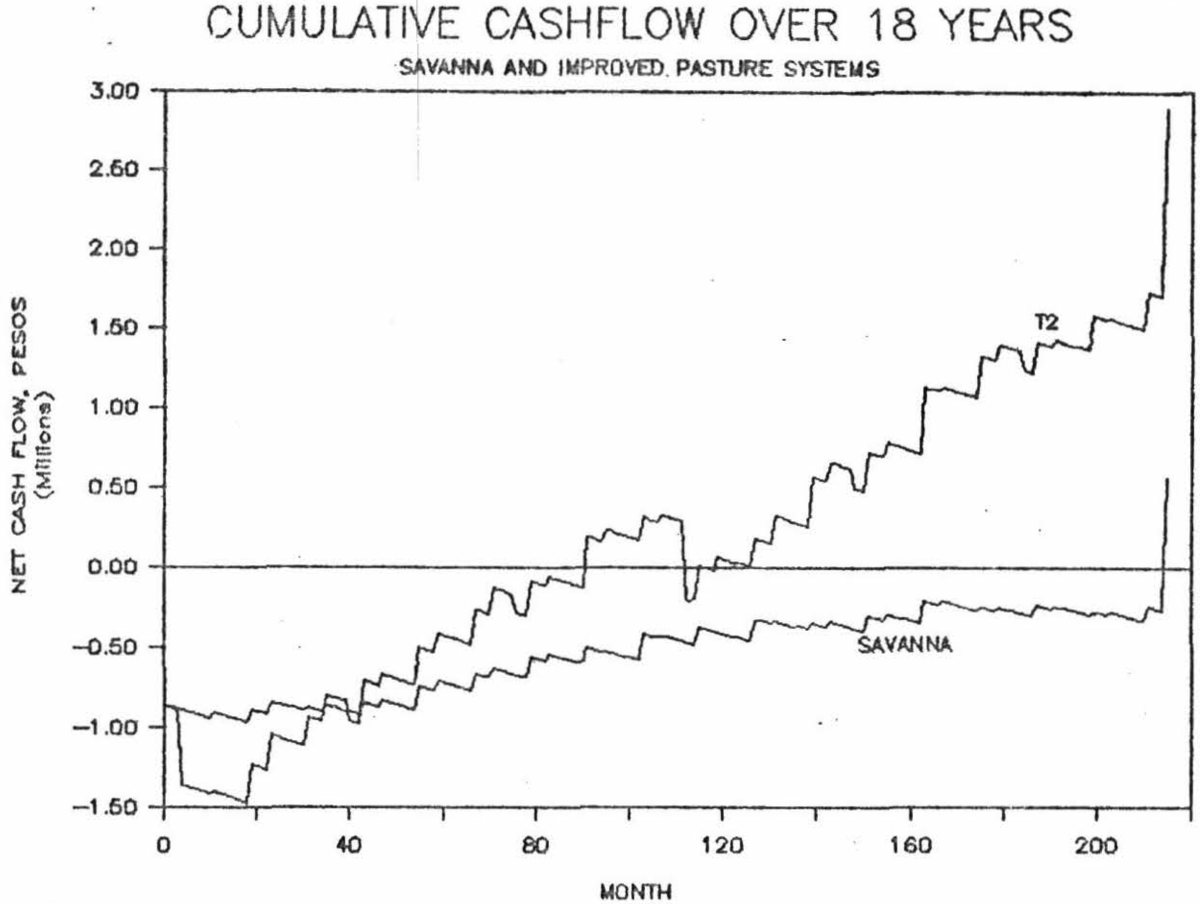
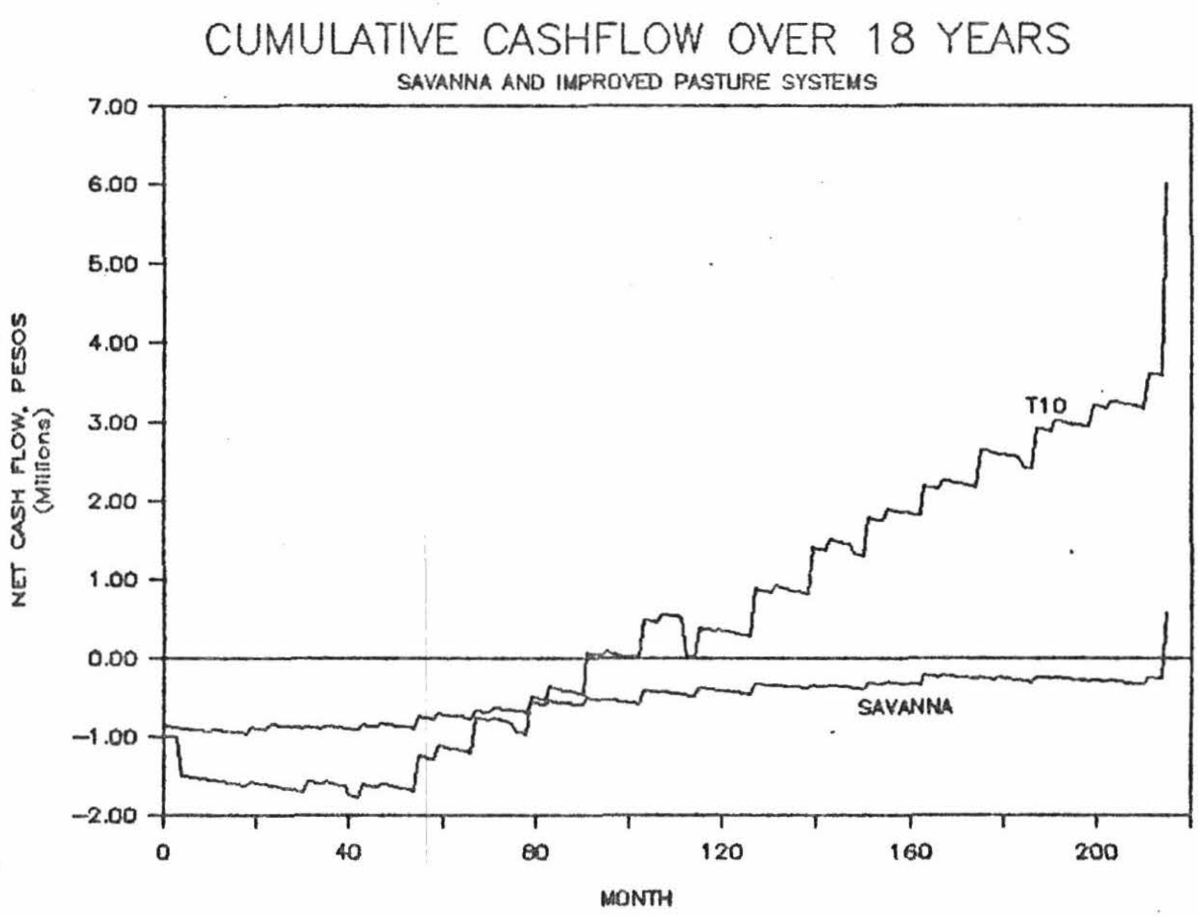
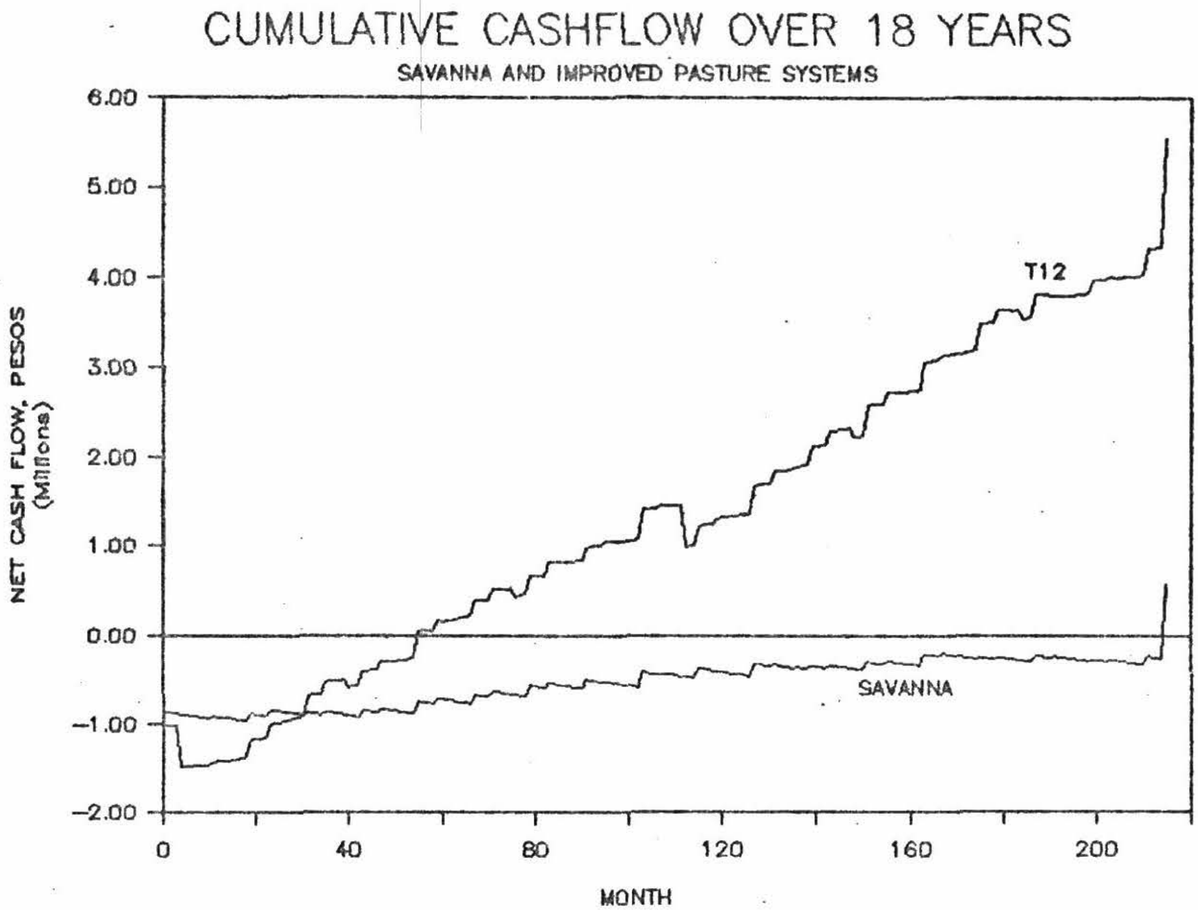


FIGURE A6


CUMULATIVE CASHFLOW OVER 18 YEARS
SAVANNA AND IMPROVED PASTURE SYSTEMS
NET CASH FLOW, PESOS (Millions)
3.00
2.50
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
-1.50
T2
SAVANNA
0
40
80
120
160
200
MONTH


CUMULATIVE CASHFLOW OVER 18 YEARS
SAVANNA AND IMPROVED PASTURE SYSTEMS
NET CASH FLOW, PESOS (Millions)
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
T10
SAVANNA
0
40
80
120
160
200
MONTH


CUMULATIVE CASHFLOW OVER 18 YEARS
SAVANNA AND IMPROVED PASTURE SYSTEMS
NET CASH FLOW, PESOS
(Millions)
6.00
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
T12
SAVANNA
0
40
80
120
160
200
MONTH

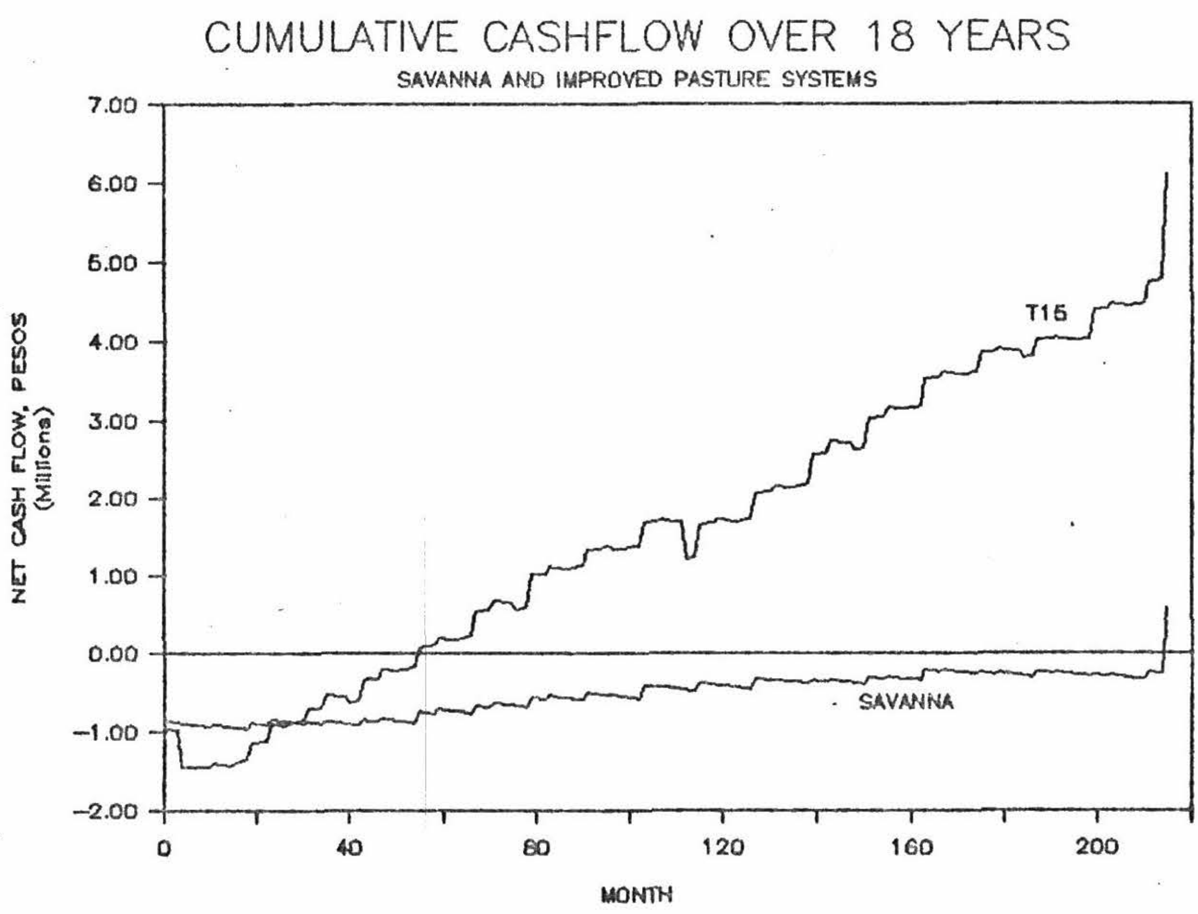
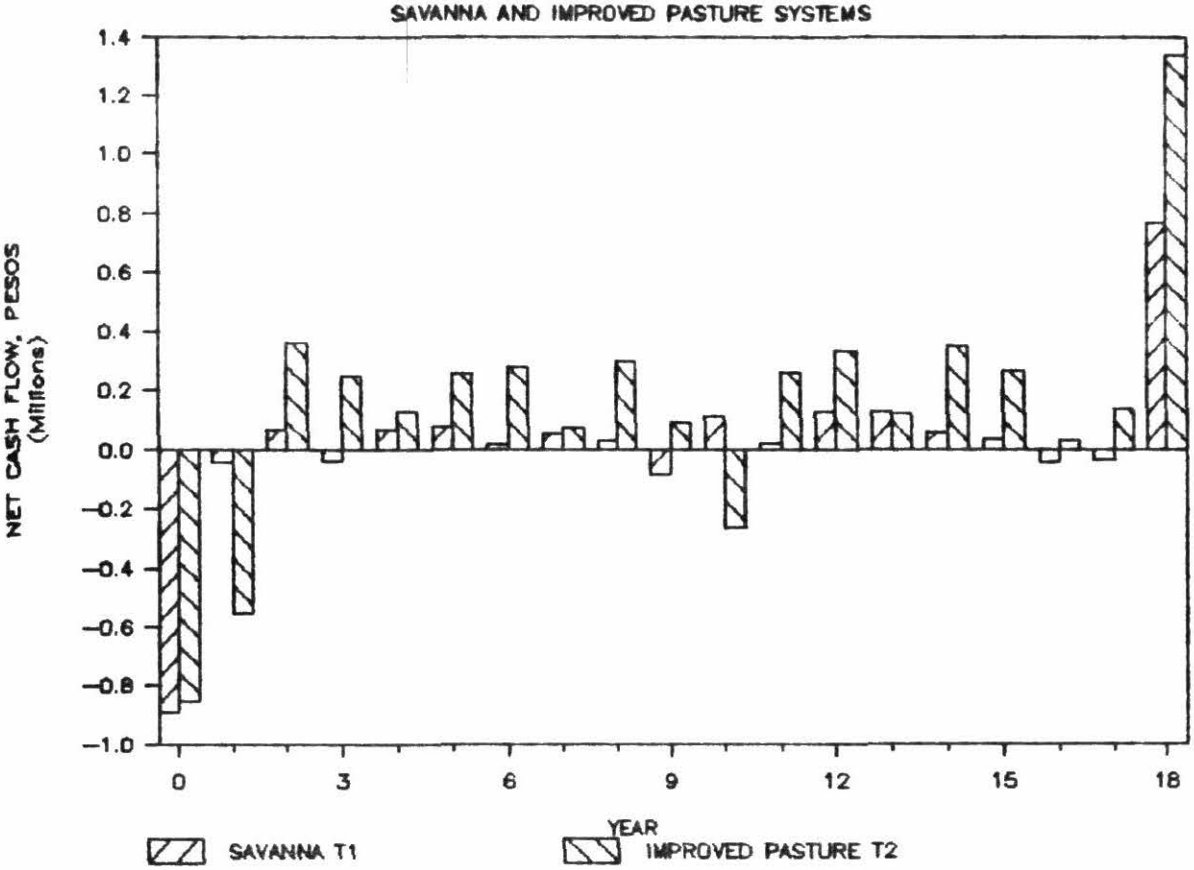

CUMULATIVE CASHFLOW OVER 18 YEARS
SAVANNA AND IMPROVED PASTURE SYSTEMS
NET CASH FLOW, PESOS
(Millions)
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
T15
SAVANNA
0
40
80
120
160
200
MONTH

FIGURE A7

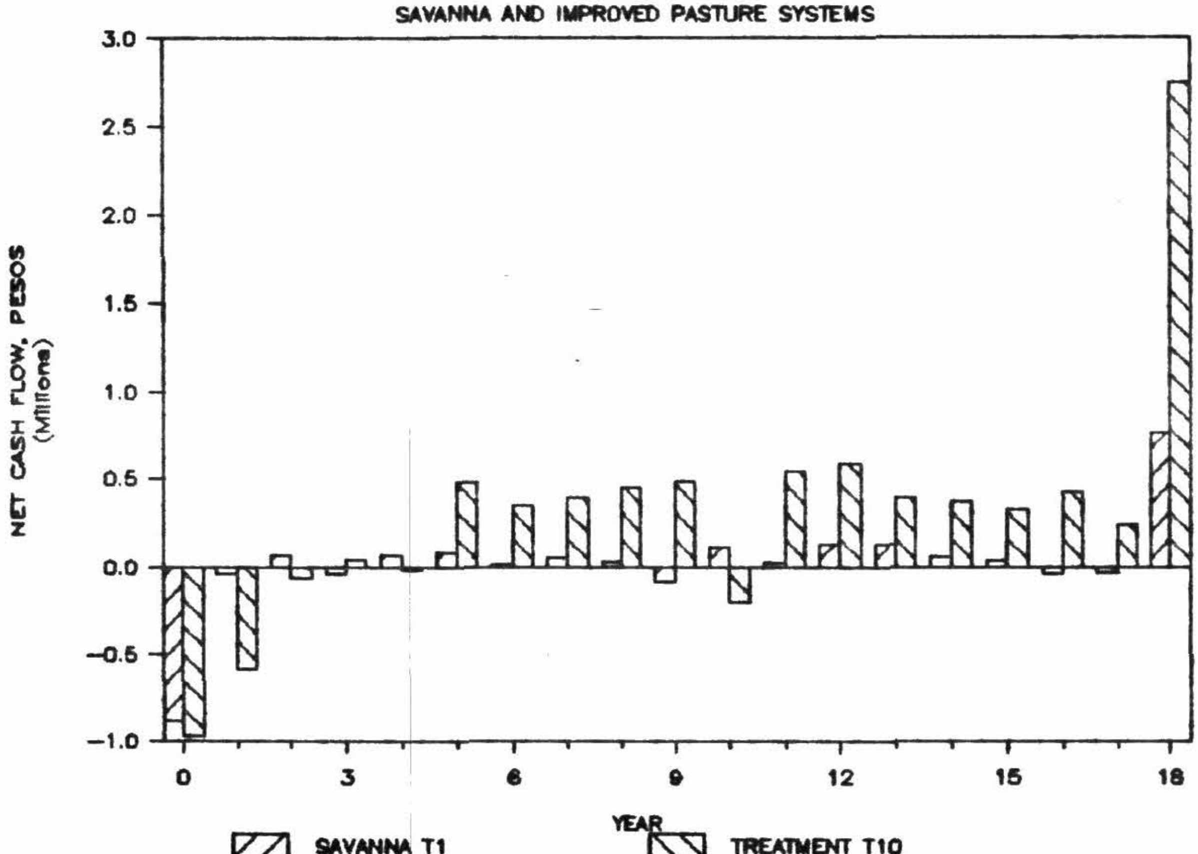
YEARLY CASHFLOW OVER 18 YEARS

SAVANNA AND IMPROVED PASTURE SYSTEMS

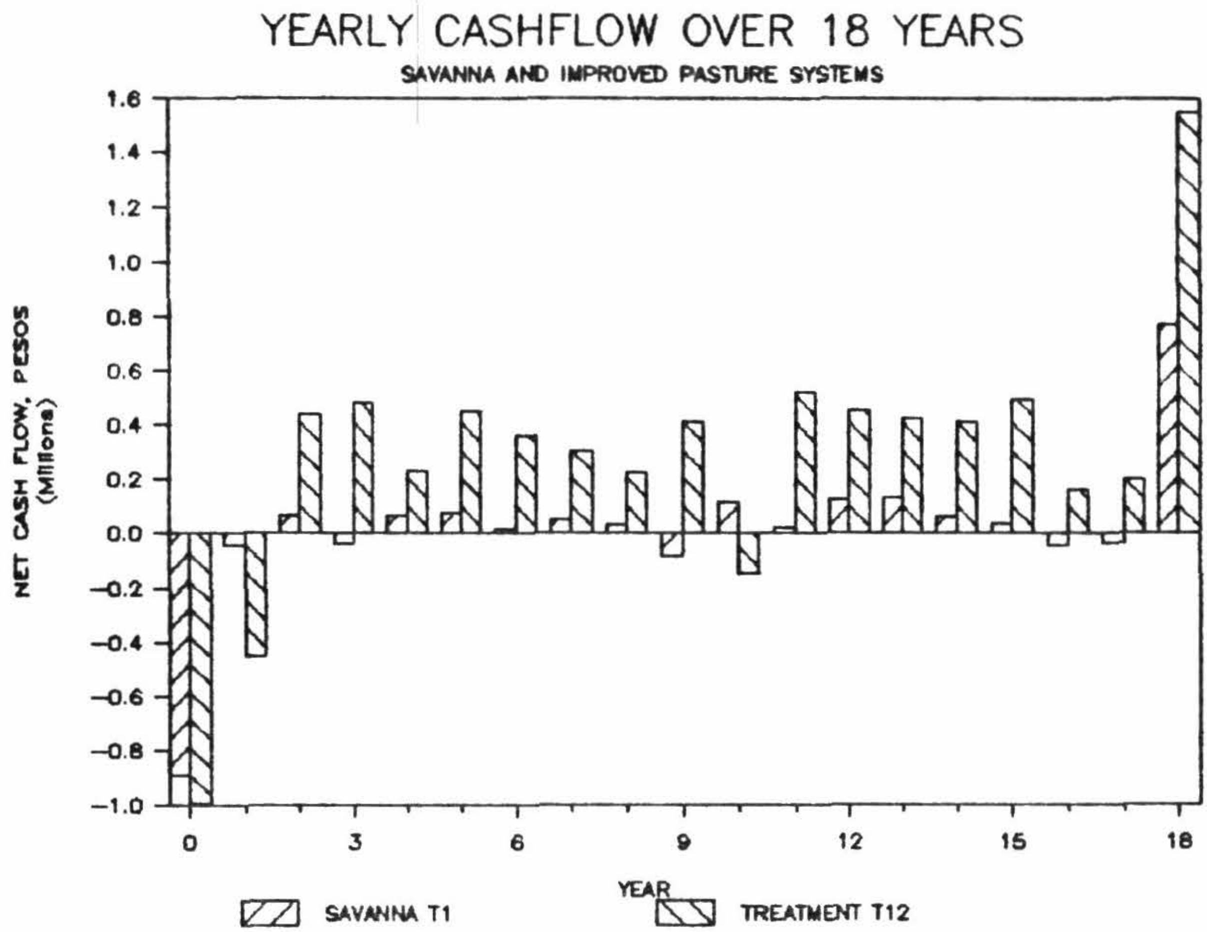


YEARLY CASHFLOW OVER 18 YEARS

SAVANNA AND IMPROVED PASTURE SYSTEMS



157


YEARLY CASHFLOW OVER 18 YEARS
SAVANNA AND IMPROVED PASTURE SYSTEMS
NET CASH FLOW, PESOS (Millions)
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
0
3
6
9
12
15
18
YEAR
SAVANNA T1
TREATMENT T12

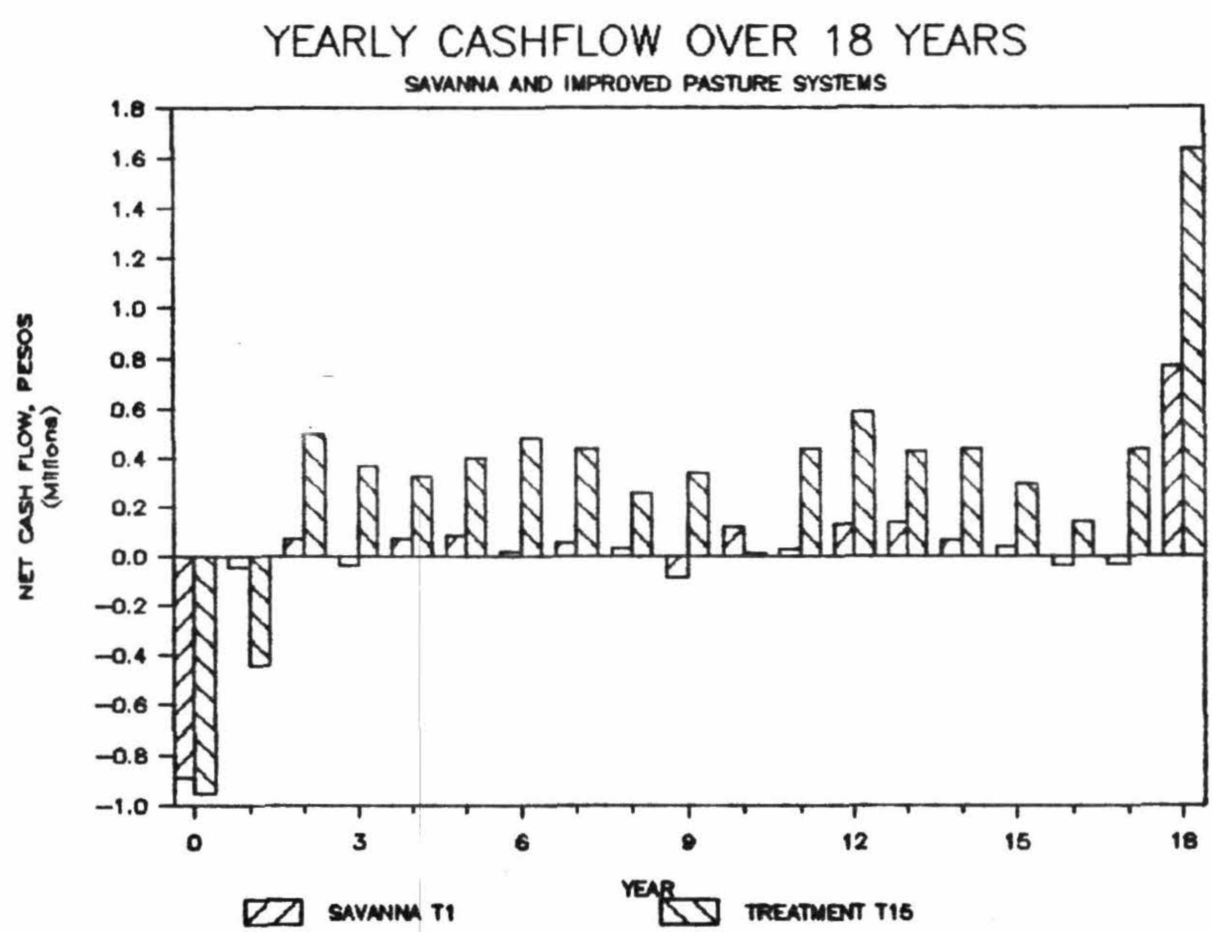
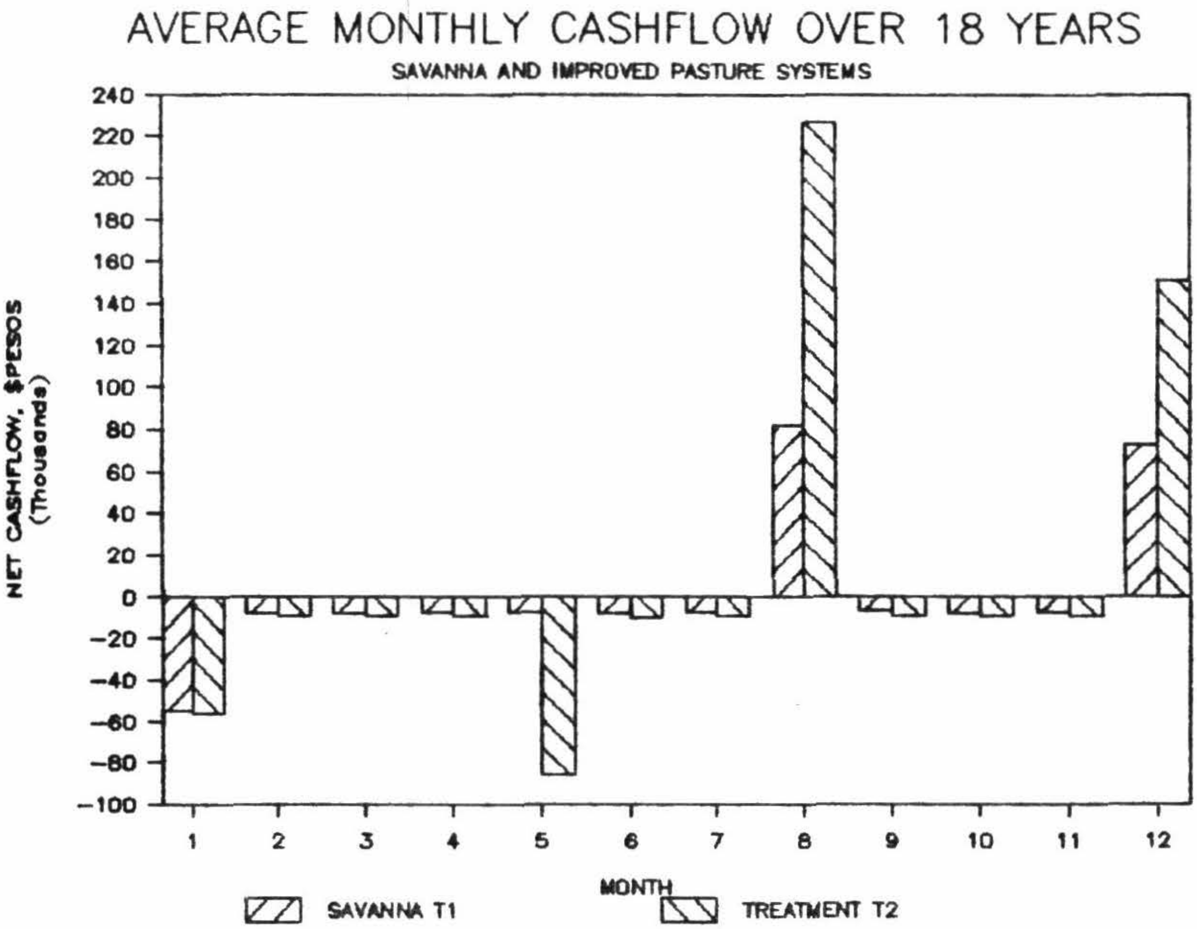
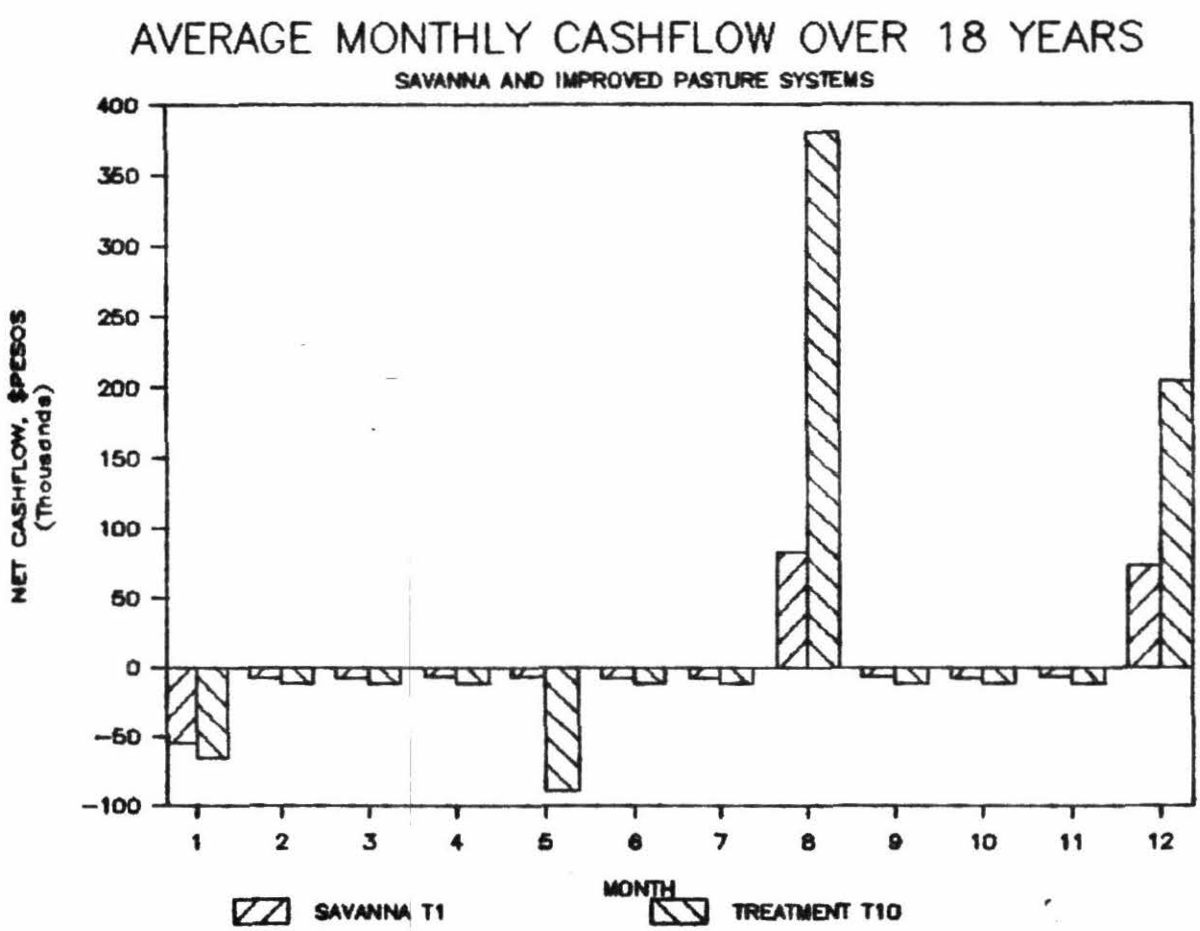
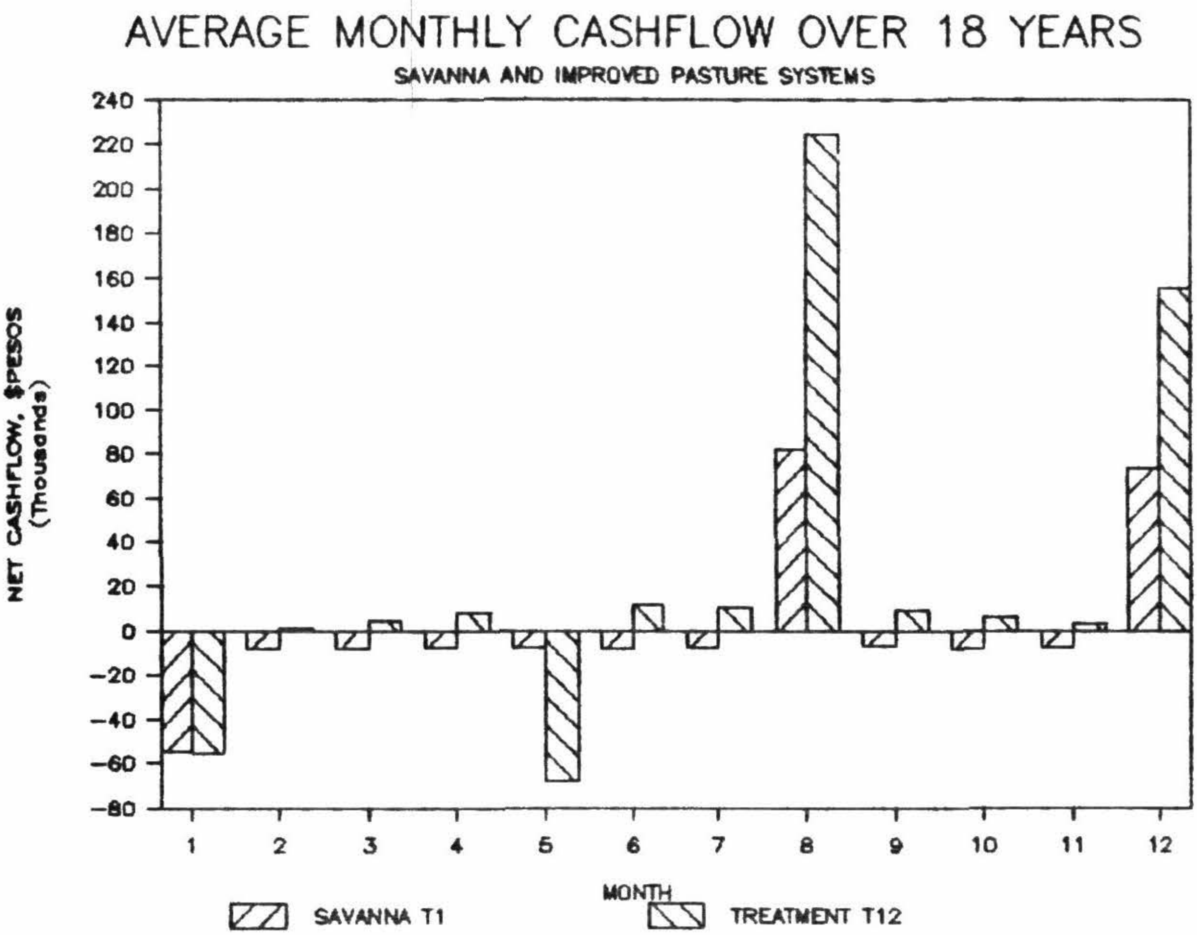
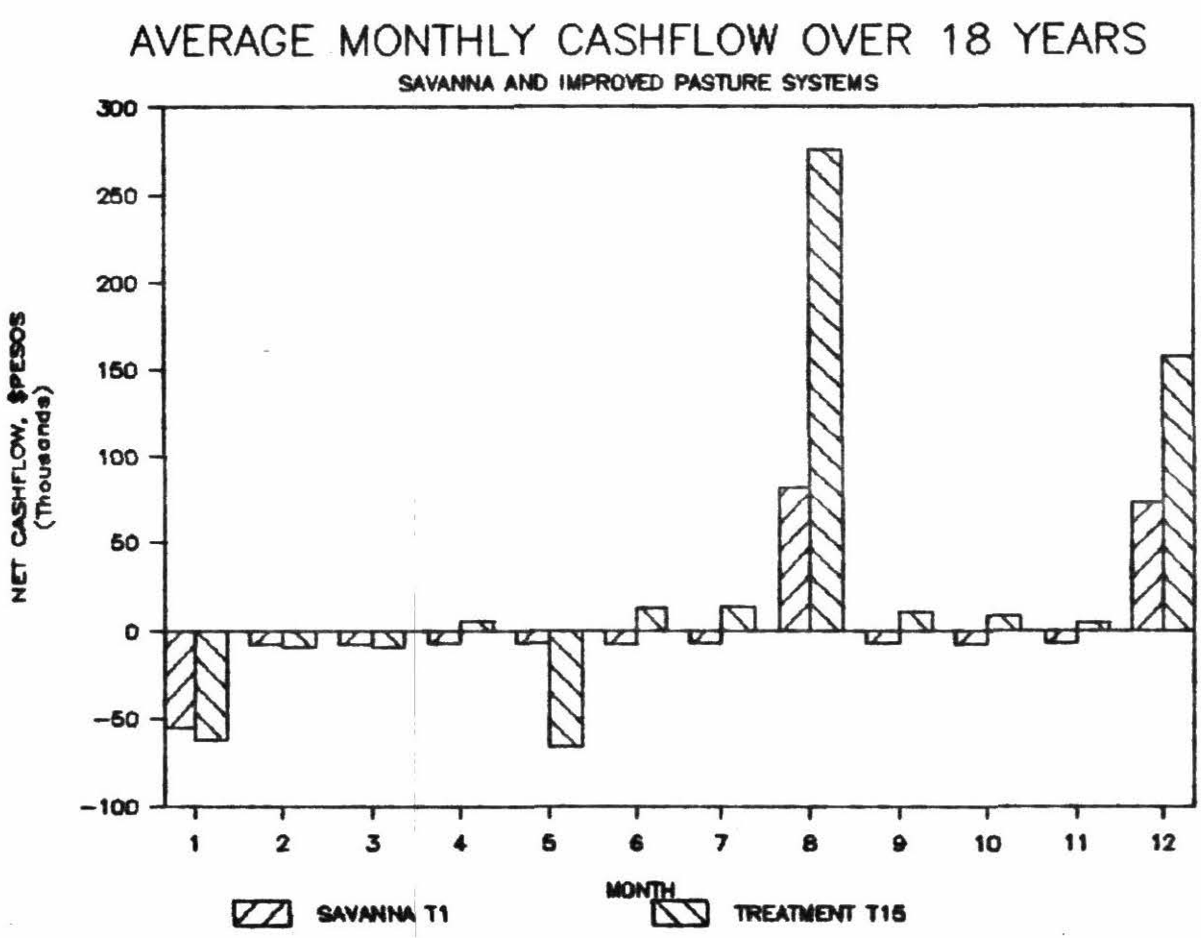

YEARLY CASHFLOW OVER 18 YEARS
SAVANNA AND IMPROVED PASTURE SYSTEMS
NET CASH FLOW, PESOS (Millions)
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
0
3
6
9
12
15
18
YEAR
SAVANNA T1
TREATMENT T15

FIGURE A8


AVERAGE MONTHLY CASHFLOW OVER 18 YEARS
SAVANNA AND IMPROVED PASTURE SYSTEMS
NET CASHFLOW, $PESOS (Thousands)
240
220
200
180
160
140
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
1
2
3
4
5
6
7
8
9
10
11
12
MONTH
SAVANNA T1
TREATMENT T2


AVERAGE MONTHLY CASHFLOW OVER 18 YEARS
SAVANNA AND IMPROVED PASTURE SYSTEMS
NET CASHFLOW, $PESOS (Thousands)
400
350
300
250
200
150
100
50
0
-50
-100
1
2
3
4
5
6
7
8
9
10
11
12
MONTH
SAVANNA T1
TREATMENT T10


AVERAGE MONTHLY CASHFLOW OVER 18 YEARS
SAVANNA AND IMPROVED PASTURE SYSTEMS
NET CASHFLOW, $PESOS (Thousands)
240
220
200
180
160
140
120
100
80
60
40
20
0
-20
-40
-60
-80
1
2
3
4
5
6
7
8
9
10
11
12
MONTH
SAVANNA T1
TREATMENT T12


AVERAGE MONTHLY CASHFLOW OVER 18 YEARS
SAVANNA AND IMPROVED PASTURE SYSTEMS
NET CASHFLOW, $PESOS (Thousands)
300
250
200
150
100
50
0
-50
-100
1
2
3
4
5
6
7
8
9
10
11
12
MONTH
SAVANNA T1
TREATMENT T15