

**TABLE 1.** Expectations for genetic effects in a diallel crossbreeding system

Breed of sire (j)	Breed of dam (i)		
	A	B	C
A	$g_A^I$ $g_A^P + g_A^M$ 0	$1/2(g_A^I + g_B^I)$ $g_A^P + g_B^M$ $\bar{h}_{AB} + s_{AB}^I$	$1/2(g_A^I + g_C^I)$ $g_A^P + g_C^M$ $\bar{h}_{AC} + s_{AC}^I$
B	$1/2(g_B^I + g_A^I)$ $g_B^P + g_A^M$ $\bar{h}_{AB} + s_{BA}^I$	$g_B^I$ $g_B^P + g_B^M$ 0	$1/2(g_B^I + g_C^I)$ $g_B^P + g_C^M$ $\bar{h}_{BC} + s_{BC}^I$
C	$1/2(g_C^I + g_A^I)$ $g_C^P + g_A^M$ $\bar{h}_{AC} + s_{CA}^I$	$1/2(g_C^I + g_B^I)$ $g_C^P + g_B^M$ $\bar{h}_{BC} + s_{CB}^I$	$g_C^I$ $g_C^P + g_C^M$ 0

where:

$g_i^I$  and  $g_i^M$  are breed average individual and maternal effects, and  $\sum g_i^I =$

$$\sum g_i^M = 0.$$

$\bar{h}_{ij}$ , is the mean heterosis effect for a two-breed reciprocal cross

$\bar{P}_j$ , is mean phenotype for one purebred =  $\bar{P} + g_j^I + g_j^M$

$X_{ij}$ , is mean phenotype for a two-breed-cross =  $\bar{P}_n + 1/2(g_i^I + g_j^I) + g_j^M + \bar{h}_{ij}$

$\hat{g}_j^M - g_j^P = \sum_1^{n-1} (X_{ij} - X_{ji}) \text{SCALESYM100}/n$ , = breed maternal less

paternal effect, because

$$(n-1)(g_j^M - g_j^P) - \sum_1^n (g_i^M - g_i^P) + (g_j^M - g_j^P) = n(g_j^M - g_j^P).$$

$\hat{g}_j^I = P_j - \bar{P}_n - \hat{g}_j^M$  = breed mean individual effect

$\bar{h}_{ij} = \frac{1}{2}(X_{ij} + X_{ji} - P_i - P_j)$  = mean heterosis for reciprocal cross.

$s_{ij}^I = \frac{1}{2}(X_{ij} - X_{ji}) - \frac{1}{2}(g_j^M - g_i^M)$  = specific reciprocal effect

$$\bar{h}_i = \text{breed mean heterosis} = \frac{\sum_1^{2(n-1)} X_{ij} - (n-1)P_i - \sum_1^{(n-1)} P_j}{2(n-1)} = \sum_1^{n-1} \bar{h}_{ij} \text{SCALESYM125}/(n-1)$$

**Table 2.** Second phase of diallel mating design to estimate heterosis for maternal effects on progeny performance ( $h^M$ )<sup>a</sup>.

Breed of dams	Breed of sires			
	A	B	C	D
A		B•A	C•A	D•A
B	A•B		C•B	D•B
C	A•C	B•C		D•C
D	A•D	B•D	C•D	
AB+BA			C(AB+BA)	D(AB+BA)
AC+CA		B(AC+CA)		D(AC+CA)
AD+DA		B(AD+DA)	C(AD+DA)	
BC+CB	A(BC+CB)			D(BC+CB)
BD+DB	A(BD+DB)		C(BD+DB)	
CD+DC	A(CD+DC)	B(CD+DC)		

$$h_{AB}^M + 1/8 r_{AB}^I = (C \cdot AB + C \cdot BA - C \cdot A - C \cdot B + D(AB) + D(BA) - D \cdot A - D \cdot B) / 4$$

<sup>a</sup>Sampling error for estimates of  $h_{ij}^M + 1/8 r_{ij}^I$  will be minimum, for any total scale of experiment, when equal numbers of contemporary progeny are produced for each mating combination, i.e. DA, DB, D(A•B) and D(B•A), and when each sire of a breed produces the same proportion of progeny in each cross.

**Table 3.** Expected fraction of defined genetic components in deviations of alternative crossbreeding categories from weighted mean of parental breeds relative to F<sub>t</sub> heterosis,  $h = d + 1/2gg$ .

generation <sup>a</sup>	Heterosis			Recombination <sup>b</sup>							
	h <sup>I</sup>	h <sup>M</sup>	h <sup>P</sup>	r <sub>gg</sub> <sup>I</sup>	r <sub>dd</sub> <sup>I</sup>	r <sub>gg</sub> <sup>M</sup>	r <sub>dd</sub> <sup>M</sup>	r <sub>gg</sub> <sup>P</sup>	r <sub>dd</sub> <sup>P</sup>	g <sup>M</sup>	g <sup>P</sup>
$\overline{F_1}$	1	0	0	0	0	0	0	0	0	0	0
$\overline{F_2}$	1/2	1	1	1/4	1/2	0	0	0	0	0	0
$\overline{F_3}$	1/2	1/2	1/2	1/4	1/2	1/4	1/2	1/4	1/2	0	0
A(A•B)	1/2	1	0								
$\overline{B_1}$ B(A•B)	SCALESYM32}			1/8	1/2	0	0	0	0	0	0
AB×A	1/2	0	1								
AB×B	$1 - \sum_1^n q_i^2$	—	>	$\frac{1}{2} - (1 - \sum_1^n q_i^2)$	$1 - \sum_1^n q_i^2$	$\frac{1}{2} (1 - \sum_1^n q_i^2)$	$1 - \sum_1^n q_i^2$	$\frac{1}{2} (1 - \sum_1^n q_i^2)$	$1 - \sum_1^n q_i^2$		
<u>Composite</u>											
n=2	1/2	1/2	1/2	1/4	1/2	1/4	1/2	1/4	1/2	0	0
n=3	2/3	2/3	2/3	1/3	2/3	1/3	2/3	1/3	2/3	0	0
n=4	3/4	3/4	3/4	3/8	3/4	3/8	3/4	3/8	3/4	0	0
Rotation	$(\frac{2^n - 2}{2^n - 1})$	—>	0	$\frac{1}{6} (\frac{2^n - 2}{2^n - 1})$	$\frac{2}{3} (\frac{2^n - 2}{2^n - 1})$	$\frac{1}{6} (\frac{2^n - 2}{2^n - 1})$	$\frac{2}{3} (\frac{2^n - 2}{2^n - 1})$	0	0		
n=2	2/3	—>	0	1/9	4/9	1/9	4/9	0	0	0	0
n=3	6/7	—>	0	1/7	4/7	1/7	4/7	0	0	0	0
n=4	14/15	—>	0	7/45	28/45	7/45	28/45	0	0	0	0
<u>C♂ Rotation♀</u>											
n=2	1	2/3	0	1/9	4/9	1/9	4/9	0	0	0	0
n=3	1	6/7	0	1/7	4/7	1/7	4/7	0	0	0	0
n=4	1	14/15	0	1/45	28/45	7/45	28/45	0	0	0	0
<u>3-breed Cross</u>											
C♂ × A • B♀	1	1	0	1/8	1/4	0	0	0	$\frac{A+B}{4} - \frac{C}{2}$	$\frac{C}{2} - \frac{(A+B)}{4}$	
A • B♂ × C♀	1	0	1	1/8	1/4	0	0	0	$\frac{C}{2} - \frac{(A+B)}{4}$	$\frac{1}{4}(A+B) - \frac{C}{2}$	
<u>4 Breed Cross</u>											
CD♂ × AB♀	1	1	1	1/4	1/2	0	0	0	$\frac{1}{4}(A+B-C-D)$	$\frac{1}{4}(C+D-A-B)$	

<sup>a</sup>Mean of reciprocal crosses, equilibrium for n sire breed rotation, or for q<sub>i</sub>, fractions of n breeds in a composite at F<sub>3</sub> or later generation.

<sup>b</sup>From Dickerson (1973) and Hill (1982).

**Table 4.** Expected fraction of defined genetic components in linear contrasts between means for alternative mating<sup>a</sup>

Code	Linear Contrast	$g^I$	$h^I$	$r^I$	$g^M$	$h^M$	$r^M$
1	BA-AA	(B-A)/2	BA	0	0	0	0
2	BA-CA	(B-C)/2	BA-CA	0	0	0	0
3	A(BA)-AA	(B-A)/4	BA/2	BA/8	(B-A)/2	BA	0
4	(BA) <sup>2</sup> -AA	(B-A)/2	BA/2	BA/4	(B-A)/2	BA	0
5	B(BA)-AA	3(B-A)/4	BA/2	BA/8	(B-A)/2	BA	0
5-3		(B-A)/2	0	0	0	0	0
4-(3+5)/2		0	0	BA/8	0	0	0
6	A(BA)-A(CA)	(B-C)/4	(BA-CA)/2	(BA-CA)/8	(B-C)/2	BA-CA	0
7	(BA) <sup>2</sup> -(CA) <sup>2</sup>	(B-C)/2	(BA-CA)/2	(BA-CA)/4	(B-C)/2	BA-CA	0
8	B(BA)-C(CA)	3(B-C)/4	(BA-CA)/2	(BA-CA)/8	(B-C)/2	BA-CA	0
8-6		(B-C)/2	0	0	0	0	0
7-(8+6)/2		0	0	(BA-CA)/8	0	0	0
9	D(BA)-AA	$\frac{D}{2} + \frac{B}{4} - \frac{3}{4}A$	(DB+DA)/2	BA/8	(B-A)/2	BA	0
10	D(A·BA)-AA	$\frac{D}{2} + \frac{B}{8} - \frac{5}{8}A$	$\frac{DB}{4} + \frac{3}{4}DA$	3BA/32	(B-A)/4	BA/2	BA/8
11	D(BA) <sup>2</sup> -AA	$\frac{D}{2} + \frac{B}{4} - \frac{3}{4}A$	(DB+DA)/2	4BA/32	(B-A)/2	BA/2	BA/4
12	D(B·BA)-AA	$\frac{D}{2} + \frac{3B}{8} - \frac{7}{8}A$	$\frac{D}{2}DB + \frac{DA}{4}$	3BA/32	3(B-A)/4	BA/2	BA/8
12-10		(B-A)/4	(DB-DA)/2	0	(B-A)/2	0	0
9-11		0	0	0	0	BA/2	-BA/4
13	D(BA-D(CA))	(B-C)/4	(DB-DC)/2	(BA-CA)/8	(B-C)/2	BA-CA	0
14	D(A·BA)-D(A·CA)	(B-C)/8	(DB-DC)/4	3(BA-CA)/32	(B-C)/4	(BA-CA)/2	(BA-CA)/8
15	D(BA) <sup>2</sup> -D(CA) <sup>2</sup>	(B-C)/4	(DB-DC)/2	(BA-CA)/8	(B-C)/2	(BA-CA)/2	(BA-CA)/4
16	D(B·BA)-D(C·CA)	3(B-C)/8	3(DB-DC)/4	3(BA-CA)/32	(B-C)/4	(BA-CA)/2	(BA-CA)/8
13-15		0	0	0	0	(BA-CA)/2	-(BA-CA)/4
15-(14+16)/2							
11-(10+12)/2		0	0	(BA-CA)/32	0	0	(BA-CA)/8

<sup>a</sup>Individual (I) and maternal (M) additive ( $g^I$  and  $g^M$ ), heterosis  $h^I$  and  $h^M$  and non-allelic gene interaction ( $r^I$  and  $r^M$ ) effects on performance traits.

**Table 5.** Level of significance (P) for a 5% mean difference (+ or -) between two strains in traits with differing Coefficient Variation (CV) and heritability ( $h^2$ ).

No progeny per		No. sires /strain $N_s$	$\overline{SE}^a$ $(\overline{G}_1 - \overline{G}_2)$	$t = \frac{\overline{G}_1 - \overline{G}_2}{SE}$	Minimum t for <sup>c</sup>	
strain $n_G$	sire $n_{GS}$				$P_{05}$	$P_{01}$
<b>a. CV = 20%; <math>h^2 = 10\%</math></b>						
280	28	10	1.95	2.57	2.10	2.88
	20	14	1.87	2.67	2.06	2.78
	14	20	1.81	2.76	2.02	2.71
	10	28	1.77	2.82	2.01	2.67
	5	56	1.72	2.90	1.98	2.62
220	20	11	2.11	2.37	2.09	2.85
	10	22	2.00	2.50	2.02	2.71
	5	44	1.94	2.57	1.99	2.63
<b>b. CV = 10%; <math>h^2 = 10\%</math></b>						
140	20	7	1.45	3.44	2.18	3.06
	10	14	1.32	3.78	2.06	2.78
	5	28	1.25	3.99	2.01	2.67
100	20	5	1.72	2.91	2.31	3.36
	10	10	1.56	3.20	2.10	2.88
	5	20	1.48	3.37	2.02	2.71
80	20	4	1.92	2.60	2.45	3.71
	10	8	1.75	2.85	2.14	2.98
	5	16	1.66	3.02	2.04	2.75
60	20	3	2.22	2.25	2.78	4.60
	10	6	2.02	2.47	2.23	3.17
	5	12	1.92	2.60	2.07	2.82
40	20	2	2.72	1.84	4.30	9.92
	10	4	2.48	2.02	2.45	3.71
	5	8	2.34	2.13	2.14	2.98

<sup>a</sup>%SE( $\overline{G}_1 - \overline{G}_2$ ) =  $\sqrt{2(390/N_G + 10/N_s)}$  with  $df = 2(N_s - 1)$ . Total phenotypic variance are expressed as the squared coefficient of variation (%), assuming one (1) progeny per dam.

<sup>b</sup>%SE( $\overline{G}_1 - \overline{G}_2$ ) =  $\sqrt{2(97.5/n_G + 2.5/N_s)}$

<sup>c</sup>See Table A.3 in Steele and Torrie (1960) or any other source of probability values for t-ratio, plus or minus mean difference (i.e. 2-tailed distributions).

## FAO TECHNICAL PAPERS

### FAO ANIMAL PRODUCTION AND HEALTH PAPERS

- 1 Animal breeding: selected articles from the *World Animal Review*, 1977 (C E F S)
- 2 Eradication of hog cholera and African swine fever, 1976 (E FS)
- 3 Insecticides and application equipment for tsetse control, 1977 (E F)
- 4 New feed resources, 1977 (E/F/S)
- 5 Bibliography of the criollo cattle of the Americas, 1977 (E/S)
- 6 Mediterranean cattle and sheep in crossbreeding, 1977 (E F)
- 7 The environmental impact of tsetse control operations, 1977 (E F)
- 7 Rev. 1. The environmental impact of tsetse control operations, 1980 (E F)
- 8 Declining breeds of Mediterranean sheep, 1978 (EF)
- 9 Slaughterhouse and slaughterslab design and construction, 1978 (E F S)
- 10 Treating straw for animal feeding, 1978 (C E F S)
- 11 Packaging, storage and distribution of processed milk, 1978 (E)
- 12 Ruminant nutrition: selected articles from the *World Animal Review*, 1 1978 (C E F S)
- 13 Buffalo reproduction and artificial insemination, 1979 (E\*)
- 14 The African trypanosomiases, 1979 (E F)
- 15 Establishment of dairy training centres, 1979 (E)
- 16 Open yard housing for young cattle, 1981 (Ar E F S)
- 17 Prolific tropical sheep, 1980 (E F S)
- 18 Feed from animal wastes: state of knowledge, 1980 (C E)
- 19 East Coast fever and related tick-borne diseases. 1980 (E)
- 20/1 Trypanotolerant livestock in West and Central Africa – Vol. 1. General study, 1980 (E F)
- 20/2 Trypanotolerant livestock in West and Central Africa – Vol. 2. Country studies, 1980 (E F)
- 20/3 Le bétail trypanotolérant en Afrique occidentale et centrale – Vol. 3. Bilan d'une décennie, 1988 (F)
- 21 Guideline for dairy accounting, 1980 (E)
- 22 Recursos genéticos animales en América Latina, 1981 (S)
- 23 Disease control in semen and embryos, 1981 (C E F S)
- 24 Animal genetic resources - conservation and management, 1981 (C E)
- 25 Reproductive efficiency in cattle, 1982 (C E F S)
- 26 Camels and camel milk, 1982 (E)
- 27 Deer farming, 1982 (E)
- 28 Feed from animal wastes: feeding manual, 1982 (C E)
- 29 Echinococcosis/hydatidosis surveillance, prevention and control: FAO/UNEP/WHO guidelines, 1982 (E)
- 30 Sheep and goat breeds of India, 1982 (E)
- 31 Hormones in animal production, 1982 (E)
- 32 Crop residues and agro-industrial by-products in animal feeding, 1982 (E/F)
- 33 Haemorrhagic septicaemia, 1982 (E F)
- 34 Breeding plans for ruminant livestock in the tropics, 1982 (E FS)
- 35 Off-tastes in raw and reconstituted milk, 1983 (Ar E F S)
- 36 Ticks and tick-borne diseases: selected articles from the *World Animal Review*, 1983 (E F S)
- 37 African animal trypanosomiasis: selected articles from the *World Animal Review*, 1983 (E F)
- 38 Diagnosis and vaccination for the control of brucellosis in the Near East, 1982 (Ar E)
- 39 Solar energy in small-scale milk collection and processing, 1983 (E F)
- 40 Intensive sheep production in the Near East, 1983 (Ar E)
- 41 Integrating crops and livestock in West Africa, 1983 (E F)
- 42 Animal energy in agriculture in Africa and Asia, 1984 (E/FS)
- 43 Olive by-products for animal feed, 1985 (Ar E F S)
- 44/1 Animal genetic resources conservation by management, data banks and training, 1984 (E)
- 44/2 Animal genetic resources: cryogenic storage of germplasm and molecular engineering, 1984 (E)
- 43 Olive by-products for animal feed, 1985 (Ar E F S)
- 44/1 Animal genetic resources conservation by management, data banks and training, 1984(E)
- 44/2 Animal genetic resources: cryogenic storage of germplasm and molecular engineering, 1984 (E)
- 45 Maintenance systems for the dairy plant, 1984 (E)
- 46 Livestock breeds of China, 1984 (E F S)
- 47 Réfrigération du lait à la ferme et organisation des transports, 1985 (F)
- 48 La fromagerie et les variétés de fromages du bassin méditerranéen, 1985 (F)
- 49 Manual for the slaughter of small ruminants in developing countries, 1985 (E)
- 50 Better utilization of crop residues and by-products in animal feeding: research guidelines - 1. State of knowledge, 1985 (E)
- 50/2 Better utilization of crop residues and by-products in animal feeding: research guidelines - 2. A practical manual for research workers, 1986 (E)
- 51 Dried salted meats: charque and carne-de-sol, 1985 (E)
- 52 Small-scale sausage production, 1985 (E)
- 53 Slaughterhouse cleaning and sanitation, 1985 (E)
- 54 Small ruminants in the Near East - Vol. I. Selected papers presented for the Expert Consultation on Small Ruminant Research and Development in the Near East (Tunis, 1985), 1987 (E)
- 55 Small ruminants in the Near East - Vol. II. Selected articles from *World Animal Review* 1972-1986, 1987 (Ar E)
- 56 Sheep and goats in Pakistan, 1985 (E)
- 57 The Awassi sheep with special reference to the improved dairy type, 1985 (E)
- 58 Small ruminant production in the developing countries, 1986 (E)
- 59/1 Animal genetic resources data banks - 1. Computer systems study for regional data banks, 1986 (E)
- 59/2 Animal genetic resources data banks - 2. Descriptor lists for cattle, buffalo, pigs, sheep and goats, 1986 (E F S)
- 59/3 Animal genetic resources data banks - 3. Descriptor lists for poultry, 1986 (E F S)
- 60 Sheep and goats in Turkey, 1986 (E)
- 61 The Przewalski horse and restoration to its natural habitat in Mongolia, 1986 (E)
- 62 Milk and dairy products: production and processing costs, 1988 (E F S)
- 63 Proceedings of the FAO expert consultation on the substitution of imported concentrate feeds in animal production systems in developing countries, 1987 (C E)
- 64 Poultry management and diseases in the Near East, 1987 (Ar)
- 65 Animal genetic resources of the USSR, 1989 (E)

66	Animal genetic resources - strategies for improved use and conservation, 1987 (E)	100	Programme for the control of African animal trypanosomiasis and related development, 1992 (E)
67/1	Trypanotolerant cattle and livestock development in West and Central Africa - Vol I, 1987 (E)	101	Genetic improvement of hair sheep in the tropics, 1992 (E)
67/2	Trypanotolerant cattle and livestock development in West and Central Africa - Vol II, 1987 (E)	102	Legume trees and other fodder trees as protein sources for livestock, 1992 (E)
68	Crossbreeding <i>Bos indicus</i> and <i>Bos taurus</i> for milk production in the tropics, 1987 (E)	103	Improving sheep reproduction in the Near East, 1992 (Ar)
69	Village milk processing, 1988 (E F S)	104	The management of global animal genetic resources, 1992 (E)
70	Sheep and goat meat production in the humid tropics of West Africa, 1989 (E/F)	105	Sustainable livestock production in the mountain agro-ecosystem of Nepal, 1992 (E)
71	The development of village based sheep production in West Africa, 1988 (Ar E F S) (Published as Training manual for extension workers, IWS5840E)	106	Sustainable animal production from small farm systems in South-East Asia, 1993 (E)
72	Sugarcane as feed, 1988 (E/S)	107	Strategies for sustainable animal agriculture in developing countries, 1993 (E)
73	Standard design for small scale modular slaughterhouses, 1988 (E)	108	Evaluation of breeds and crosses of domestic animals, 1993 (E)
74	Small ruminants in the Near East - Vol III North Africa, 1989 (E)	109	Bovine spongiform encephalopathy, 1993 (E)
75	The eradication of ticks, 1989 (E/S)	110	L'amélioration génétique des bovins en Afrique de l'Ouest, 1993 (F)
76	<i>Ex situ</i> cryoconservation of genomes and genes of endangered cattle breeds by means of modern biotechnological methods, 1989 (E)	Availability: Avril 1993	
77	Training manual for embryo transfer in cattle, 1991 (E)	Ar	- Arabic Multil - Multilingual
78	Milking, milk production hygiene and udder health, 1989 (E)	C	- Chinese * Out of print
79	Manual of simple methods of meat preservation, 1990 (E)	E	- English ** In preparation
80	Animal genetic resources - a global programme for sustainable development, 1990 (E)	F	- French
81	Veterinary diagnostic bacteriology - a manual of laboratory procedures of selected diseases of livestock, 1990 (E F)	P	- Portuguese
82	Reproduction in camels - a review, 1990 (E)	S	- Spanish
83	Training manual on artificial insemination in sheep and goats, 1991 (E)	<i>The FAO Technical Papers are available through the authorized</i>	
84	Training manual for embryo transfer in water buffaloes, 1991 (E)	<i>FAO Sales Agents or directly from Distribution and Sales Section,</i>	
85	The technology of traditional milk products in developing countries, 1990 (E)	<i>FAO, Viale delle Terme di Caracalla, 00100 Rome, Italy</i>	
86	Feeding dairy cows in the tropics, 1991 (E)		
87	Manual for the production of anthrax and blackleg vaccines, 1991 (E F)		
88	Small ruminant production and the small ruminant genetic resource in tropical Africa, 1991 (E)		
89	Manual for the production of Marek's disease, Gumboro disease and inactivated Newcastle disease vaccines, 1991 (E F)		
90	Application of biotechnology to nutrition of animals in developing countries, 1991 (E F)		
91	Guidelines for slaughtering, meat cutting and further processing, 1991 (E)		
92	Manual on meat cold store operation and management, 1991 (E S)		
93	Utilization of renewable energy sources and energy saving technologies by small scale milk plants and collection centres, 1992 (E)		
94	Proceedings of the FAO expert consultation on the genetic aspects of trypanotolerance, 1992 (E)		
95	Roots, tubers, plantains and bananas in animal feeding, 1992 (E)		
96	Distribution and impact of helminth diseases of livestock in developing countries, 1992 (E)		
97	Construction and operation of medium-sized abattoirs in developing countries, 1992 (E)		
98	Small scale poultry processing, 1992 (E)		
99	<i>In situ</i> conservation of livestock and poultry, 1992 (E)		