FACTORS AFFECTING PRODUCTIVITY ON DAIRY FARMS IN TROPICAL AND SUB-TROPICAL ENVIRONMENTS

D. V. Kerr[1], T. M. Davison[2], R. T. Cowan[2] and J. Chaseling[1]

Faculty of Environmental Sciences, Grifffith University, Kessels Road, Nathan, Queensland 4111, Australia

Summary

The major factors affecting productivity on dairy farms in Queensland, Australia, were determined using the stepwise linear regression approach. The data were obtained from a survey conducted on the total population of dairy farms in Queensland in 1987. These data were divided into six major dairying regions. The technique was applied using 12 independent variables believed by a panel of experienced research and extension personnel to exert the most influence on milk production. The regression equations were all significant ($p < 0.001$) with the percentage coefficients of determination ranging from 62 to 76% for equations developed using total farm milk production as the dependent variable. Three of the variables affecting total farm milk production were found to be common to all six regions. These were; the amount of supplementary energy fed, the area set aside to irrigate winter feed and the size of the area used for dairying. Higher production farms appeared to be more efficient in that they consistently produced milk production levels higher than those estimated from the regression equation for their region. Other methods of analysis including robust regression and non linear regression techniques were unsuccessful in overcoming this problem and allowing development of a model appropriate for farms at all levels of production.

(**Key Words** : Dairy Farms, Milk Production, Regression, Surveys)

Introduction

Dairy production systems in tropical and sub-tropical environments are relatively new. Dairy farms were established in the sub tropical and tropical areas of Queensland, Australia, after the first World War as a pioneering industry and many of the problems associated with developing feeding systems for these farms have been addressed through practical experience and research. The predominant breed is now Holstein-Friesian and farmers are paid on the basis of milk volume produced. During the summer months these cattle are subjected to temperatures and humidity in excess of the optimum for milk production (Davison et al., 1988). There have been major developments in feeding systems over the past 20 years, using technology such as irrigation, introduced temperate and tropical pasture species, supplementation, nitrogen fertilizer and hay or silage (Cowan, 1985). Herd improvement, using techniques of artificial insemination and herd recording, is used on about half of these farms (Dairy Herd Improvement Report, 1994). These developments have been proven in the research environment (Cowan, 1985) but little was known of their impact and level of adoption at the farm level.

It was felt that the further development of these farming systems would be aided through an understanding of the relative effects of various inputs on milk productivity. To provide information on the levels of inputs used and to assess the relative importance of these, a quantitative survey was conducted during 1987 recording the annual inputs and outputs for the total population of dairy farms in Queensland. The information was used to establish a baseline data base of the inputs used on farms, assess the relative level of associations these have with milk production, and make assessment of those interactions which may be important for further study.

One of the major aims of the survey was to aid farmers in realising their main objective namely, improving total farm profit. An improvement in profit must be within the physical constraints of the farm, most

[1]Address reprint requests to Mr. D. V. Kerr, Faculty of Environmental Sciences, Griffith University, Kessels Road, Nathan, Queensland 4111, Australia.

[2]Queensland Department of Primary Industries, Mutdapilly Research Station, Mail Service 825 Peak Crossing Queensland 4306 Australia.

Received July 19, 1994
Accepted May 27, 1995

importantly the size of the farm. Therefore, the only alternatives available to a farmer are the re-allocation of uses of available land, improvement of land and/or variation in amount and type of external sources of feed.

A key variable associated with profit on dairy farms in Queensland is gross margin per farm and the largest contribution to increased gross margins per farm in recent years has been increases in total farm production (Chopping and Walker, 1993). As this variable is a major factor in profitability it was used in this study to measure the productivity of the farm. Other commonly used measures of productivity such as milk production per hectare or milk production per cow depend largely on individual farm soil type variability and preferred management options and are thus difficult to interpret in a meaningful way. Because of this they were not used in this analysis. This situation arises in many tropical and sub-tropical dairy regions and is addressed in the discussion section of this paper.

Farming Systems

For the purposes of the study the Queensland dairy industry was divided into the six regions of North Queensland, Central Queensland, North Coast, West Moreton, South Coast and Darling Downs (figure 1). In all regions cows graze pastures or fodder crops throughout the year. Dairy farms use tropical pasture or crop species during summer, and annual temperate species such as dryland or irrigated oats, rye grass and clover during winter. Tropical pastures are used extensively in coastal regions (1, 2, 3, 4 and 5) with grazed crops being dominant in inland regions (2, 4 and 6). These tropical pastures are low in digestible energy (Minson, 1971) and many tropical soils are low in the elements needed for plant growth, particularly nitrogen and phosphorus (Davison et al., 1985), thus fertilizers are a major input for pastures and crops. The ranges of temperature and rainfall for each of these six regions are shown in table 1.

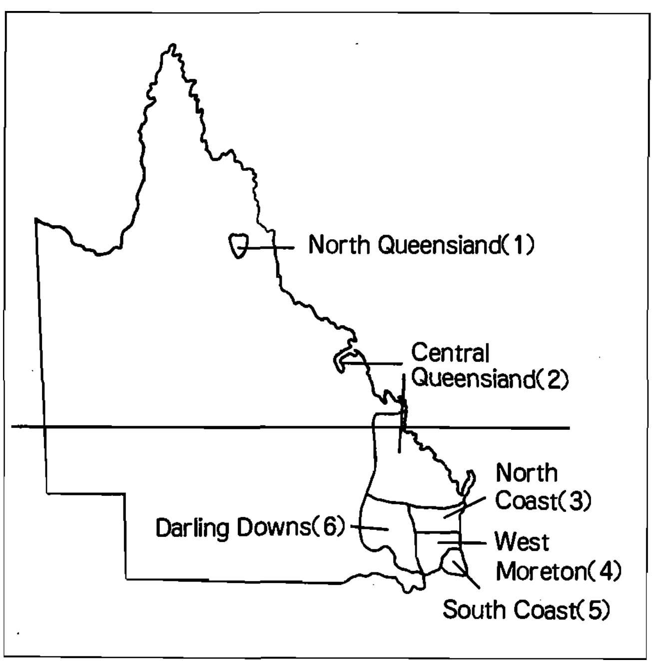

Figure 1. Dairy regions of Queensland, Australia

TABLE 1. THE AVERAGE MAXIMUM, AVERAGE MINIMUM AND AVERAGE RAINFALL FOR THE MAJOR CENTRE IN EACH REGION. REGIONS ARE NORTH QUEENSLAND(1), CENTRAL QUEENSLAND(2), NORTH COAST(3), WEST MORETON(4), SOUTH COAST(5), DARLING DOWNS(6)

Region No.	Average Rainfall (mm)	Average maximum temperature ℃ in summer	Average minimum temperature ℃ in winter
1	1,284	28.8	10.2
2	842	31.9	11.6
3	1,779	30.7	7.0
4	894	31.8	7.2
5	935	28.1	9.9
6	717	29.8	3.0

About 60 percent of farms utilize irrigation, and the greater part of this is used to grow rye grass and clover pastures during winter and spring. Fertilizers are intensively used on these pastures, and to a lesser extent on tropical pastures. A small percentage (about 2%) of both irrigated and dryland farms incorporate silage into their feeding systems. The main supplement fed is grain in the forms of sorghum, maize or barley. Molasses is also fed in regions where transport costs are low enough to make it economically viable (regions 1, 3, 4 and 5).

Marketing Structure

A relatively high percentage (between 47.6 and 72.6%) of the milk produced in each region is used in the fresh milk market (Queensland Daiy Industry Authority, pers. comm.). This means there must be a continual supply of liquid milk to factories year round and there are financial incentives to encourage farmers to supply milk at a constant rate each month. To achieve this goal all dairy farmers in Queensland calve cows throughout the year. Winter milk is more expensive to produce, as it depends on irrigated annual temperate pastures and most milk factories offer financial incentives for winter production. Milk quality standards for fat, solids not fat and protein must also be maintained. These requirements for year round production and quality mean that farmers must attempt to have as uniform a level of nutrition as possible for the whole herd.

Data and Analysis

All dairy farmers were approached in the survey and a total of 1989 supplied all the information requested; ninety farmers were unwilling or unable to supply the required information. The data were collected by filling out a form during a personal interview by the local dairy extension officer from the Queensland Department of Primary Industries. The survey was conducted from September 1987 to December 1987, and the data collected relate to the 1986/87 financial year. The questions were designed to provide quantitative estimates of production and inputs used during that year, including types and amounts of supplements fed, fertilizers applied, areas of the farm used for summer and winter grazing areas of dryland and irrigated crops or pasture, number of cows milked, the extent and duration of use of artificial insemination (AI) and herd recording, and design of the dairy premises.

Initial exploratory analysis of these data suggested that some farms were atypical and these were omitted from analysis. Across regions a total of 151 farms where the milk production per cow was below 1,500 litres per year were omitted. Milk production levels per cow below this figure would indicate a farming system that uses no inputs, as production levels of this magnitude can be obtained from cows grazing native pastures alone. Across all regions an additional 15 farms were excluded due to other factors such as large areas of legume or small total farm size, with a maximum of three farms excluded in any one region. Artificial insemination usage data for region 3 was not available.

A total of 12 independent variables selected by a panel of experienced research and extension personnel to exert the most influence on milk production, were used in the analysis. The variable 'energy' was obtained from the total amount of supplement fed to all milkers on the farm for the year multiplied by metabolizable energy content (MJ) of each supplement (NRC, 1989). The variables 'potash', 'nitrogen', 'phosphorus' and 'hay/silage' were expressed in kilograms. The variables 'winter irrigation area', 'summer irrigation area', 'total farm area' and 'Legume area' were expressed in hectares. These nine variables were grouped together and referred to as nutritional variables as they either directly or indirectly contribute to the nutrition of the dairy herd.

The variable 'herd recording' was expressed as the number of years the farmer had been recording the milking herd, while 'AI usage' was defined as the percentage of cows in the herd being artificially bred. The variable 'shed type' was recorded as either -1, a walk-through or 1, a rotary or herringbone. As there were only 17 rotary dairies throughout the state they were combined with the herringbone dairies for analysis. These three variables were grouped together and referred to as management variables as they are instrumental in the efficient management of the dairy herd. The mean and standard deviation for nutritional variables are shown in table 2 and management variables in table 3.

The levels of production per cow varied from 2,685 litres per lactation in region 2 to 3,527 litres per lactation in region 1. These production levels indicate the level of nutrition is likely to be well below that needed for Holstein-Friesian cows to reach their genetic potential (M. Tierney, pers. comm.). In the low milk production per cow ranges shown in the 1986-87 survey the relationship between nutritional inputs and milk production is linear. This agrees with findings in the work reported by Moe and Tyrrell (1975). Using the data in table 2 and appropriate response rates it can be seen that a high proportion of nutritional inputs are purchased either directly as concentrates or hay, or as farm inputs such as fertilizer and water for irrigation. This suggests the farmer adjusts cow numbers in a way that maintains nutritional inputs well below the genetic potential of the cow. This assumption may be inaccurate at very low purchased inputs, where the natural farm productivity will account for a large part of the cow's nutrition, or at very high purchased inputs where the genetic potential of the cow is being approached. However for the major part we believe these data are in the linear section of this relationship.

The number of cows milked is recognized to be a major factor influencing total farm milk production. It was not included as a separate variable in the analysis as its effect is incorporated through all other nutritional inputs which depend on the number of cows milked.

The possibility of non-linear responses to the main inputs was explored using a variety of non-linear functional forms. In all cases the non-linear terms were non significant and the use of a linear form was considered adequate for the given purpose, and provided a simpler model which could be interpreted by farmers.

Initially, potential interactions between variables based on theoretical knowledge and previous experimental evidence were investigated. The only significant interaction within nutritional variables was between energy

TABLE 2. MEAN AND STANDARD DEVIATION (SD) FOR ALL NUTRITIONAL VARIABLES INCLUDED IN THE STUDY FOR ALL REGIONS. REGIONS ARE NORTH QUEENSLAND(1), CENTRAL QUEENSLAND(2), NORTH COAST(3), WEST MORETON(4), SOUTH COAST(5), DARLING DOWNS(6)

Variable	Parameter	Region					
		1	2	3	4	5	6
Milk production	mean	380	277	325	261	421	228
(litres × 10^3/yr)	S.D.	197	137	163	171	291	125
Supplementary energy	mean	118	95	108	77	124	67
(MJ × 10^4 farm/year)	S.D.	63	58	85	68	106	44
Nitrogen	mean	71	41	65	47	68	33
(kg × 10^2/farm/year)	S.D.	93	47	68	58	82	36
Summer irrigation area (ha)	mean	3.0	8.9	2.4	9.3	12.4	3.8
	S.D.	7.9	14.0	5.9	11.6	21.0	10.1
Winter irrigation area (ha)	mean	6.7	8.2	8.4	9.0	15.0	3.4
	S.D.	9.6	11.9	9.9	11.5	15.9	8.3
Total farm area (ha)	mean	155.6	306.0	142.2	160.3	194.6	234.1
	S.D.	74.7	241.1	83.6	122.9	146.4	164.1
Total hay and/or silage	mean	17	29	9	64	62	65
	S.D.	111	74	22	119	227	93
Legume area (h)	mean	5.1	8.9	3.1	11.1	12.1	10.5
	S.D.	8.4	13.4	8.1	11.3	16.0	14.9
Phosphorus (kg/year)	mean	2,120	448	954	110	371	310
	S.D.	2,385	981	1,515	275	879	743
Potash (kg/year)	mean	3,472	213	764	109	188	66
	S.D.	4,924	984	2,117	623	851	603

TABLE 3. MEAN AND STANDARD DEVIATION (SD) FOR ALLMANAGEMENT VARIABLES INCLUDED IN THE STUDY FOR ALL REGIONS. REGIONS ARE NORTH QUEENSLAND(1), CENTRAL QUEENSLAND(2), NORTH COAST(3), WEST MORETON(4), SOUTH COAST(5), DARLING DOWNS(6)

Variable	Parameter	Region					
		1	2	3	4	5	6
AI-use	mean	55	44	data not	43	68	34
(% of herd)	S.D.	44	44	available	44	42	43
Number of	mean	5	3	2	3	5	3
years herd recording	S.D.	6	6	5	6	8	7
Type of dairy shed:							
Type 1 rotary or herringbone	type 1	153	134	229	97	83	223
Type 2 walk-through	type 2	68	70	138	119	36	475

and nitrogen in region 2. The inclusion of this interaction factor improved the coefficient of determination for that region by only one percent, and for consistency with other regions was not considered of sufficient magnitude to be included in the results.

There were some significant interactions between nutritional variables and management variables. More detailed exploration of these interactions showed that the farms not using AI and herd recording were in the low usage range of the nutritional inputs and as such were below the input level needed to demonstrate a response. This may reflect two levels of response, however it was felt that any inaccuracies incurred by using the average response was greatly outweighed by the increase in parsimony in the model and the resulting interpretability to the farmer.

A stepwise linear regression approach was thus adopted to analyse these data with significance determined at the 95% level of confidence using the statistical package MINITAB™. The dependent variable used was total farm milk production (litres per year). Throughout the analysis, emphasis was placed on identifying important variables, as the major purpose was to assess the relative contributions of these to prductivity.

Results

Farm Inputs

There was a wide range in the level of milk production per farm in each region, and total farm production was lower in those regions feeding less supplementary energy. The application of phosphorus and potash in region 1 was much higher than in any of the other 5 regions and this may be associated with higher total farm production and lower basal soil fertility. In regions 4 and 5 there was a high level of silage feeding, while in region 6 a high level of hay feeding. The more southern areas of Queensland (regions 4, 5 and 6) had a larger proportion of legume on farms (table 2).

The mean level of supplementary energy per farm varied between regions from 67×10^4 to 124×10^4 MegaJoules of Metabolizable Energy (MJ ME), with a large standard deviation (44×10^4 and 106×10^4 respectively) (table 2). Farm size varied greatly between and within regions and, in general, the larger farms were in the drier regions (2 and 6). On the farms using herd recording, the milking cows had been recorded for between two and five years. The use of AI varied from 34 to 68% (table 2).

The proportion of herringbone and rotary dairies was relatively low in region 6 (32%), intermediate in region 4 (45%) and highest in regions 1, 3 and 5 (62 to 70%), (table 3).

TABLE 4. PARTIAL REGRESSION COEFFICIENTS OF ALL SIGNIFICANT VARIABLES ($P < 0.05$) FOR ALL REGIONS AND THE WHOLE STATE. STANDARD ERROR IN BRACKETS UNDER EACH COEFFICIENT. REGIONS ARE NORTH QUEENSLAND(1), CENTRAL QUEENSLAND(2), NORTH COAST(2), WEST MORETON(4), SOUTH COAST(5), DARLING DOWNS(6), WHOLE STATE(7)

Partial regression coefficient	Region						
	1	2	3	4	5	6	7
Constant	716	56,460	90,938	61,592	50,504	72,519	71,433
	(17,397)	(13,140)	(12,321)	(13,468)	(22,364)	(6,520)	(5,035)
Energy	0.116	0.132	0.101	0.119	0.139	0.126	0.128
	(0.012)	(0.01)	(0.007)	(0.01)	(0.012)	(0.007)	(0.004)
Nitrogen	2.95	4.9	–	–	4.8	8.55	4.36
	(0.84)	(1.35)			(2.2)	(0.91)	(0.47)
Winter irrigation area	3,012	2,367	4,710	3,400	5,640	–	3,078
	(797)	(581)	(543)	(680)	(1,188)		(277)
Summer irrigation area	2,182	–	–	3,407	1,667	1,295	1,103
	(855)			(670)	(730)	(315)	(244)
Hay and/or silage	0.256	0.203	–	–	0.296	0.121	0.181
	(0.6)	(0.07)			(0.05)	(0.032)	(0.02)
Legume area	–	2,649	–	–	–	1,482	1,040
		(476)				(213)	(200)
Phosphorous	7.7	–	16.5	–	–	–	10.3
	(3.2)		(3.5)				(2.3)
Potash	–	17.6	–	–	–	–	4.1
		(6.0)					(1.3)
AI usage	362	–	–	342	–	–	127
	(161)			(152)			(57)
Herd recording in	4,443	–	3,024	–	–	–	1,118
years	(1,130)		(982)				(397)
	798	76	394	208	216	87	95
Farm area in hectares	(96)	(23)	(65)	(55)	(86)	(18)	(15)
Shed type	20,420	–	23,410	25,163	–	14,818	18,283
	(7,494)		(5,732)	(6,960)		(3,165)	(2,463)

Total Farm Production

The analyses of the main variables contributing to total farm milk production are shown in table 4. In all equations 62 to 81 percent of the variation associated with total farm milk production could be explained in terms of the independent variables (table 5).

TABLE 5. COEFFICIENTS OF DETERMINATION (R^2), NUMBER OF FARMS AND THE ROOT MEAN SQUARE ERROR FOR EACH EQUATION FOR ALL REGIONS AND THE WHOLE STATE. REGIONS ARE NORTH QUEENSLAND (1), CENTRAL QUEENSLASD(2), NORTH COAST(3), WEST MORETON(4), SOUTH COAST(5), DARLING DOWNS(6) AND WHOLE STATE(7)

Parameter	Region						
	1	2	3	4	5	6	7
Percentage coefficient of determination (R^2)	76.9	68.9	62.4	70.4	81.4	65.0	70.3
Number of farms	221	204	366	215	119	697	1,822
Root mean square error	93,636	7,6507	100,299	92,720	125,599	73,930	95,914

The nutritional variable which consistently related to total production for all regions and statewide was the amount of supplementary energy fed to cows. Farm area had an effect on total farm milk production in all regions with each additional hectare increasing milk production by between 76 litres (region 2) and 798 litres (region 1). The management variable of herd recording had an effect in regions 1 and 3 with AI usage having an effect in regions 1 and 4. Shed type had an effect in most regions, with the combined rotary and herringbone designs increasing milk production for the farm by between 14,818 and 25,163 litres of milk for regions 6 and 4 respectively.

The area of winter irrigation was important in all regions except 6 where there were smaller areas set aside (average of 3.4 hectares per farm). Most of the irrigation was used to water temperate species. the effect of this fodder source is shown by the highly significant ($p < 0.001$) partial regression coefficients for winter irrigation area shown in five of the six regions and across the whole state.

Discussion

This study has identified the major variables associated with milk production in Queensland. These have been broadly categorised into feeding and management. Feeding can be further divided into direct feeding and indirect feeding variables. The direct feeding variables are energy fed in the form of grain, molasses and concentrate supplements and the amount of hay or silage fed. The indirect feeding variables can be classed as those that have an effect on pasture production, such as fertilizer inputs and the area of irrigation.

The analysis of milk production per unit area or per cow were not pursued for the following reasons. A typical coastal farm in Queensland (regions 2, 3, 4 and 5) has a great deal of variability in land types. Experienced extension personnel have estimated an average of 80 percent of a typical farm in these regions consists of ridges and hills and only 20 percent consist of irrigable creek flats. On the Darling Downs (region 6) the proportion of ridges and hills is approximately 45 percent. As the data available could not be used to distinguish between these land types, an average per hectare milk production estimate would not be comparable across farms or districts.

In addition, a great deal of the milk production on the average farm is obtained from off farm inputs such as concentrates. It has been estimated that the milk obtained from sources other than paddock feed was 39 percent for irrigation farms and 61 percent for dryland farms in 1991-92 in region 2 and 30 percent and 44 percent respectively for the same year in regions 3 and 4 (Chopping and Walker, 1993). These off farm inputs mean that measures of milk production per hectare may not be true indicators of the productivity of the physical farm unit, and are thus inappropriate for comparing farms.

The production per cow measure of efficiency was also difficult to assess because of the wide variation in systems of production. Depending on farm location and quality and resources available in the district, the same total milk production can be obtained by milking more cows at a lower milk production per cow level or milking less cows at a higher milk per cow production level. Both methods of obtaining milk may be profitable depending on the circumstances.

On a statewide basis 70 perecnt of the variability in total farm production can be explained by the regression equations using all 12 of the recognized variables associated with production. The West Moreton region (region 3) has been extensively studied and the major variables identified in this study were energy, winter irrigation area, summer irrigation area, AI use, farm area, and shed type. The identification of these variables as important are consistent with the results from other input-output studies conducted in this region (Rayner and Young, 1962, Rees et al., 1972). Rayner and Young noted that after cow numbers were accounted for, the amount of fodder used accounted almost entirely for the remaining physical quantity of dairy production. The major inputs analysed in their survey were cows milked, tonnes of grain equivalent fed and equivalent acres of forage. This result can be compared with the present study where a large amount of the variation is explained by the amount of supplement fed and the area of winter irrigation.

Rees et al. (1972) collected information on 82 dairy farms in the Wide Bay region of Queensland, a subset of region 3 used here. Their study related milk fat production to measures of paddock feed production. The results from both studies can be directly related to each other by using the fact that milk fat production is a relatively consistent component of milk. In 1972 the average fat content of milk in the region was assumed to be 4.2 percent (Rees et al., 1972) thus the increase of 203 (SD = 27) kilograms of milk fat production per hectare attributable to irrigation can be equated to 4,833 (SD = 643) litres of milk. This is consistent with the present study where increases in milk production were estimated to be 4,710 (SD = 543) litres of milk.

It is recognized that care should be exercised in using coefficients from equations involving several variables. Mosteller and Tukey (1977) contend that regression equations are rarely obtained from systems where the variables are few in number, well clarified and measured with small errors. It is only under these circumstances that measurements from regression coefficients can be attempted, and quantitative effects quoted confidently. In this study the partial regression coefficients are biologically sensible but their true size is uncertain.

Given this limitation, response rates for milk from supplemental energy when converted from a litres per MegaJoule to litres per grain equivalent vary from 1.6 litres of milk per kilogram of grain equivalent in region 5 to 1.2 litres of milk per kilogram of grain equivalent in region 3, with a state average of 1.5 litre per kilogram. The 1.2 response rate agrees with other surveys (Cowan, 1985). Other factors could affect milk response to supplementary feeding on a dairy farm. For example, Moe and Tyrell (1975) suggest that in practice, metabolised energy (ME) values may be lower than the NRC values indicated as they are quoted for animals at maintenance levels of nutrition. This would mean the corrected energy used in the regression analyses could be an overestimate. It is also possible the response may include the cumulative effects of long term grain feeding, which leads to big cows with larger appetites and enhanced responses (Cowan, 1985).

Regions with larger applications of nitrogen had lower response rates to nitrogen, which may indicate some curvature in the true response to nitrogen fertilizer. Other studies have demonstrated a greater response at low rather than high application rates (Cowan et al., 1993, Buchanan and Cowan, 1988 and Rees et al., 1972). Rees et al. (1972) estimated responses to the application of nitrogen fertilizer to be in the order of 16.6 (SD = 4.8) litres of milk (0.7 kilograms of fat) per kilogram of nitrogen. This estimated response rate is higher than in the present study, but Rees et al. (1972) suggested that the response may be curvilinear with higher than average responses when only small quantities of nitrogen were applied. In the present study, measurements were conducted over a greater range of nitrogen fertilizer inputs, and this effect was not apparent.

It is not known why significant responses to the application of nitrogen were not detected in the two regions, 3 and 4, but Reason et al. (1989) noted that nitrogen responses under experimental conditions in south-east Queensland were affected by rainfall variability, low basal fertility of some paddocks and the choice of pasture species. Through the period of this survey, rainfall was similar to the levels recorded by Reason et al. (1989). In most regions it was below the 100 year long-term mean, with some areas recording rainfall with a probability of being exceeded in 80 percent of years. Another factor could be that some regions, particularly in north Queensland, were at the upper end of the response curve to the level of nitrogen and this lowered the response rate when a linear fit was carried out. Cowan et al. (1993) showed that the response begins to diminish as levels of application exceed 200 kilograms of nitrogen per hectare. A third factor could be that nitrogen effects were being seen through other variables, such as area for winter irrigation, or there may be substantial differences between regions in basal soil fertility.

Residuals of these regression relationships were skewed upward, indicating that the models would underestimate large observed values. To accommodate the skewed residual patterning within the linear model, analyses were repeated with the inclusion or deletion of other independent variables (Draper and Smith, 1966) such as breeding values and estimates of managerial ability and also using robust regression techniques (Rousseeuw and Leroy, 1987). No additional variables could explain the under-fitting of farms with higher production levels nor did the robust regression technique satisfactorily allow for these skewed residuals. This could suggest that farms producing larger quantities of milk may represent a population in which linear response relationships are inappropriate. This is consistent with studies by Dawson and Hubbard (1987) where analyses of size economies of dairy farms in England and Wales showed that the long-run average cost functions are skewed to exhibit greater economies than diseconomies of size. The better managed farms produce a given level of output at lower average cost and have larger optimal levels of output. Turkington et al. (1978) describe the need for two separate equations to predict per cow production in Britain. Their first equation was used to predict per cow production on all farms except those where the annual yield was at least 750 litres per cow greater than expected. These farms were treated as a separate population and a second equation fitted.

Rees et al. (1972) used a technique called stabilised treatment groups where any bias between treatment groups was eliminated by ranking and re-ranking each farm in ascending order based on the most important inputs (Minson and Rees, 1976). The primary purpose of the present study was to identify major inputs for each region. The results of the earlier and present studies would appear to be consistent with the similarity of response to area of irrigation and nitrogen fertilizer quoted above, and similar estimates of the effects of concentrate feeding (1.2 kilograms of milk per kilogram of concentrate in Rees et al., 1972 and between 1.2 and 1.6 in the present study). These results suggest that differences in techniques of analysis had little effect on interpretation of the data.

Across the state, all variables thought by experts to exert the most influence on total farm milk production were shown to be important, but not all these variables exerted the same influence in all regions. Different variables influenced total farm production differently in each region. Therefore, quoting statewide or other regional response rates for calculating the economic viability of a particular technology may be inappropriate.

This study has provided a useful statistical baseline for the key variables associated with milk production in Queensland. This baseline can be used to compare production levels and inputs in future studies.

Acknowledgments

The authors acknowledge the efforts of dairy extension officers from the Queensland Department of Primary Industries and dairy farmers throughout Queensland in obtaining the data for this study and for helpful comments from the referee.

Literature Cited

Buchanan I. K. and R. T. Cowan. 1988. Pasture response to nitrogen fertilizer on Dairy farms in south-east Queensland, MPY-DH13 Final Report, Queensland Department of Primary Industries, Brisbane, Australia.

Chopping G. D. and R. W. Walker. 1993. Target 10 Profitable Milk Production Seminar, Queensland Department of Primary Industries, Brisbane, Australia.

Cowan R. T. 1985. The Challenge: Efficient Dairy Production, Australian Society of Animal Production Dairy Production Conference, Albury-Wodonga 25-28 March 1985.

Cowan R. T., T. M. Davison, K. F. Lowe, G. K. Reason and G. D. Chopping. 1993. Integrating pasture technology research with farm management, 17th International Grassland Conference 2:1286-1288.

Dairy Herd Improvement Report. 1994. Wacol Herd Improvement Laboratory, Queensland Department of Primary Industries, Wacol, Australia.

Davison T. M., R. T. Cowan and R. K. Shepherd. 1985. Milk production from cows grazing on tropical pastures 2. Effects of stocking rate and level of nitrogen fertilizer on milk yield and pasture-milk yield relationships, Australian Journal of Experimental Agriculture 25:515-523.

Davison T. M., B. A. Silver, A. T. Lisle and W. N. Orr. 1988. The influence of shade on milk production of Holstein-Friesian cows in a tropical upland environment, Australian Journal of Experimental Agriculture 28:149-154.

Dawson P. J., L. J. Hubbard. 1987. Management and size economies in the England and Wales dairy sector, Journal of Agricultural Economics, 38:27-37.

Draper N. and H. Smith. 1966. Applied Regression Analysis, John Wiley and Son, New York.

Minson D. J. 1971. The nutritive value of tropical pastures, Journal of the Australian Institute of Agricultural Science 37:255.

Minson, D. J. and M. C. Rees. 1976. The advantages and disadvantages of using survey data to derive production responses to nutrient inputs by the stabilised group method, Proceedings of the Australian

Society of Animal Production, Adelaide, South Australia.

Moe P. W. and H. F. Tyrrell. 1975. Efficiency of conversion of digested energy to milk. Journal of Dairy Science 58:602-610.

Mosteller F. and J. W. Tukey. 1977. Data Analysis and Regression, Addison-Wesley Publishing Company, Philippines.

NRC. 1989. Nutrient Requirements of Dairy Cattle, Subcommittee on Dairy Cattle Nutrition, National Research Council, National Academy Press, Washington, DC.

Rayner I. H. and J. G. Young. 1962. Relation between input resources and output on a group of dairy farms in the Moreton distinct Queensland, Australian Journal of Experimental Agriculture and Animal Husbandry, 2 (7):248-50.

Reason G. K., J. Bodero, K. F. Lowe, G. E. Rayment and McGuigan. 1989. Milk production from nitrogen fertilised rain grown pastures, DAQ49: Final Report Queensland Department of Primary Industries, Brisbane, Australia.

Rees M. C., D. J. Minson and J. D. Kerr. 1972. Relation of dairy productivity to feed supply in the Gympie district of south-eastern Queensland, Australian Journal of Experimental Agriculture and Animal Husbandry, 12(59):553-60.

Rousseeuw P. J. and A. Leroy. 1987. Robust Regression and outlier detection, John Wiley, New York.

Turkington, D. J. and W. S. Townson. 1978. Statistical analysis of ICI 'Dairymaid' results with a view to providing a method of advising farmers on their nitrogen usage on grass for dairy cows, Grass and Forage Science 33:69-70.