Indigenous Thai Beef Cattle Breeding Scheme Incorporating Indirect Measures of Adaptation: Sensitivity to Changes in Heritabilities of and Genetic Correlations between Adaptation Traits

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ABSTRACT : A model Indigenous Thai beef cattle breeding structure consisting of nucleus, multiplier and commercial units was used to evaluate the effect of changes in heritabilities of and genetic correlations between adaptation traits on genetic gain and profitability. A breeding objective that incorporated adaptation was considered. Two scenarios for improving both the production and the adaptation of animals where also compared in terms of their genetic and economic efficiency. A base scenario was modelled where selection is for production traits and adaptation is assumed to be under the forces of natural selection. The second scenario (+Adaptation) included all the information available for base scenario with the addition of indirect measures of adaptation. These measures included tick count (TICK), faecal egg count (FEC) and rectal temperature (RECT). Therefore, the main difference between these scenarios was seen in the records available for use as selection criteria and hence the level of investments. Additional genetic gain and profitability was generated through incorporating indirect measures of adaptation as criteria measured in the breeding program. Unsurprisingly, the results were sensitive to the changes in heritabilities and genetic correlations between adaptation traits. However, there were more changes in the genetic gain and profitability of the breeding program when the genetic correlations of adaptation and its indirect measures were varied than when the correlations between these measures were. The changes in the magnitudes of the genetic gain and profit per cow stresses the importance of using reliable estimates of these traits in any breeding program. ***(Asian-Aust. J. Anim. Sci. 2004. Vol 17, No. 8 : 1039-1046)***

Key Words : Beef Cattle, Breeding Program Design, Adaptation, Breeding Objectives, Tropics

INTRODUCTION

In Thailand, as is also the case in other tropical and subtropical areas, expression of economically important productive traits such as growth and fertility is restricted through the effects of environmental stresses such as of poor nutrition, disease challenges and heat and humidity. Under village production systems, indigenous breeds are commonly preferred, primarily because of their adaptation to these local stresses. However, the production capacity of these breeds is low when compared to their temperate counterparts (mostly *Bos taurus*) or imported *B. indicus* breeds. Consequently, the challenge is to develop breeding programs that will improve production traits and at least maintain adaptation in a sustainable way.

There are two options for improving both the production and the adaptation of animals. One is to concentrate on selection for production traits in the presence of environmental stress, thus allowing adaptation to respond as a correlated set of traits. The other is to attempt to understand the biology of adaptation and its relationship with production, and so develop criteria that are directed at improving both adaptation and production (Franklin, 1986). The second approach requires good estimates of genetic and phenotypic parameters for production and adaptive characteristics, some of which are available (Mackinnon et al., 1991a, b; Davis, 1993; Burrow, 2001). Reliable genetic parameter estimates would allow for development of optimal selection indices that are directly applicable to programs selecting for improved performance.

삭제됨: .

Genetic parameter estimates may come from another population, a different generation and from a limited number of animals and may therefore be inaccurate and result in less efficient indices. Knowledge of the effect of changes in the genetic parameters of adaptation traits is required for effective breeding program design. It is important to understand how such changes influence the economic returns generated. This paper evaluates the effect of changes in heritabilities of and genetic correlations between adaptation traits on genetic gain and profitability. It also compares the two options (Franklin, 1986) for improving both the production and the adaptation of animals in terms of their genetic and economic efficiency. These options differ in the records available for use as selection criteria. The aim was to evaluate the impact on genetic gain and profitability of including tick count (TICK), faecal egg count (FEC) and rectal temperature (RECT) in the index as indirect measures of adaptation for a breeding population as described by Intarathum et al. (2002).

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Table 1. Description of traits in the breeding objective and selection criteria

Abbreviation	Description
Breeding objective traits	
SWd	Sale live weight (kg) at 2 years - direct component
SWm	Sale live weight (kg) - maternal component
CoSW	Mature Cow Sale Weight (kg) - salvage value
CoWR	Cow weaning rate (%) - calves weaned per 100 cows joined
ADAP	Adaptation - survival.
MEAT	Saleable meat percentage of carcase (%)
Selection criteria	
WWT	Live weight at 200 days of age
YWT	Live weight at one year of age
HGI	Hearth girth at 200 days of age
HIP	Hip height at 200 days of age
BODY	Body length at 200 days of age
SSIZ	Scrotal circumference at yearling age
DCAL	Days to calving (interval bull in date to calving date)
AFC	Age at first calving
TICK	Tick count at yearling age
RECT	Rectal temperature at yearling age
FEC	Faecal egg count at yearling age
FAT	Real time ultra-sound rump fat at yearling age
EMA	Real time ultrasound eye muscle area at yearling age

MATERIAL AND METHODS

The computer program ZPLAN (Karras et al., 1997) developed at the University of Hohenheim, Germany was used to model the Indigenous Thai beef cattle breeding structure. Based on the biological, technical and economic parameters, ZPLAN uses a deterministic approach to calculate the annual genetic gain for the breeding objective, genetic gain for single traits and return of investment adjusted for costs (profit) using the gene-flow method (Hill, 1974) and selection index procedures. These calculations assume that the population parameters and selection strategies are unchanged during the investment period and consider only one round of selection. The program calculates selection indices for breeding animals and applies order statistics to obtain adjusted selection intensities for populations with finite sizes.

Breeding objective

The evaluation of the efficiency of any breeding scheme requires the definition of a breeding objective that comprises those traits that influence the cost and returns for the producer. The Indigenous Thai beef cattle are raised in a tropical environment that is characterized by multiple stresses such as ecto- and endo-parasites, endemic diseases, heat stress resulting from high temperatures and humidity and seasonally poor nutrition. Consequently, adaptation to these stresses becomes important. Traits considered in the breeding objective are in Table 1.

The justification of inclusion of some traits (e.g. SWd, CoSW, MEAT and ADAP) in the breeding objective is obvious. The CoWR is important because it contributes to higher net calf crop (number of calves weaned per cow mated). The assumed economic values of traits in the breeding objective are presented in Table 2. These were derived in discussion with staff from the Department of Livestock Development (DLD), Bangkok, Thailand (Intarathum et al., 2002).

Population structure and selection groups

The breeding structure modelled consisted of three tiers: nucleus, multiplier and commercial unit. The nucleus is the tier that generates genetic gain. This tier was closed with all replacements sourced from within and selected on indices that included all available information. The multiplier unit expanded the genetic material for use by the commercial unit. A total population of 800,000 breeding cows was considered, with 1,200 cows (0.0015%) forming the nucleus, 40,000 cows (0.05%) forming the multiplier unit and the remaining 758,800 cows in the commercial unit. Bulls to be used as sires in the multiplier unit were selected from a subset of bulls that did not qualify to be used in the nucleus. Any possible movement of cows from one tier to the next was ignored. Mating in all the tiers was by natural mating.

The modelled population structure resulted in ten selection groups, being:

1) and 3) Sires from the nucleus to breed sires (1) and dams (3) for the nucleus;

2) and 4) Dams from the nucleus to breed sires (2) and dams (4) for the nucleus;

5) and 7) Sires from the nucleus to breed dams (5) for the multiplier unit and sires (7) for the commercial unit.

6) and 8) Dams from the multiplier unit to breed dams (6) for the multiplier unit and sires (8) for the commercial unit.

9) Sires from the commercial unit to breed dams and slaughter stock for the commercial unit; and

10) Dams from the commercial unit to breed dams for the commercial unit and slaughter stock.

Underlying biological and technical parameters describing the population structure are presented in Table 4. The costs of recording are based on records from DLD, Thailand and Australian experience.

Genetic and phenotypic parameters

Genetic and phenotypic parameters used were based on

Table 2. Economic values of traits in the breeding objective (v), phenotypic standard deviations (σ_p), heritabilities (h^2) and genetic correlations between selection criteria and traits in breeding objective and among traits in the breeding objective

Trait[1]	v (Baht)[2] per unit	σ_p	h^2	SWd	CoSW	CoWR	ADAP	MEAT
SWd (kg)	20	22.0	0.25	1.00	0.80	0.05	0.00	0.05
WWT (kg)	-	16.0	0.20	0.60	0.80	0.05	0.00	0.05
YWT (kg)	-	18.0	0.25	0.70	0.80	0.05	0.00	0.05
CoSW (kg)	10	22.0	0.20	0.80	1.00	0.05	0.00	0.05
HGI (cm)	-	8.0	0.10	0.60	0.60	0.05	0.00	0.02
HIP (cm)	-	6.0	0.20	0.60	0.60	0.05	0.00	0.02
BODY (cm)	-	8.0	0.40	0.60	0.60	0.05	0.00	0.02
CoWR (cm)	5,000	40.0	0.05	0.05	0.05	1.00	0.10	0.00
SSIZ (cm)	-	1.8	0.30	0.30	0.20	0.20	0.00	0.00
DCAL (cm)	-	23.0	0.10	-0.10	-0.10	-0.50	0.00	0.00
AFC (years)	-	0.4	0.10	-0.10	-0.10	-0.20	0.00	0.00
ADAP (score)	3,000	1.0	0.20	0.00	0.00	0.10	1.00	0.00
TICK (log)	-	0.6	0.42	-0.05	-0.10	0.00	-0.15	0.00
RECT (degree)	-	0.1	0.17	-0.05	-0.10	-0.05	-0.15	0.00
FEC (log)	-	0.6	0.35	0.00	-0.05	-0.05	-0.15	0.00
MEAT (%)	200	2.0	0.40	0.05	0.05	0.00	0.00	1.00
FAT (cm)		1.5	0.30	0.05	0.10	0.00	0.00	0.00
EMA (cm^2)		6.0	0.25	0.25	0.20	0.00	0.00	0.00
SWm (kg)	20	-	0.10	0.00	0.00	0.00	0.00	0.00

[1] See table for description of traits [2] 1 US$=40 Baht (April 2004)

Table 3. Genetic (below diagonal) and phenotypic (above diagonal) correlations between selection criteria traits

Trait[1]	WWT	YWT	HGI	HIP	BODY	SSIZ	DCAL	AFC	TICK	RECT	FEC	FAT
WWT		0.70	0.70	0.60	0.60	0.26	-0.03	0.00	0.00	-0.09	-0.02	0.00
YWT	0.80		0.50	0.40	0.40	0.38	-0.01	0.00	-0.06	-0.13	-0.01	0.00
HGI	0.70	0.65		0.50	0.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HIP	0.75	0.65	0.50		0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BODY	0.70	0.65	0.30	0.70		0.00	0.00	0.00	0.00	0.00	0.00	0.00
SSIZ	0.25	0.35	0.10	0.10	0.10		0.00	0.00	0.01	0.00	-0.02	0.00
DCAL	-0.10	-0.10	0.05	0.05	0.05	-0.20		0.00	0.15	-0.05	0.00	0.00
AFC	-0.10	-0.10	-0.10	-0.10	-0.10	-0.10	0.10		0.00	0.00	0.00	0.00
TICK	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.06	-0.01	0.00
RECT	-0.10	-0.10	-0.05	-0.05	0.00	0.00	0.05	0.00	0.15		0.01	0.00
FEC	-0.06	-0.05	-0.05	-0.05	0.00	0.00	0.05	0.00	0.30	-0.03		0.00
FAT	0.05	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
EMA	0.20	0.25	0.15	0.15	0.15	0.05	0.00	0.00	0.00	0.00	0.00	0.20

[1] See Table 1 for description of traits

parameters of the Angus breed (Barwick et al., 1999) and from literature (eg. Koots et al., 1994a,b; Burrow, 1999, Baik et al., 2002). These parameters are presented in Table 2 and 3. Only a small positive correlation between CoWR and ADAP of 0.10 was assumed. Correlations between ADAP and selection criteria TICK, FEC and RECT are assumed negative indicating that reduced TICK, RECT and FEC are signs of increased adaptation.

Selection criteria and information sources for two scenarios

Two scenarios were modelled, the first being the base situation (Base) where all criteria excluding the indirect traits for adaptation were measured in the nucleus and the multiplier unit. The selection criteria were chosen in consultation with DLD staff and it was assumed that these traits could either be recorded in the nucleus or in the multiplier unit, see Table 1. While all these criteria were measured in the nucleus, measurement of HGI, HIP, BODY, SSIZ, DCAL and AFC was assumed to also occur in the multiplier unit.

The base scenario modelled a situation where selection is for production traits and adaptation is assumed to be under the forces of natural selection. In a second scenario (+Adaptation), three indirect measures of adaptation, namely TICK, FEC and RECT were included in addition to all the information available for base scenario. This was to address the issue of whether their measurement as criteria for breeding programs incorporating adaptation is warranted.

All the selection groups had information contributed from records on the individual. The information available on the dam and paternal half sibs differed for the selection

Table 4. Biological and technical parameters describing the modelled herd structure and recording costs

	Nucleus	Multiplier	Commercial
Productive lifetime (years)			
Sires (groups 1, 3, 5, 7 and 9)	2	3	3
Dams (groups 2, 4, 6, 8 and 10)	5	6	7
Age at first calving (years)			
Sires	2.5	2.5	2.5
Dams	2.5	2.7	2.7
Survival rate (including both death and culling)			
Bulls (annual)	0.80	0.80	0.70
Cows (annual)	0.95	0.90	0.90
Survival from birth to 1 year	0.95	0.95	0.95
Survival from birth to 2 years	0.98	0.98	0.95
Reproductive and other parameters			
Calving rate	0.80	0.78	0.78
Proportion of male calves suitable for breeding	0.90	0.90	0.90
Proportion of female calves suitable for breeding	0.90	0.90	0.90
Proportion of female kept for replacement	0.75	0.75	0.75
Number of sires selected per year for breeding in the nucleus	40	-	-
Number of females per male	25	50	50
Herd size in the commercial unit	-	-	50
Investment parameters			
Investment period (years)	20		
Discount rate for returns	0.08		
Discount rate for costs	0.05		
Costs (Baht)[1] incurred and time of occurrence (years, in parentheses)			
Fixed costs per cow in the nucleus	30 (2)		
Weaning weight	4 (0.55)		
Yearling weight	4 (1)		
Cow weight	4 (3)		
Heart and hip height	9 (1)		
Scrotal size	5 (1)		
Days to calving	10 (2)		
Ultra-sound scanning	160 (1.1)		
Temperature	10 (1)		
Faecal egg count	48 (1)		
Tick count	48 (1)		
Bull transport from nucleus to multiplier unit	150 (1)		
Bull transport from multiplier to commercial unit	100 (1)		

[1] 1 US$=40 Baht (April 2004).

groups, reflecting the different ages at which selection decisions are made for each group. Table 5 shows the number of records and information sources for indices used to select sires and dams for the nucleus, multiplier and commercial units.

Variations and parameter sensitivity to changes in heritabilities of and genetic correlations between adaptation traits

An optimisation of breeding structures has to be based on calculations of the effectiveness of different critical parameters. The heritabilities and the genetic correlations used in the present study were based on literature values. An overestimation of expected response from selection based on a selection index will arise from sampling error of genetic parameters used in constructing an index (Hazel et al., 1994). Under the −Adaptation scenario which represented the highest level of performance recording, variations and sensitivity to changes in the heritabilities of and genetic correlations between the adaptation traits was investigated, keeping the genetic variance constant, since these parameters will likely change if estimated under the conditions in Thailand. The heritabilities of ADAP were varied from 0.10 to 0.40 and from 0.05 to 0.25 for RECT. The heritabilities of TICK and FEC were varied from 0.30 to 0.50. The genetic correlations were varied from -0.30 to -0.10 between ADAP and its indirect traits and from 0.20 to 0.45 between the indirect measures.

RESULTS AND DISCUSSION

Comparison of scenarios for improving both production and adaptation

Genetic gain and returns for traits in the breeding

Table 5. Number of records and information sources used to select sires and dams for the nucleus, multiplier and commercial units[1]

Selection group	Information sources[2]	No. of records	WWT	YWT	CoSW	HGI	HIP	BODY	SSIZ	DCAL	AFC	TICK	RECT	FEC	FAT	EMA
Sires for the nucleus and multiplier unit (groups 1, 3, 5 and 7)																
	Ind	1	✓	✓		✓	✓	✓	✓			✓	✓	✓	✓	✓
	Dam	1	✓	✓	✓	✓	✓	✓		✓	✓					
	PHS-males	10	✓	✓		✓	✓	✓	✓			✓	✓	✓	✓	✓
	PHS-females	20	✓	✓		✓	✓	✓				✓	✓	✓	✓	✓
Dams for the nucleus (groups 2 and 4)																
	Ind	1	✓	✓		✓	✓	✓	✓			✓	✓	✓	✓	✓
	Dam	1	✓	✓	✓	✓	✓	✓		✓	✓					
	PHS- males	10	✓	✓		✓	✓	✓	✓			✓	✓	✓	✓	✓
	PHS-females	20	✓	✓		✓	✓	✓				✓	✓	✓	✓	✓
Dams for the multiplier unit (groups 6 and 8)																
	Ind	1				✓	✓	✓								
	Dam	1				✓	✓	✓		✓	✓					
Sires for the commercial unit (group 9)																
	Ind	1				✓	✓	✓	✓							
	Dam	1				✓	✓	✓		✓	✓					
Dams for the commercial unit (group 10)																
	Ind	none														

[1] See Table 1 for description of traits. TICK, RECT and FEC only apply to the −Adaptation scenario. [2] Ind, the individual, PHS, paternal half sibs.

Table 6. Genetic gain and returns in traits in the breeding objective, costs and profit per cow in the population for the two scenarios

Breeding objective trait[1]	Base		+ Adaptation	
	Genetic gain per year	Return per cow (Baht)[2]	Genetic gain per year	Return per cow (Baht)
SWd (kg)	2.08	143.02	1.89	136.37
CoSW (kg)	1.83	62.30	1.71	60.03
CoWR (%)	0.22	23.48	0.25	24.52
ADAP (score)	0.00	2.22	0.01	26.37
MEAT (%)	0.04	16.35	0.03	14.54
Genetic gain per cow and year (Baht)	80.07		107.27	
Total return per cow (Baht)		247.37		261.83
Mean generation interval (years)	3.90		3.90	
Fixed costs per cow (Baht)	3.04		3.04	
Variable costs per cow (Baht)	1.63		1.75	
Total costs per cow (Baht)	4.67		4.79	
Profit per cow (Bhat)	242.70		257.05	

[1] See Table 1 for description of traits. [2] 1 US$=40 Baht (April 2004).

objective, costs and profit per cow in the population for the two different scenarios modelled are presented in Table 6. As sale weight maternal was considered to be genetically uncorrelated to other traits and no information was used it contributed nothing to the genetic progress. As expected, the genetic gain per year for SWd and MEAT was higher in the base scenario than in the −Adaptation scenario. In both the scenarios, SWd made the highest contribution to the return per cow. In the base scenario, ADAP ranked last in contributing to returns as a consequence of the very low favourable correlation between CoWR and adaptation to the environment. Inclusion of indirect measures of adaptation as selection criteria resulted in increased contribution of ADAP to returns, and additional genetic gain and profitability per cow and year. This shows that measuring of these indirect traits in the nucleus confers reasonable advantages to breeding programs that are aimed at improving production in stressful environments. The additional cost of measuring these traits in the nucleus (0.12 Baht per cow in the population) should not be an issue because the benefits accrued offsets them at a ratio of 1:120. Though the influence of costs in determining the acceptance of any beneficial technology in breeding programs in developing countries should not be underestimated.

Sensitivity to changes in heritabilities of and genetic correlations between adaptation traits

Table 7 and 8 show the genetic gain in the traits in the breeding objective, returns and profit per cow in the population for the +Adaptation scenario when the heritabilities of and genetic correlations between ADAP and adaptation traits are varied. Obviously, the results were sensitive to the changes in heritabilities of and genetic correlations between ADAP and adaptation traits. The gain

Table 7. Effect of heritabilities of adaptation traits on genetic gain per year and profitability for the −Adaptation scenario

Criterion[1]	ADAP			RECT			TICK			FEC		
	0.10	0.30	0.40	0.05	0.10	0.25	0.30	0.40	0.50	0.30	0.40	0.50
Genetic gain per year												
SWd (kg)	1.89	1.89	1.89	1.91	1.90	1.88	1.90	1.89	1.88	1.90	1.88	1.86
CoSW (kg)	1.71	1.71	1.71	1.73	1.72	1.70	1.71	1.710	1.70	1.71	1.71	1.69
CoWR (%)	0.25	0.25	0.25	0.24	.25	0.26	0.25	0.25	0.25	0.25	0.25	0.26
ADAP (score)	0.01	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
MEAT (%)	0.03	0.03	0.03	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Genetic gain per cow (Baht)[2]	107.13	107.46	107.46	103.47	105.21	109.31	105.00	106.89	108.77	106.24	108.28	110.28
Total return per cow (Baht)	261.75	261.94	261.94	259.79	260.70	262.98	260.47	261.61	262.74	261.29	262.37	263.45
Profit per cow (Baht)	256.97	257.16	257.15	255.01	255.92	258.19	255.69	256.82	257.95	256.50	257.59	258.66

[1] See Table 1 for description of traits. [2] 1 US$=40 Baht (April 2004).

Table 8. Effect of genetic correlations between adaptation and its indirect traits on genetic gain per year and profitability for the + Adaptation scenario

Criterion[1]	ADAP and TICK			ADAP and RECT			ADAP and FEC		
	-0.10	-0.20	-0.30	-0.10	-0.20	-0.30	-0.10	-0.20	-0.30
Genetic gain/year									
SWd (kg)	1.92	1.85	1.74	1.91	1.87	1.80	1.93	1.85	1.74
CoSW (kg)	1.72	1.68	1.60	1.73	1.68	1.61	1.73	1.67	1.58
CoWR (%)	0.26	0.24	0.23	0.25	0.25	0.26	0.25	0.25	0.25
ADAP (score)	0.009	0.014	0.021	0.010	0.013	0.017	0.009	0.014	0.020
MEAT (%)	0.04	0.03	0.03	0.04	0.03	0.03	0.04	0.03	0.03
Genetic gain/cow (Baht)[2]	102.32	114.06	132.32	104.33	111.23	121.93	102.52	113.61	130.43
Total return/cow (Baht)	259.05	265.61	275.87	260.31	263.90	269.59	259.38	265.16	274.21
Profit/cow (Baht)	254.27	260.83	271.09	255.52	259.12	264.81	254.59	260.38	269.42

[1] See Table 1 for description of traits. [2] 1 US$=40 Baht (April 2004).

in SWd decreased while the return and profit per cow increased as the heritability of each of the traits increased (Table 7). The return and profit per cow will increase as a consequence of the increased accuracy of selection for the objective, which occurs at higher heritabilities.

Not surprisingly, an increase (from -0.10 to -0.30) in the genetic correlations between ADAP and its indirect measures resulted in an increase in returns and profit per cow (Table 8). The interrelationships between progress in production and adaptation is especially seen in the genetic gain per year for SWd. The selection pressure on this trait is decreased if selection accuracy for ADAP increases. The genetic gain in MEAT marginally decreased when the genetic correlation between ADAP and any of the indirect traits was increased from -0.10 to -0.30. The magnitude of these changes depended on the heritability of the indirect trait, TICK>FEC>RECT. Only very small changes occurred in the expected genetic gain and profitability of the breeding program when the genetic correlations between thee indirect traits were varied (results not tabled). This indicates that genetic correlation estimates between ADAP and its indirect measures are more important than correlations between the indirect measures themselves in the design of breeding programs. Furthermore as correlations between indirect traits increase, genetic gain is slightly reduced since any two traits explain more of the same variation in the target trait ADAP.

The changes in the magnitude of the genetic gain and profit per cow emphases the importance of using reliable estimates of these traits in any breeding program. The estimates for the adaptation traits used in this study were mostly estimated under northern Australian conditions and were assumed to be similar to those that would be obtained under the conditions in Thailand. In Thailand, the humidity level is expected to be higher while production levels are lower than in Australia. There is the need to estimate reliable genetic and phenotypic parameters for Thai conditions because parameters specific to particular breeds and environments should be used in breeding program designs (Burrow, 2001).

General

This study evaluated the effect of changes in the level of heritability (keeping genetic variance constant) and genetic correlations between adaptation traits on genetic gain and profitability using as model the Indigenous Thai beef cattle breeding structure which consists of a nucleus, multiplier and commercial unit. It also compared two options (the two scenarios) that have been suggested for the improvement of both production and adaptation of animals in stressful environments. To the best of our knowledge, this is the first attempt to compare these options in terms of the genetic and economic efficiency of breeding programs incorporating adaptation as a trait in the breeding objective. Nitter et al.

(1994) and Archer et al. (2004) have already pointed out the potential shortcomings in the methodology applied in ZPLAN and these will therefore not be repeated here. This study has demonstrated the effects of changes in heritability and genetic correlations between adaptation traits and of inclusion of indirect measures of adaptation in the index on genetic gain and the overall profitability of breeding programs in a stressful environment. Whilst heat tolerance is least amenable to managerial solutions, TICK and FEC may be managed using drugs or vaccines. Nonetheless, breeding for disease resistance/tolerance and therefore adaptation, has an advantage in that once achieved, it is expected to be permanent and passed on to future generations.

Although the general profitability of the base scenario can be increased by optimising the size of the multiplier unit to 0.055% (44,000 cows) of the total population (Intaratham et al., 2002), the benefits would still be lower than in the −Adaptation scenario notwithstanding the extra costs incurred in measuring TICK, RECT and FEC. It should be noted that measurements of these criteria (especially TICK and RECT) requires quiet animals. Producers also prefer less temperamental animals for ease of management. *B. indicus* are more temperamental than *B. taurus* when reared under comparable conditions (Burrow, 1997). Consequently, including temperament as a trait in the breeding objective is warranted. The issue would be how to accurately and cheaply measure it under extensive management systems since correlations between various measures of temperament and productive and adaptive traits are weak (Fordyce et al., 1996; Burrow, 2001). Under extensive management systems, temperament is largely an independent trait (Burrow, 2001). Burrow (1997) reviewed the numerous, vastly different methods that can be used to measure temperament and showed that estimates of heritability of temperament were consistent across methods. Under Thailand conditions, temperament could be measured as the time taken for an animal to cover a set distance after leaving a crush i.e. flight time (Burrow et al., 1988). This method is objective, safe, quick and easy to implement on-farm.

In contrast to measurement of temperament, methods used to measure TICK, FEC and RECT are almost standard. TICK is measured as number of ticks on one side of each animal following field infestations (Wharton and Utech, 1970), FEC as the number of worm eggs per gram of faeces (Roberts and O'Sullivan, 1950) and RECT as the rectal temperature under conditions of heat stress. However, depending on the design of the recording system, RECT so recorded might not reflect resistance to heat stress but other factors such as activity level of body (as a result of the grazing behaviour) or body fat distribution. If infrared equipment is used instead of the conventional mercury thermometer, without control, the reading obtained might be a reflection of the animal's surface (skin) temperature rather than of resistance to heat stress. In such a situation, animals might be moved to a shaded area and allowed to acclimatise before the measurement is taken. Whereas this study showed that measuring of these indirect measures of adaptation on both sires and dams was profitable, costs can be reduced if they are only measured in nucleus males. It is better to measure high-cost criteria only on candidates likely to have a high impact on the breeding population. In most livestock species, the sires used in nucleus have the greatest influence on the entire population.

Apart from reliable genetic and phenotypic parameters, estimates of economic values are also required in the design of breeding programs. Economic values are calculated by changing the value of the genetic merit of a trait by one unit allowing no simultaneous change in genetic merit of other traits. Breeding objectives should account for inputs, such as feed, husbandry and marketing costs, as well as for outputs, such as income from sale of products, surplus offspring and cows. But defining objectives in economic terms, which is difficult enough in temperate agriculture, becomes even more problematic in the tropics because of the greater environmental and managerial complexity (Franklin, 1986). Nevertheless, economic information can be collected in research stations (e.g. those of DLD) or in large-scale farms and used to derive economic values for most traits using the methods and perspectives reviewed by Kahi (2000).

The challenge will be how to estimate the economic value of an aggregate trait like ADAP. In cases of uncertain information, it is better to use baseline values rather than no values at all for the purpose of designing the program (Kahi and Nitter, 2004). These values may later be updated as more data are collected and analyzed once the breeding program is in place and experience has been gained. In the present study, ADAP was linked to cow survival and therefore its economic value was similar to that of cow survival. Cow survival influences the productive herdlife, which determines the lifetime profitability of an animal since the costs of production are largely influenced by the ability of animals to cope with the prevailing environmental stresses (Baker and Rege, 1994).

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IMPLICATIONS

The present study shows that it is profitable to incorporate indirect measures of adaptation in breeding programs aimed at improving productivity in a stressful tropical or subtropical environment. Concentrating on selection for only production traits while leaving adaptation to the forces of natural selection should only be a second option if the breeding program is to be sustainable in the long run. The changes in the magnitudes of the genetic gain and profit per cow stresses the importance of using reliable estimates of these traits in any breeding program. There is therefore the need to estimate reliable genetic and phenotypic parameters under the conditions in Thailand. Further work on estimation of economic values for production traits and ADAP is also needed.

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