Cow/Calf Session II

"Beef Breed Characterization and Utilization"

Moderator: **Gary Rupp**

Germplasm Utilization In Beef Cattle

K. E. Gregory, L. V. Cundiff
ARS, USDA, Roman L. Hruska
U. S. Meat Animal Research Center
and **R. M. Koch**
University of Nebraska, Roman L. Hruska
U.S. Meat Animal Research Center
U.S. Department of Agriculture
Clay Center, NE 68933

Introduction

Crossbreeding can be used in beef cattle production to provide heterosis. Specific crossbreeding systems provide opportunity to use breed differences in additive genetic merit for specific characters to synchronize performance characteristics and general adaptability of genetic resources with climatic environment, nutritive environment and other resources that are most economical to provide. Complementarity can be exploited in part of self-contained herds through use of terminal sire breeds that have greater additive genetic merit for growth rate than associated mature weight maintained in cow herds. Breed crossing is the initial step in forming new composite breeds to provide an alternative, or, a supplement to continuous crossbreeding systems to use heterosis and to achieve and maintain a more optimum additive genetic (breed) composition than is possible with most continuous crossbreeding systems. Thus, crossbreeding, particularly leading to the formation of composite breeds, can provide a means to use both non-additive (heterosis) and additive (breed differences) effects of genes simultaneously (1).

The germplasm resources now available for beef production vary considerably in performance level for specific characters (2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12). Thus, there is great opportunity to use breed differences in major bioeconomic traits to optimize additive genetic (breed) composition. There are major differences in feed resource requirements associated with differences in performance level (13). A challenge to beef cattle breeding research is to develop optimum procedures for synchronizing performance characteristics of cattle germplasm resources with the feed resources that are most economical to provide in order to maximize **output** of product with greatest value per unit of **input** on a life cycle basis.

There are three basic approaches which may be used to synchronize cattle germplasm resources with other production resources and with market requirements. These are: (1) identify or select the breed that is the best fit or match to the production requirement, (2) use specific crossbreeding systems involving breeds that will complement each other most effectively to approach an optimum balance on characteristics or (3) form composite breeds based on the optimum contribution by each of several breeds to achieve the general adaptability and performance characteristics desired for the production situation. The two latter approaches use heterosis and are favored for commercial production. Composite breeds offer the greatest opportunity to use breed differences to achieve and maintain optimum performance levels for a wide range of production situations. Selection among breeds is considerably more effective than intra-breed selection for all bioeconomic traits (1, 13).

Crossbreeding

Experimental Results. Results from a three-breed diallel crossing experiment conducted at the Fort Robinson Beef Cattle Research Station and the Roman L. Hruska U.S. Meat Animal Research Center involving the Angus, Hereford and Shorthorn breeds showed that when advantages of individual heterosis on survival and growth of F_1

crossbred calves and the advantages of maternal heterosis on reproduction and maternal ability of crossbred cows are combined, that weight of calf weaned per cow exposed to breeding is increased by 23% or about 79 lb (1, 14, 15, 16, 17, 18). The effect of individual heterosis on survival and growth of the F_1 crossbred calf was responsible for 8.5% or 29 lb of this total increase. Crossbred cows were compared with straightbred cows when both were raising crossbred calves by the same sires of a different breed. The crossbred cow through increased reproduction rate and greater maternal ability contributed 14.8% or about 51 lb to the total effect of heterosis. Thus, more than 60% of the increased performance from heterosis was attributable to use of crossbred cows.

Heterosis added 1.3 years to cow longevity. Cumulative production to 12 years of age revealed effects of heterosis of one additional calf weaned per cow exposed and a 30% increase in 200 day calf weight weaned per cow exposed (19, 20).

Further, computations using results from this experiment indicate that the value of the increased production as a result of heterosis is greater than two times the cost of achieving it (13).

Experimental Evaluation of Heterosis Retained in Rotation Crossbreeding.

This experiment was conducted for two additional generations to evaluate heterosis retained in continuous rotation crossbreeding systems; i.e., two-and three-breed rotations (1). Results from this phase of the experiment are summarized in Tables 1 and 2. For the first generation (Table 1), agreement is close between the expected and observed difference involving the straightbred controls and the two-and three-breed crosses. In the second generation (Table 2), the observed difference is 71% and 67% greater than the expected difference for the two-breed and three-breed rotations, respectively. The fact that retention of heterosis was greater than expected based on retention of heterozygosity in the second generation is interpreted to be the result of greater effects of heterosis on reproduction and maternal traits in young females than in mature females (14, 15). The first generation involved mature females, whereas, the second generation involved females that varied from 2- to 6-yr of age. However, a high percentage of the calves were produced by 2- and 3-yr old dams.

Results from this phase of the experiment support the conclusion that retention of heterosis is proportional to retention of heterozygosity in rotational crossbreeding and can be predicted with precision if the F_1 level of heterosis and the mating procedure are known. These results are interpreted to indicate that heterosis observed in crosses among *Bos taurus* breeds of cattle is due primarily to dominance effects of genes and can be accounted for by recovery of accumulated inbreeding depression that has occured in breeds since their formation.

TABLE 1. Effects of heterosis in rotational systems of crossbreeding- first generation - Hereford, Angus and Shorthorn breeds

Item	Control	Two-breed rotation	Three-breed rotation
Mating type:			
Cow	Straightbred	F_1 cross	F_1 cross
Calf	Straightbred	Backcross	3-breed cross
No. of matings	431	410	211
Calf crop weaned, %	75	79	83
200-day weight, lb.	432	476	487
Weight weaned per cow exposed:			
Mean, lb.	324	377	404
Observed difference, lb.		53	80
Observed difference, %		16	24
Expected difference, %[a]		19	23

[a]Based on heterosis effects of 8.5% for individual traits and 14.8% for maternal traits and assumption that retention of heterosis is proportional to retention of heterozygosity.

TABLE 2. Effects of heterosis in rotational systems of crossbreeding — second generation - Hereford, Angus and Shorthorn breeds

Item	Control	Two-breed rotation	Three-breed rotation
Mating type:			
Cow	Straightbred	First backcross	3-breed cross
Calf	Straightbred	Second backcross	First backcross
No. of matings	367	388	239
Calf crop weaned, %	69	78	84
200-day weight, lb.	417	454	463
Weight weaned per cow exposed:			
Mean, lb.	287	355	388
Observed difference, lb.		68	101
Observed difference, %		24	35
Expected difference, %[a]		14	21

[a]Based on heterosis effects of 8.5% for individual traits and 14.8% for maternal traits and assumption that retention of heterosis is proportional to retention of heterozygosity.

A summary of results expected from different crossbreeding systems as a result of heterosis and complementarity is provided by Table 3. Complementarity is achieved by mating breeds in a specific sequence to maximize the impact of the desired characteristics and to minimize the impact of undesired characteristics of breeds on efficiency of the production system. Its effects are measured at the herd level rather than the individual level (21).

Some of the advantages and disadvantages of different crossbreeding systems are reviewed (1).

Rotational Crossbreeding Systems. Rotational crossbreeding systems have the advantage of using heterosis in all females and progeny in self-contained commercial herds (Table 3); however, fluctuation in additive genetic (breed) composition between generations requires use of breeds that are generally compatible (Table 4 and 5). This requirement restricts the use of breed differences to optimize additive genetic (breed) composition for synchronizing genetic resources with other production resources and precludes the use of complementarity. Results based on experimentation indicate that weight marketed per cow ex-

TABLE 3. Comparison of crossbreeding systems

Mating Type	Percent of herd[a]	Percent of calves marketed[a]	Ind. het.[b]	Mat. het.[b]	Terminal sire contribution[c]	Estimated increase in weight marketed per cow exposed[a,b,c]
			(%)			
Two-breed rotation crossbreeding system						
A·B-Rotation	100	100	5.6	9.9	0	15.5
						Total 15.5
Three-breed rotation crossbreeding system						
A·B·C-Rotation	100	100	7.3	12.7	0	20.0
						Total 20.0
Static terminal-sire crossbreeding system[d]						
A·A	25	16.6(♂)	0	0	0	0
B·A	25	16.7(♂)	8.5	0	0	1.4
C x (B·A)	10	13.3(♂+♀)	8.5	14.8	0	3.1
T x (B·A)	40	53.4(♂+♀)	8.5	14.8	5.0	15.1
						Total 19.6
Two-breed rotation and terminal-sire crossbreeding system						
A·B-Rotation	50	33.3(♂)	5.6	9.9	0	5.2
T x (A·B-Rotation)	50	66.7(♂+♀)	8.5	9.9	5.0	15.6
						Total 20.8
Three-breed rotation and terminal-sire crossbreeding system						
A·B·C-Rotation	50	33.3(♂)	7.3	12.7	0	6.7
T x (A·B·C-Rotation)	50	66.7(♂+♀)	8.5	12.7	5.0	17.5
						Total 24.2

[a]Assumes 80% calf crop weaned and a 20% replacement rate.
[b]Based on heterosis effects of 8.5% for individual traits and 14.8% for maternal traits and assumes that loss of heterosis is proportional to loss of heterozygosity.
[c]Assumes a 10% increase in breeding value for calf weight produced per cow exposed for terminal sires (T).
[d]Breeds A, B and C are assumed to be approximately equal in size, milk production and maturation rate. Females of cross (B·A) are bred to sires of breed C to produce their first calf crop because of likelihood of calving difficulty; after first calf crop, they are bred to terminal sire (T), which are assumed to have a breeding value for increased calf weight produced per cow exposed of 10% greater than breeds A and B.

osed to breeding can be increased by 15.5% in a continuous two-breed rotation crossbreeding system and by 20% in a continuous three-breed crossbreeding system (Table 3).

Static Terminal-Sire Crossbreeding System. A static, terminal-sire crossbreeding system provides opportunity to synchronize germplasm resources with other production resources in about 50% of the cow herd, to use maximum (F_1) heterosis in about 67% of the calves marketed and to use complementarity in about 50% of the calves marketed (Table 3). Weight marketed per cow exposed to breeding can be increased by 19.6% in a static, terminal-sire crossbreeding system (Table 3). A disadvantage is complexity and thus high management and facility requirements of the system. An additional disadvantage is lack of opportunity to use heterosis in all breeding and market animals.

Rotational-Terminal-Sire Crossbreeding Systems. A breed-rotational system involving young cows to meet replacement requirements combined with a terminal-sire system on mature cows, when dystocia problems are less, makes use of both individual and maternal heterosis from rotation crossing plus complementarity and individual heterosis from terminal crossing. Maximum (F_1) individual heterosis and complementarity are achieved in the terminal sire component of the herd, which contributes about 67% of the calves marketed. Weight marketed per cow exposed to breeding can be increased by 20.8% in a two-breed rotation combined with a terminal-sire crossbreeding system and by 24.2% in a three-breed rotation combined with a terminal-sire crossbreeding system (Table 3).

Composite Breed Formation

Concepts and Considerations. The distribution of numbers by herd size in the U.S. beef breeding herd is as follows: 35% represented by herds of 50 cows or fewer; 55% represented by herds of 100 cows or fewer, and 87% represented by herds of 500 cows or fewer. Further, of farm and ranches that have beef cows, 80% have 50 cows or fewer, 93% have 100 cows or fewer and more than 99% have 500 cows or fewer (22)

With 55% of the U.S. beef breeding herd and 93% of the farms and ranches that have beef cows represented by units of 100 cows or fewer, there are obvious limitations on feasible options for optimun crossbreeding systems. The limitations are most significant if female replacements are produced within the herd and natural service breeding is used. Further, fluctuation between generations in additive

TABLE 4. Genetic composition and heterosis expected in a two-breed rotation

Generation	Sire breed	Additive genetic (breed) composition: Dam A	Dam B	Calf A	Calf B	Heterozygosity % relative to F_1: Dam	Calf	Estimated increase in weight weaned per cow exposed
		(%)						%[a]
1	A		100	50	50	0	100	8.5
2	B	50	50	25	75	100	50	19.0
3	A	25	75	63	37	50	75	13.8
4	B	63	37	31	69	75	63	16.4
5	A	31	69	66	34	63	69	15.2
6	B	66	34	33	67	69	66	15.8
7	A	33	67	67	33	66	67	15.5
8	B	67	33	33	67	67	67	15.5

[a]Based on heterosis effects of 8.5% for individual traits and 14.8% for maternal traits, when retention of heterosis is proportional to retention of heterozygosity.

TABLE 5. Genetic composition and heterosis expected in a three-breed rotation

Generation	Sire breed	Additive genetic (breed) composition						Heterozygosity % relative to F_1		Estimated increase in weight weaned per cow exposed
		Dam			Calf					
		A	B	C	A	B	C	Dam	Calf	%[a]
		(%)								
1	A			100	50	0	50	0	100	8.5
2	B	50	0	50	25	50	25	100	100	23.3
3	C	25	50	25	12	25	62	100	75	21.2
4	A	12	25	62	56	12	31	75	88	18.6
5	B	56	12	31	28	56	16	88	88	20.5
6	C	28	56	16	14	28	58	88	84	20.2
7	A	14	28	58	57	14	29	84	86	19.7
8	B	57	14	29	29	57	14	86	86	20.0

[a]Based on heterosis effects of 8.5% for individual traits and 14.8% for maternal traits, when retention of heterosis is proportional to retention of heterozygosity.

genetic (breed) composition in breed-rotation crossbreeding systems restricts the extent to which breed differences in average additive genetic merit for specific characters can be used to match climatic adaptability and performance characteristics to the climatic and nutritive environment and other resources that may be most economical to provide. Thus, the formation of composite breeds based on a multi-breed foundation is a potentially attractive alternative, or supplement, to continuous crossbreeding systems. *Once a new composite breed is formed, it can be managed as a straightbred population, and the management problems that are associated with small herd size and with fluctuations between generations in additive genetic composition in rotational crossing systems are avoided.*

Retention of initial heterozygosity after crossing and subsequent random (**inter se**) mating within the crosses is proportional to (n-1)/n, where n is the number of breeds involved in the cross (23, 24, 25). This loss in heterozygosity occurs between the F_1 and F_2 generations. If inbreeding is avoided, further loss of heterozygosity in an **inter se** mated population does **not** occur. This expression i.e., (n-1)/n assumes equal contribution of each breed used in the foundation of a composite breed. Table 6 provides information on level of heterozygosity relative to the F_1 that is retained after equilibrium is reached for two-, three- and four-breed rotation crossbreeding systems and is presented for two-, three-, four-, five-, six-, seven-and eight-breed composites, with breeds contributing in different proportions in several of the composites. Where the breeds used in the foundation of a composite do not contribute equally, percentage of mean F_1 heterozygosity retained is proportional to $1 - \sum_{i}^{n} P_i^2$, where p_i is the fraction of each of n breeds used in the pedigree of a composite breed (24); e.g., heterozygosity retained in a three-breed composite formed from 3/8 breed A, 3/8 breed B and 1/4 breed C can be computed as $1 - [(3/8)^2 + (3/8)^2 + (1/4)^2] = 65.6\%$. Obviously, the maximum number of breeds that can contribute to an optimum additive genetic (breed) composition is preferred because retention of heterozygosity is a function of the number of breeds included in the foundation [i.e., (n-1)/n]. Estimates of increase in weight produced per cow exposed to breeding, based on the assumption that retention of heterosis is approximately proportional to retention of heterozygosity, are presented in Table 6 for each mating type.

The potential of composite breed formation for using heterosis as an alternative to more complex crossbreeding systems and as a procedure for using genetic differences among breeds to achieve and maintain a more optimum additive genetic (breed) composition was first suggested in a published form in 1969 and again in 1973 (24, 25).

Existing breeds of cattle are mildly inbred lines, and to the extent that heterosis is due to the dominance effects of genes, heterosis is the recovery of accumulated inbreeding depression (1, 24). Deviation of heterosis from linear association with heterozygosity results from epistatic effects of genes. For loss of favorable epistatic combinations that may either have become fixed or are maintained by selection in parental breeds, the deviation from linearity of loss in heterosis with loss in heterozygosity is negative (greater); however, for loss of unfavorable epistatic combinations that may have become fixed through chance, the deviation from linearity of loss in heterosis with loss in heterozygosity obviously is likely to be positive (less). Both genetic situations may exist, and the likelihood is greater for favorable than for unfavorable epistatic combinations in parental breeds. Also, heterosis may deviate from heterozygosity in a positive direction if a threshold effect of heterozygosity should exist.

Other than for characters affected by natural or automatic selection (fitness), the likelihood is small that fixed favorable epistatic combinations are important because of changing selection goals that have characterized beef cattle breeding.

If retention of heterosis is linearly associated with retention of heterozygosity, composite breed formation offers much of the same opportunity as rotational

TABLE 6. Heterozygosity of different mating types and estimated increase in performance as a result of heterosis

Mating type	Heterozygosity % relative to F_1	Estimated increase in weight weaned per cow exposed[a] (%)
Pure breeds	0	0
Two-breed rotation	66.7	15.5
Three-breed rotation	85.7	20.0
Four-breed rotation	93.3	21.7
Two-breed composite:		
F_3 - 1/2A, 1/2B	50.0	11.6
F_3 - 5/8A, 3/8B	46.9	10.9
F_3 - 3/4A, 1/4B	37.5	8.7
Three-breed composite:		
F_3 - 1/2A, 1/4B, 1/4C	62.5	14.6
F_3 - 3/8A, 3/8B, 1/4C	65.6	15.3
Four-breed composite:		
F_3 - 1/4A, 1/4B, 1/4C, 1/4D	75.0	17.5
F_3 - 3/8A, 3/8B, 1/8C, 1/8D	68.8	16.0
F_3 - 1/2A, 1/4B, 1/8C, 1/8D	65.6	15.3
Five-breed composite:		
F_3 - 1/4A, 1/4B, 1/4C, 1/8D, 1/8E	78.1	18.2
F_3 - 1/2A, 1/8B, 1/8C, 1/8D, 1/8E	68.8	16.0
Six-breed composite:		
F_3 - 1/4A, 1/4B, 1/8C, 1/8D, 1/8E, 1/8F	81.3	18.9
Seven-breed composite:		
F_3 - 3/16A, 3/16B, 1/8C, 1/8D, 1/8E, 1/8F, 1/8G	85.2	19.8
Eight-breed composite:		
F_3 - 1/8A, 1/8B, 1/8C, 1/8D, 1/8E, 1/8F, 1/8G, 1/8H	87.5	20.4

[a]Based on heterosis effects of 8.5 percent for individual traits and 14.8 percent for maternal traits and assumption that retention of heterosis is proportional to retention of heterozygosity.

crossbreeding for retaining individual and maternal heterosis, in addition to heterosis in male reproductive performance (Table 6). Further, composite breeds offer the opportunity to use genetic differences among breeds to achieve and maintain the performance level for such traits as climatic adaptability, growth rate and size, carcass composition, milk production and age at puberty that is most optimum for a wide range of production environments and to meet different market requirements. Further, composite breeds may provide *herds of any size* with an opportunity to use heterosis and breed differences simultaneously.

Composite breeds do not permit the use of different genotypes (complementarity) for male and female parents. However, specialized paternal and maternal composite breeds may be developed for use in production systems in which the production resource base and market requirements favor the exploitation of complementarity. Between-breed selection is highly effective for achieving and maintaining an optimum additive genetic composition for such specialized populations by using several breeds to contribute to the foundation population for each specialized composite breed. There is the potential to develop general purpose composite breeds through careful selection of fully characterized candidate breeds to achieve an additive genetic composition that is better adapted to the production situation than is feasible through continuous crossbreeding or through intra-breed selection.

The maintenance of effective population size sufficiently large that the initial advantage of increased heterozygosity is not dissipated by early re-inbreeding is essential for retention of heterozygosity (heterosis) in composite breeds. Thus, the resource requirement for development and use of composite breeds as seedstock herds is high, and from an industry standpoint requires a highly viable and creative seedstock segment. Early re-inbreeding and a small number of inadequately characterized parental breeds contributing to foundation of composite breeds have likely been major causes for failure of some previous effort at composite breed development.

For the seedstock segment involving composite breeds, it is suggested that the number of females be appropriate for the use of not less than 25 sires per generation. Use of 25 sires per generation would result in a rate of increase in inbreeding of about .5% per generation. With an average generation interval of 5 years, the accumulated inbreeding in a composite breed after 50 years (e. g., 10 generations) would be 5%. Further, a large number of sires of each purebreed contributing to a composite breed should be sampled in order to minimize the rate of inbreeding in subsequent generations of **inter se** mating. *Inbreeding may be viewed as the "other side of the coin" to heterosis and must be avoided in order to retain high levels of heterozygosity (heterosis) in composite breeds.*

Another potential advantage of composite breeds is that their response to selection should be greater than that in parental breeds because of increased genetic variation expected as a result of differences in gene frequencies in the contributing parent breeds and greater selection intensity possible because of a higher reproduction rate as a result of heterosis (24).

The information needed to make composite breed formation a predictable procedure is: (1) characterization of candidate foundation breeds in a range of production environments to provide the basis for effective selection among breeds to approach the most favorable additive genetic (breed) composition consistent with the role perceived for each composite, and (2) determination of the extent to which retention of heterosis is linearly associated with retention of heterozygosity.

Summary of Rationale for Experimental Evaluation of Composite Populations.

1. Heterosis (hybrid vigor) in major bioeconomic traits including reproduction, calf survival, maternal ability, growth rate and longevity of beef cattle is important.
2. Large differences exist among breeds of beef cattle for major bioeconomic traits including growth rate and size, composition of gain, milk production, dystocia, age at puberty and climatic adaptability.

3. About 55% of the cows in U.S. beef breeding herd are in units of 100 or fewer cows. This involves about 93% of the farms and ranches that have beef cows.
4. Crossbreeding systems may be used to achieve high levels of heterosis. However, optimum crossbreeding systems are difficult to adapt in herds that use fewer than 3 or 4 bulls.
5. Fluctuation in breed composition between generations in rotation crossbreeding systems can result in considerable variation among cows and calves in level of performance for major bioeconomic traits unless breeds used in the rotation are similar in performance characteristics.
6. Composite populations may offer potential to:
   a. Use high levels of heterosis on a continuing basis provided retention of heterosis is approximately proportional to retention of heterozygosity.
   b. Achieve and maintain optimum breed composition needed to match performance characteristics of cattle populations to production resources and to market requirements.
   c. Achieve and maintain uniform performance levels from one generation to the next.

Germplasm Utilization Project

Based on the foregoing concepts and considerations, the background of information presented and the stated rationale, a major beef cattle breeding project was implemented at the Roman L. Hruska U.S. Meat Animal Research Center with the following experimental objectives (26).

Experimental Objectives.

1. Determine the percentage of initial heterosis (F_1) that is retained in composite populations; i.e., to what extent is retention of heterosis proportional to retention of heterozygosity?
2. Determine the additive genetic variance, particularly for traits contributing to reproductive performance, in composite populations relative to parental purebreed populations contributing to the composites; i.e., is selection for male and female reproductive traits more effective in com-

TABLE 7. Matings to establish composites and retention of heterozygosity and expected retention of heterosis

	Composites			
	MARC I	MARC II	MARC III	Mean
Parents of F_1's[a]	(C x LH) x (B x LA) OR (C x LA) x (B x LH) Reciprocals	(GH) x (SA) OR (GA) x (SH)	(PA) x (RH) OR (PA) x (HR) Reciprocals	
Breed Composition of F_1 and Subsequent Generations	.25B, .25C, .25L .125H, .125A	.25G, .25S .25H, .25A	.25P. .25R .25H, .25A	
F_1 Heterozygosity[b]	.94	1	1	.98
F_2 Heterozygosity	.78	.75	.75	.76
F_3 Heterozygosity	.78	.75	.75	.76
F_1 Heterosis[c]	$.94\ H^i + 1\ H^m$	$1\ H^i + 1\ H^m$	$1\ H^i + 1\ H^m$	$.98\ H^i + 1\ H^m$
F_2 Heterosis	$.78\ H^i + .94\ H^m$	$.75\ H^i + 1\ H^m$	$.75\ H^i + 1\ H^m$	$.76\ H^i + .98\ H^m$
F_3 Heterosis	$.78\ H^i + .78\ H^m$	$.75\ H^i + .75\ H^m$	$.75\ H^i + .75\ H^m$	$.76\ H^i + .76\ H^m$
F_4 Heterosis	$.78\ H^i + .78\ H^m$	$.75\ H^i + .75\ H^m$	$.75\ H^i + .75\ H^m$	$.76\ H^i + .76\ H^m$

[a]Composites established from same animals used in purebred foundation where C = Charolais, L = Limousin, H = Hereford, B = Braunvieh, A = Angus, G = Gelbvieh, S = Simmental, P = Pinzgauer, and R = Red Poll.

[b]Retention of initial (F_1) heterozygosity following crossing and subsequent random mating within the crosses (Inter se) is proportional to $1 - \sum_i^n P_i^2$, where P_i is the fraction of each of n breeds contributing to the foundation of a composite population. Loss of heterozygosity occurs between the F_1 and F_2 generations. If inbreeding is avoided, further loss of heterozygosity does not occur.

[c]H^i denotes individual heterosis expressed by progeny and H^m denotes maternal heterosis expressed by dam of progeny and assumes retention of heterosis is proportional to retention of heterozygosity.

posite populations than in the contributing purebreeds?

3. Develop effective selection criteria and procedures to improve both male and female reproductive performance in beef cattle;
4. Determine the feasibility of developing new populations of beef cattle based on a multi-breed (composite) foundation as an alternative to rotational and other crossbreeding systems to utilize heterosis; and
5. Determine the feasibility of using genetic differences among breeds for making more rapid progress toward optimizing such biological characters as climatic adaptability, growth rate and mature size, carcass composition and milk production.

Experimental Procedures.

Matings were made to establish three composite populations as indicated by Table 7. Composite populations were formed from the same genetic base that is represented in the nine contributing purebreeds. The experiment was initiated with the production of F_1 progeny for composites MARC I and MARC II in 1978 and for composite MARC III in 1980. The nine contributing purebreeds have been produced simultaneously with the three composites. The experiment will be completed with the calf crop to be born in 1991. For composite MARC I, F_1 progeny were produced from 1978 through 1983; for composite MARC II, F_1 progeny were produced from 1978 through 1982 and for composite MARC III, F_1 progeny were produced from 1980 through 1984. Approximate number of progeny to be produced in each breed group (nine contributing purebreeds and three composite populations) in the last three calf crops is shown in Table 8.

The calving schedule shown in Table 8 involving composites (MARC I, MARC II and MARC III) F_1generation, F_2 generation and F_3 generation and contributing purebreeds will provide the basic data essential for: (1) estimating linearity of association of heterosis with heterozygosity in composite populations; (2) estimating genetic and phenotypic parameters in order to determine selection response, particularly for traits contributing to fitness in both composite and purebred populations; and (3) developing selection criteria and procedures for both male and female reproductive phenomena.

In 1988, 1989 and 1990, a sample of male calves produced in each of the nine purebreeds and in the F_3 generation from each of the three composite populations (12 breed groups) are castrated at weaning and fed diets of two energy densities to four slaughter end points. Feed efficiency, carcass composition and meat palatability are evaluated at different weight constant, time constant and fat constant end points.

Milk production/comsumption data are recorded on 3-, 4-and 5-year-old females from the nine purebreeds, and

TABLE 8. Approximate number of calving females and number of steers fed to obtain growth, feed efficiency and carcass and meat data for each breed group in the terminal phase of the experiment

BREED GROUP	YEAR 1989	YEAR 1990	YEAR 1991	Estimated total number of Steers to be Fed for Growth, Feed Efficiency and Carcass and Meat Data in 1988, 1989 and 1990
		PUREBREEDS		
HEREFORD (H)	110	103	90	90
ANGUS (A)	90	90	90	90
LIMOUSIN (L)	110	110	90	90
BRAUNVIEH (B)	90	91	90	90
CHAROLAIS (C)	99	100	90	90
GELBVIEH (G)	90	90	90	90
SIMMENTAL (S)	90	90	90	90
RED POLL (R)	90	90	90	90
PINZGAUER (P)	89	94	90	90
PUREBREED TOTAL	858	858	810	810
		COMPOSITES		
1/4C, 1/4B, 1/4L, 1/8H, 1/8A MARC I				
F_1	100	89	71	
F_2	110	110	111	
F_3	90	108	120	120
1/4S, 1/4G, 1/4H, 1/4A MARC II				
F_1	85	69	55	
F_2	106	108	87	
F_3	105	112	120	120
1/4R, 1/4H, 1/4P, 1/4A MARC III				
F_1	93	76	61	
F_2	127	107	120	
F_3	65	102	133	120
COMPOSITE TOTAL	881	881	878	360

on F_2 cows nursing F_3 calves from the three composite populations in 1990 and 1991. Three evaluations of milk production consumption are recorded in each year on 24 cow/calf pairs from each of the 12 breed groups using the weigh-nurse-weigh procedure when calves average 2, 4 and 5 months of age.

Examples of types of data collected throughout the experiment are reflected by Tables 9 and 10. Emphasis has focused on collection of data for the full range of bioeconomic traits, with high priority given to traits that contribute to male and female reproductive efficiency. This includes data on scrotal circumference and sexual aggressiveness in males and data on pelvic area in both males and females. *The concept is that breed differences may be used to achieve and maintain optimum additive genetic (breed) composition for major bioeconomic traits needed for different production-marketing ecosystem; e.g., (1) growth rate and size, (2) milk production, (3) carcass composition, (4) age at puberty and (5) climatic adaptability. Once composite populations are established with optimum additive genetic (breed) composition for the categories of traits listed, selection opportunity may be used to improve traits that contribute to fitness.* Thus, collection of data on traits that will permit development of selection criteria and procedures to optimize selection response for traits that contribute to fitness has received high priority.

TABLE 9. Germplasm utilization project early results - 1978-1985

OBSERVED AND EXPECTED
HETEROSIS FOR BIRTH, WEANING, AND YEARLING WEIGHT

Contrast	Traits: Birth Weight, lb.	200-day Weight, lb.	368-day Weight, lb.
Mean Heterosis Observed and Expected in the Three Composite Populations For Bulls			
F_1 Minus Purebreeds	3.1	44	64
F_2 Minus Purebreeds	4.2	40	70
F_3 Minus Purebreeds	5.3	42	64
Expected Heterosis in F_3[a]	2.4	33	49
Mean Heterosis Observed and Expected in the Three Composite Populations for Heifers			
F_1 Minus Purebreeds	3.7	35	51
F_2 Minus Purebreeds	4.4	35	60
F_3 Minus Purebreeds	6.4	42	68
Expected Heterosis in F_3[a]	2.8	27	39

[a]Based on level of heterosis in the F_1 and retention of heterozygosity.

TABLE 10. Germplasm utilization project early results - 1979-1986

OBSERVED AND EXPECTED HETEROSIS FOR REPRODUCTION TRAITS

Contrast	Puberty (%)	Adjusted age at puberty (days)	Concept. rate, yearling (%)	Concept. rate, all ages (%)	Calf crop wnd (%)
Mean Heterosis Observed and Expected in the Three Composite Populations					
F_1 minus Purebreeds[a]	11	-30	5	7	6
F_2 minus Purebreeds[a]	13	-26	11	6	5
Expected Heterosis in F_2[b]	8	-23	4	5	5

OBSERVED AND EXPECTED HETEROSIS FOR MATERNAL TRAITS AND REPRODUCTION TRAITS COMBINED WITH MATERNAL TRAITS

Contrast	Birth wt, (lb)	200-day wt, (lb)	200-day calf wt per cow exposed (lb)	Actual calf wt wnd per cow exposed (lb)
Mean Heterosis Observed and Expected in the Three Composite Populations				
F_1 minus Purebreeds[a]	5	35	55	53
F_2 minus Purebreeds[a]	5	34	50	49
Expected Heterosis in F_2[b]	4	27	42	40

[a]F_1 and F_2 females from the first and second generation of the same breed composition producing F_2 and F_3 generation progeny.

[b]Based on level of heterosis in the F_1 and retention of heterozygosity.

Summary of Results.

Early results from this comprehensive experiment are presented in Tables 9 and 10 (26). These results are based on the production of approximately 1,700 calves in each year since 1978. They provide the basis for the following conclusions.

1. High levels of heterosis were observed for growth, reproduction and maternal traits.
2. Retention of heterosis for growth, reproduction and maternal traits is **not** less than retention of heterozygosity. The heterosis level maintained for growth, reproduction, and maternal traits is greater than expected (76%), based on retention of heterozygosity. If inbreeding is avoided, further loss in heterosis is not expected.
3. Composite populations offer an effective alternative breeding system to crossbreeding for using heterosis.
4. Composite populations offer an effective procedure for using genetic differences among breeds to achieve and maintain optimum performance levels for such bioeconomic traits as growth rate and size, composition of gain, milk production and age at puberty for a wide range of production situations and to meet different market requirements.

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