size, and gained more ($P < 0.05$) in body weight, than those fed the complete diet.

3.2.7.4. **Discussion**.

It is of interest to note that hens offered choice feeding *ad libitum* in a single feeder at 32 °C did not show as marked a drop in total feed intake as did those fed the complete diet. These results, obtained over the 10-week laying period in Experiment 5, agree well with the previous short-term study of Blake *et al.* (1984).

With respect to ME, protein and Ca, and from a consideration of all results presented for Experiments 1 to 5, it is generally evident from the results at 32°C that laying hens did not meet their needs for these essential nutrients when they were offered a complete diet. The fact is, however, that hens in both feeding treatments in Experiment 5 consumed the same amounts of ME, protein and Ca. For protein, for example, the birds on both treatments consumed slightly more protein than the 18 g/d recommended by ARC (1975), SCA (1987) and Woolford (1990).

Viewed overall, the results reported in this thesis demonstrate that hens, when given the opportunity to learn how to self-select a diet at an early age, can balance their nutrient intakes to correctly meet their nutrient requirements at high temperatures. Other authors (e.g. Blake *et al.*, 1984) have fed three diets, each being high in either energy, protein or Ca, by way of self-selection and have reported unsatisfactory hen performance. However, these researchers did not train their birds to recognise these diets before the experiment actually started, while in the current study hens were trained to choice feeding from 12 weeks of age.

Table 27. Mean ± SEM daily intakes of grain, protein and oyster-shell grit of hens as affected by feeding treatments in Experiment 5.

Week	Grain intake (g/bird/d)		Protein-meal intake (g/bird/d)		Oyster-shell-grit intake (g/bird/d)	
	Choice feeding1)	Complete diet[2]	Choice feeding	Complete diet3)	Choice feeding	Complete feeding4)
1	77.8 ± 0.8	77.4 ± 0.7	27.6 ± 0.3	27.4 ± 0.2	9.5 ± 0.1	9.5 ± 0.1
2	77.0 ± 0.7	76.4 ± 0.7	27.3 ± 0.2	27.2 ± 0.3	9.4 ± 0.1	9.4 ± 0.1
3	77.4 ± 0.6	77.8 ± 0.6	27.5 ± 0.2	27.5 ± 0.2	9.5 ± 0.1	9.5 ± 0.1
4	78.7 ± 0.8	78.6 ± 0.9	27.9 ± 0.3	27.8 ± 0.3	9.6 ± 0.1	9.6 ± 0.1
5	78.6 ± 0.9	78.4 ± 0.9	27.8 ± 0.3	27.8 ± 0.3	9.6 ± 0.1	9.6 ± 0.1
6	77.7 ± 0.9	77.9 ± 0.9	27.5 ± 0.3	27.6 ± 0.3	9.5 ± 0.1	9.5 ± 0.1
7	79.2 ± 0.9	79.0 ± 0.9	28.0 ± 0.3	28.0 ± 0.3	9.5 ± 0.1	9.7 ± 0.1
8	79.4 ± 1.0	79.2 ± 1.0	28.1 ± 0.3	28.0 ± 0.3	9.5 ± 0.1	9.7 ± 0.1
9	78.8 ± 1.0	79.1 ± 1.0	27.9 ± 0.3	28.0 ± 0.3	9.4 ± 0.1	9.7 ± 0.1
10	79.2 ± 1.0	75.4 ± 1.3	28.1 ± 0.3	28.0 ± 0.3	9.7 ± 0.1	9.6 ± 0.1

1) whole maize; 2) calculated value of 67.7 % maize meal in the complete diet; 3) estimate based on protein sources in the complete diet; 4) estimate based on Ca source in the complete diet; no asterisk non-significant result (P > 0.05).

Table 28. Mean ± SEM daily intakes of ME, protein and Ca of hens as affected by feeding treatments in Experiment 5.

Week	ME intake (kJ/hen/d)		Protein intake (g/bird/d)		Ca intake (g/bird/d)	
	Choice feeding	Complete diet	Choice feeding	Complete diet	Choice feeding	Complete feeding
1	1396 ± 52.0	1388 ± 57.7	18.9 ± 0.2	18.8 ± 0.2	3.6 ± 0.03	3.6 ± 0.03
2	1381 ± 61.6	1375 ± 64.5	18.7 ± 0.2	18.6 ± 0.2	3.6 ± 0.03	3.5 ± 0.04
3	1390 ± 64.8	1393 ± 64.4	18.9 ± 0.1	18.9 ± 0.1	3.6 ± 0.03	3.6 ± 0.03
4	1413 ± 63.1	1410 ± 61.9	19.1 ± 0.2	19.1 ± 0.2	3.6 ± 0.04	3.6 ± 0.04
5	1410 ± 60.7	1407 ± 59.7	19.1 ± 0.2	19.1± 0.2	3.6 ± 0.05	3.6 ± 0.05
6	1394 ± 59.2	1399 ± 58.5	18.9 ± 0.2	19.0 ± 0.2	3.6 ± 0.05	3.6 ± 0.04
7	1421 ± 57.2	1417 ± 56.1	19.3 ± 0.2	19.2 ± 0.2	3.6 ± 0.05	3.7 ± 0.05
8	1420 ± 54.9	1471 ± 55.1	19.3 ± 0.2	19.3 ± 0.2	3.6 ± 0.06	3.7 ± 0.06
9	1414 ± 54.2	1420 ± 53.3	19.2 ± 0.2	19.3 ± 0.2	3.5 ± 0.06	3.6 ± 0.06
10	1421 ± 52.4	1368 ± 53.6	19.3 ± 0.2	19.2 ± 0.2	3.7 ± 0.06	3.6 ± 0.06

No asterisk, non-significant result (P > 0.05).

From consideration of egg numbers and egg weights, Scott and Balnave (1985) suggested that the hen's primary goal was to attain a level of egg production and egg weight sufficient to ensure reproductive success. This could be achieved by either obtaining the necessary nutrients through consumption of feed or by mobilising nutrients stored as body tissue. This suggestion may explain why the choice-fed hens in the present study (see Tables 26, 29 and 30) were able to lay more eggs of larger size, while at the same time they gained more body weight than those fed a complete diet (Tables 26 and 31).

A likely cause of the increase in body weight of choice-fed hens appears to be related to the form of grain used in Experiment 5, since Karunajeewa (1978a) indicated that hens given whole grains were able to utilise ME more efficiently, and thus gain more body weight, than those given ground grain in mash diets. In a later study the same author and his co-worker also reported that laying hens offered whole wheat gained more weight than those offered the crushed grain (Karunajeewa and Tham, 1984).

The current results contrast with those of Blake *et al.* (1984), who found that hens on choice feeding gained less body weight than those fed a complete diet at high temperatures because in that case hens utilised their body reserves to maintain egg production and egg weight. Such difference in results between experiments may be due to different experimental approaches, or to variations in the duration of training the birds to recognise their diets, and in the duration of each study. In their study, for example, Blake *et al.* used three diets, each being high in either energy, protein and Ca. These diets were provided *ad libitum* for laying hens in three feeders for an experimental period of only 28 d (compared to one feeder and 70 d in the current work).

In addition, they did not train their birds to recognise these diets before the experiment actually started while in the present study hens were trained to choice feeding at 12 weeks of age. The present study is thus consistent with the suggestions of Mastika (1987) and Forbes and

Shariatmadari (1994) that the poor results reported by Blake *et al.* (1984) were possibly due to the fact that the hens used were not experienced in choice feeding.

Table 29. Mean ± SEM daily total feed intake, egg weight and FCR of hens as affected by feeding treatments in Experiment 5.

Week	**Total feed intake (g/bird/d)**		**Egg weight (g)**		**FCR (g feed intake/g egg weight)**	
	Choice feeding	Complete diet	Choice feeding	Complete diet	Choice feeding	Complete feeding
1	114.9 ± 1.3	114.2 ± 1.1	55.6 ± 0.6**	54.8 ± 0.7**	2.0 ± 0.07	2.0 ± 0.06
2	113.7 ± 1.1	113.2 ± 1.1	55.7 ± 0.6**	55.0 ± 0.6**	2.0 ± 0.05	2.0 ± 0.05
3	114.4 ± 1.0	114.8 ± 1.0	55.9 ± 0.6**	55.3 ± 0.5**	2.0 ± 0.05	2.0 ± 0.05
4	116.3 ± 1.3	116.1 ± 1.4	56.0 ± 0.5	55.7 ± 0.5	2.0 ± 0.05	2.0 ± 0.05
5	115.8 ± 1.4	116.1 ± 1.4	56.2 ± 0.5**	55.7 ± 0.5**	2.0 ± 0.05	2.0 ± 0.05
6	114.7 ± 1.4	115.1 ± 1.4	56.6 ± 0.6	55.9 ± 0.5	2.0 ± 0.05	2.0 ± 0.05
7	117.0 ± 1.4	116.7 ± 1.4	57.3 ± 0.7**	56.7 ± 0.7**	2.0 ± 0.05	2.0 ± 0.05
8	117.3 ± 1.5	117.0 ± 1.5	57.7 ± 0.8**	57.2 ± 0.4**	2.0 ± 0.05	2.0 ± 0.05
9	116.4 ± 1.5	116.9 ± 1.5	58.7 ± 1.0*	58.3 ± 1.1*	1.9 ± 0.05	2.0 ± 0.05
10	117.0 ± 1.5	116.6 ± 1.4	58.5 ± 1.2**	57.9 ± 1.2**	2.0 ± 0.05	2.0 ± 0.05

*, $P < 0.05$; **, $P < 0.01$; no asterisk, non-significant result ($P > 0.05$).

Table 30. Mean ± SEM weekly egg production, albumen quality and yolk colour of hens as affected by feeding treatments in Experiment 5.

Week	**Egg production (%)**		**Albumen quality (Haugh units)**		**Yolk colour (Roche Fan score)**	
	Choice feeding	Complete diet	Choice feeding	Complete diet	Choice feeding	Complete feeding
1	88.1 ± 0.1*	87.1 ± 0.5*	97.0 ± 1.4	97.5 ± 1.3	10.0 ± 0.9	10.5 ± 0.8
2	88.2 ± 0.5*	87.3 ± 0.5*	98.0 ± 1.3	98.5 ± 1.3	11.5 ± 0.9	11.5 ± 0.9
3	86.7 ± 0.7	86.3 ± 0.6	100.5 ± 1.4	100.0 ± 1.5	11.5 ± 0.9	12.0 ± 0.9
4	85.7 ± 0.9*	84.9 ± 1.1*	98.5 ± 1.4	97.5 ± 1.4	12.0 ± 0.9	11.5 ± 0.8
5	84.9 ± 1.3*	83.8 ± 1.5*	101.5 ± 1.5	101.5 ± 1.7	11.5 ± 0.8	11.5 ± 0.8
6	83.0 ± 1.7**	81.5 ± 2.0**	99.5 ± 1.6	99.5 ± 1.6	12.0 ± 0.8	11.5 ± 0.8
7	79.4 ± 2.5**	77.9 ± 3.0**	100.5 ± 1.6	100.5 ± 1.7	11.5 ± 0.8	11.5 ± 0.7
8	78.0 ± 3.3*	77.2 ± 3.4*	98.5 ± 1.6	99.0 ± 1.6	11.5 ± 0.7	11.5 ± 0.7
9	77.1 ± 3.9*	76.3 ± 4.1*	99.5 ± 1.6	99.5 ± 1.6	11.5 ± 0.7	12.0 ± 0.7
10	76.8 ± 4.3	76.2 ± 4.5	100.5 ± 1.6	100.0 ± 1.5	12.0 ± 0.7	12.5 ± 0.7

*, $P < 0.05$; **, $P < 0.01$; no asterisk, non-significant result ($P > 0.05$).

Table 31. Mean ± SEM weekly body weight, egg-shell thickness and egg specific gravity of hens as affected by feeding treatments in Experiment 5.

Week	**Body weight (g)**		**Egg-shell thickness (µm)**		**Egg specific gravity (g/ml)**	
	Choice feeding	Complete diet	Choice feeding	Complete diet	Choice feeding	Complete feeding
1	1664 ± 56.6	1643 ± 71.2	354.5 ± 0.5	354.5 ± 0.5	1.079 ± 0.007	1.079 ± 0.006
2	1687 ± 60.2	1628 ± 65.4	350.0 ± 1.9	351.5 ± 2.0	1.078 ± 0.007	1.078 ± 0.007
3	1714 ± 62.8	1662 ± 62.7	351.0 ± 2.2	351.5 ± 2.2	1.078 ± 0.005	1.078 ± 0.005
4	1689 ± 58.3	1682 ± 58.7	342.5 ± 3.9**	344.0 ± 4.6**	1.077 ± 0.005	1.077 ± 0.006
5	1700 ± 56.0	1688 ± 62.2	341.5 ± 5.2	342.5 ± 5.4	1.077 ± 0.006	1.077 ± 0.006
6	1761 ± 64.3	1709 ± 66.1	338.5 ± 6.0	335.0 ± 6.9	1.078 ± 0.005	1.078 ± 0.005
7	1728 ± 64.5	1707 ± 66.9	341.0 ± 6.9	341.5 ± 6.8	1.077 ± 0.005	1.077 ± 0.005
8	1760 ± 67.0	1720 ± 68.4	336.5 ± 7.0	337.5 ± 7.2	1.077 ± 0.006	1.077 ± 0.006
9	1692 ± 66.3	1668 ± 67.4	335.5 ± 7.3	336.5 ± 7.4	1.077 ± 0.006	1.077 ± 0.006
10	1715 ± 65.8	1743 ± 65.8	334.5 ± 7.5	332.5 ± 7.8	1.076 ± 0.007	1.076 ± 0.007

**, $P < 0.01$; no asterisk, non-significant result ($P > 0.05$).

In general, the results of Experiment 5 support those of Scott and Balnave (1988), who concluded that when feed is limited at high temperatures, hens trained to self-select nutrients from separate energy- and protein-rich feeds are better able to sustain egg output and body weight than those fed complete diets.

In summary, laying hens allowed to self-select nutrients from whole maize, protein meal and oyster-shell grit *ad libitum* in a single feeder at 32 °C were able to lay more eggs of larger size and gained more body weight while maintaining similar total feed intake, ME intake, protein intake, Ca intake, albumen quality, yolk colour, egg-shell thickness, egg specific gravity and FCR as compared to hens on a complete, meal diet.

3.3. Feed and water restriction experiments.

3.3.1. Introduction.

Feeding and watering of animals is of fundamental importance to any farm production system, because the feed eaten (normally dry) and digested must be converted into a liquid solution for enzyme action to occur and for digestion and absorption to take place (Bogart and Taylor, 1983). Under the *ad libitum* conditions in which layers are normally fed (Payne, 1967; Smith, 1973; Slennett, 1976; Wilson and Emmans, 1979; Robinson and Sheriden, 1982; Leclerq *et al.*, 1984; Sainsbury, 1984; North and Bell, 1990) and watered (Hill *et al.*, 1979; McDonald *et al.*, 1988; Bailey, 1990), the quantity of water consumed is related to the amount of feed eaten (Dixon, 1958; Ibarbia, 1968). This relationship has been shown to be both qualitative and quantitative, hourly changes in feed intake corresponding closely with hourly changes in water intake (Anderson and Hill, 1968; Wood-Gush and Horne, 1970; Hill and Powell, 1977; Savory, 1978; Hill *et al.*, 1979).

In contrast, there are three main problems of offering layers feed *ad libitum* as discussed in Chapter 2, section 2.1. They are: (1) over-consumption of feed (Balnave and Jackson, 1973); (2) obesity (Morris, 1968; Sykes, 1972; Kari *et al.*, 1977; Neill *et al.*, 1977; Bennett, 1978; Lilburn *et al.*, 1987; Robbins *et al.*, 1988; Smith, 1990); and (3) mortality (Singsen *et al.*, 1958; Hannagan and Wills, 1973). Another problem that is often associated with *ad libitum* watering (Maxwell and Lyle, 1957; Listern-Moore, 1972) is that hens tend to drink water beyond their metabolic requirements. This leads to the production of wet droppings which may be a problem for poultry litter management (smell, flies) during the summer months, particularly in some wet areas of the tropics (Okumura *et al.*, 1977).

These findings suggest that restricted feeding and watering is a potentially important aspect of nutritional management that probably can be applied to overcome the problems of over-eating (Sainsbury, 1984; Gleaves, 1989; North and Bell, 1990) and wet droppings (Maxwell and Lyle, 1957; Al-Khazarji *et al.*, 1970; Keys, 1977; North and Bell, 1990) on layer farms.

Quite extensive studies have been made of both restricted feeding (see Lee *et al.*, 1971a; Balnave, 973; Pearson and Shannon, 1979 for reviews) and watering (see Bailey, 1990 for review) on all types of poultry, but in both cases the results have been conflicting. In the case of restricted feeding, the differences between findings of various workers are undoubtedly due to differences in feed restriction method, the extent of restriction, and the environmental temperatures and strains of layers used (MacIntyre and Aitken, 1959; Robinson, 1976; Kari *et al.*, 1977; Lee, 1987), while the disparity in results from restricted watering can be explained in term of different methods used in the various experiments (Bailey, 1990).

A number of methods of applying feed restriction have been used in practice with laying hens and while these can be divided into two basic types, i.e., qualitative and quantitative feed restriction (Balnave, 1978; Leeson and Summers, 1991), there is still conflicting evidence on their value and on which is best (Sainsbury, 1984). On the other hand, Lee *et al.* (1971b) concluded from their study with broiler breeder pullets that the preferred method is that of quantitative feed restriction because of its advantageous effects on egg mass, rate of lay and economy of feeding.

The quantity of feed eaten by birds may be regulated either by restricting the feeding time or water intake or by pre-weighing the feed each day (Robinson, 1976; Gerry and Muir, 1976; Balnave, 1978; Sainsbury, 1984). Allowing access to feed for a short time each day has been used for many years because it requires a lower degree of management, but the method often fails to give consistent control over feed intake, one reason for this being that the birds learn to consume larger quantities of feed in the shorter period available to them (Robinson, 1976; Slennett, 1976; Sainsbury, 1984).

The same behaviour as in the time-restricted feeding method (above) was also noticed in time-restricted watering (Bailey, 1990). Therefore, allocating the amount of feed by weight (Slennett, 1976; Sainsbury, 1984) and of water by volume (Bailey, 1990) are no doubt the most accurate methods of restriction.

The present investigation reports on the possibility of overcoming the problems of over-eating and wet droppings by physically restricting the feed and water intake in laying hens. From a research point of view, restricted feeding (Sherwood, 1959; Jackson, 1970; Polin and Wolford, 1972; Bell and Moreng, 1972) and watering (Maxwell and Lyle, 1957; Hill and Richards, 1969, 1975; Spiller *et al.*, 1976) of White Leghorn hens have consistently resulted in improved feed utilisation.

From an economic viewpoint, feed efficiency is of great interest to egg producers because of the relatively high cost of feed compared to other inputs in commercial egg production (Gleaves, 1989; Hunton, 1992). The indication for this improvement is reviewed by Bailey (1990), who reports that the water : feed intake ratio is indicative of feed utilisation. Indeed, hens with a high water : feed intake ratio have an improved feed utilisation (Van Kampen, 1983). This relationship, however, has been developed from variations between birds allowed *ad libitum* intakes of feed and water (Hurnik *et al.*, 1977; Van Kampen, 1983), and there is no information available as to whether similar relationships exist when either feed, or water intakes, or both, are restricted.

Any divergence from the relationship developed under *ad libitum* conditions could be of significance in regions such as West Timor, Indonesia, the author's home country, where poultry are currently restrictedly fed and watered, but where development trends are towards "improved", *ad libitum* feeding. The two experiments to be reported in this section studied the effects of short-term feed and water restriction programs on the utilisation of feed and on the relationships between feed and water in laying hens fed a complete diet at an environmental temperature of 20 °C.

3.3.2. **Common materials and methods.**

3.3.2.1. **General procedures for feed- and water-restriction experiments (Experiments 6 and 7).**

Two experiments (i.e. feed restriction in Experiment 6 and water restriction in Experiment 7) were conducted in the John Hammond Animal Climate Laboratory, University of New England. Each experiment lasted 3 weeks, and was followed by a recovery period of 3 weeks. The experiments were carried out consecutively from January 1, 1992, to March 25, 1992.

A total of 30 White Leghorn hens of the Leach 'Reds' strain (New Hampshire x Single Comb WL) were used. The birds, which had been maintained from 18 to 62 weeks of age in a floor-pen at the nearby Laureldale Farm, were brought into a 3.6 x 3.6 m room in the climate laboratory on December 18, 1991. The room was air-conditioned at 20 ± 1 °C and 60 ± 2 % RH. On arrival, all birds were weighed and housed individually in cages measuring 45 x 30 x 40 cm, and supplied with feed and water *ad libitum*. The cages had individual feed and water containers at the front (left and right sides respectively). Both feeders and drinkers were filled each day with measured amounts of feed and water for two weeks of a preliminary period which was designed to allow the birds to adjust to the cage environment.

The amount of feed and water offered each day (200 g and 450 ml respectively) was chosen to ensure that the birds had *ad libitum* access during this period. The feed used throughout both experiments was a mash form of a commercial layer diet (17 % CP 11.72 MJ ME/kg; 3.4 % Ca). Starting on the 7th d of the preliminary period, both the feed and water intakes of each bird were recorded daily in order to establish mean daily intakes under *ad libitum* conditions according to the method described by Savory (1978).

3.3.2.2. **Experiment 6**.

After a preliminary period of two weeks a period of experimental feed restriction began on January 1, 1992, and continued until January 21, 1992. The hens were 64 weeks of age when feed restriction began, and at that time 28 of the 30 birds available were individually leg-banded and randomly divided into 4 restricted-feeding treatment groups, each of 7 birds. The remaining birds served as spares.

The birds in treatment 1 served as an *ad libitum*-fed control group; those in treatments 2, 3 and 4 were restricted to 80, 60 and 40 % respectively of each individual hen's mean feed intake during the 2nd week of the preliminary period. All birds were watered *ad libitum* on a daily basis by measuring any water remaining and then placing 450 ml of fresh water in each drinker. After three weeks of feed restriction, a 3-week recovery period was allowed in which the hens had feed and water available *ad libitum* as during the preliminary period.

3.3.2.3. **Experiment** 7.

Experimental water restriction commenced as soon as the 3-week recovery period after Experiment 6 was complete (February 12, 1992), and continued for 3 weeks before concluding on March 4, 1992. All basic procedures in this experiment were the same as described for Experiment 6. The birds used in Experiment 7 were the same as those used in Experiment 6 with the exception of bird No. 6 in treatment 4 that died suddenly in the second last week of the recovery period and was replaced by spare bird No. 29.

All birds were re-randomised to cages and were then randomly allocated to four restricted watering treatment groups of 7 birds/treatment. The birds in treatment 1 served as an *ad libitum*-watered control group and those in the other three groups (treatments 2, 3 and 4) were restricted to 85, 70 and 65 % of their respective mean *ad libitum* water intakes recorded in the week immediately before the experiment began.

Special attention with regard to animal welfare considerations was given to the birds in treatment 4; in terms of a balanced experimental design a water intake of 55 % of *ad libitum* would have been appropriate, but this was considered to be too stressful, and 65 % was adopted as a more acceptable, but still meaningful, alternative. The amounts of feed offered *ad libitum* to the birds during this experiment were the same as in the preliminary period. After three weeks of water restriction a recovery period of 3 weeks was allowed in which all birds were provided with feed and water *ad libitum* until March 25, 1992.

3.3.2.4. **Data collection**.

The following performance data were collected for each hen during the 2nd week of the preliminary period and throughout both experiments.

(1). Body weight was recorded to the nearest 1 g at the commencement of each experiment and at weekly intervals throughout.

(2). Feed and water intake were recorded daily and determined by subtracting individual refusals collected at 08.00 h from the amounts offered. Residues of feed and water were not included as part of the next days' ration.

(3). Egg production, egg weight and shell quality as measured by specific gravity were recorded daily; the eggs were weighed individually on scales sensitive to 0.1 g. Specific gravity was determined by using the suspension weighing technique described by Eym (1969). Records of each hen's daily egg production, egg weight and shell quality were collected at 13.30 h. Egg production in each group was calculated on a weekly basis as a hen-day egg production (the total (of eggs in a week multiplied by 100 divided by the number of birds in each treatment) as described by Sainsbury (1984) and North and Bell (1990).

(4). Data concerning weekly FCR was determined as g of feed intake/g of egg weight (Hurwitz and Plavnik, 1989; Feltwell, 1992, Hunton, 1992; Katle, 1992).

(5). Water : feed intake ratios were expressed as ml of water drunk/g of feed consumed (Medway and Kare, 1959).

(6). Correlation coefficients were calculated on a weekly basis for all four treatments in both experiments for the relationship between water and feed intakes.

(7). Mortality was recorded as it occurred.

(8). It was not possible to individually sample and analyse (for dry matter content) the faeces of birds in these experiments, but routine subjective, visual observations were made in order to monitor the possible incidence of 'wet droppings'.

3.3.2.5. **Statistical analysis**.

All performance data collected were statistically analysed by using a oneway analysis of variance according to the procedure described by Burr (1982); regression analyses were run using the Minitab system (Ryan *et al.*, 1985).

3.3.3. **Experiment 6 - The effects of feed restriction at 20 °C**.

3.3.3.1. **Introduction**.

The practice of limiting feed intake is synonymous with the term "feed restriction" as applied to birds and is usually interpreted to mean an actual restriction of nutrient intake by the birds for optimum performance in order to achieve a desirable goal such as improved efficiency of feed utilisation for egg production (Singsen *et al.*, 1959). Undoubtedly, restricted feeding of laying hens has consistently resulted in improved feed utilisation (Sherwood, 1959; Jackson, 1970; Polin and Wolford, 1972; Bell and Moreng, 1972).

Gleaves (1989) pointed out in his review that feed efficiency is of great interest to poultry producers because of the relatively high cost of feed compared with other inputs; feed comprises, on average, about 70 % of total variable costs in most poultry production (McMahon *et al.*, 1974; Lee, 1977; Elson, 1979; Wilson and Emmans, 1979; Emmans and Charles, 1989; Behrends, 1990; Wei, 1992). On this basis it is essential to minimise feed costs (Leeson and Summers, 991).

A number of methods of applying feed restriction have been used in practice to improve the nutrient utilisation of laying hens by restricting their feed intake either by limiting the amount of feed offered or by restricting feeding time (Robinson, 1976; Gerry and Muir, 1976; Balnave, 1978; Sainsbury, 1984). From a practical viewpoint, allowing access to feed for a short time each day has been used for many years because it requires a lower degree of management (Robinson, 1976; Slennett, 1976; Sainsbury, 1984). Therefore, at the time the current work began, all information on restricted feeding had been gained under conditions similar to those in large, intensive production units, that is, based on automated feeding. As a consequence, restricted feeding regimes are commonly described on a time basis.

Such systems are rarely found in developing countries, where labour is cheaper and daily feeding by hand is commonly practised. Moreover, in many developing countries, there are seasonal shortages in the supply of feedstuffs associated with time since the last harvest and the additional question then arises: what are the likely effects on production of periods of forced, but unplanned, feed restriction?

Thus, the current work was designed to establish restricted feeding regimes appropriate to developing countries, that is, based on daily feed to be offered, and to determine the effects of graded levels of feed restriction on production. According to Slennett (1976) and Sainsbury (1984), allocating the amount of feed by weight is no doubt the most accurate method of restriction compared to restricting feeding time because in the latter method the birds learn to consume larger quantities of feed in the shorter period available to them.

The aim of the current work was therefore to study the effects of feed restriction on egg production, body weight and on the utilisation of feed in light-weight White Leghorn cross hens kept at an environmental temperature of 20 °C. A 3-week period of feed restriction was chosen because of its relevance to conditions in West Timor, Indonesia, the author's home country, where on a seasonal basis feed and water become scarce for short periods (2-4 weeks normally) before the next harvest and at the end of the dry season respectively.

3.3.3.2. **Experimental hypothesis and design.**

The hypothesis developed was that restricted feeding of laying hens for a short period, instead of allowing them to eat *ad libitum* would not adversely affect egg production, and that when returned to full feeding the hens would quickly recover to *ad libitum* levels. The system can be imposed in areas such as West Timor, Indonesia, where the availability of feed is limited, especially in the period immediately before harvest. In order to test this hypothesis, a oneway analysis of variance involving four levels of feeding treatments and 28 White Leghorn hens of the Leach 'Reds' strain serving as replicates was used. Treatment 1 was an *ad libitum* fed control; treatments 2, 3 and 4 were restricted to 80, 60 and 40% of *ad libitum* intake.

3.3.3.3. **Results and discussion.**

The results of all performance data collected from Experiment 6 together with SEM, are summarised in Tables 32 to 40, all feed offered to the restricted groups 2, 3 and 4 was consumed. The regressions of water intake (dependent variable) on feed intake (independent variable) for Experiment 6 are presented in Table 40 and illustrated in Figure 3.

The data in Table 32 show that feed restriction caused a significant ($P < 0.01$) reduction in the mean body weight during the 1st week and highly significant ($P < 0.001$) reductions in the 2nd and 3rd weeks of the experiment. Although the mean body weight of the four groups of hens in Experiment 6 (Table 32) differed significantly, the reduction of body weight in weeks 2 and 3 was considerably lower than in week 1 (Table 32 and Figure 2).

Table 32. Mean body weight (g) ± SEM of hens during feed restriction and a subsequent recovery period in Experiment 6.

Period	Week	Treatment1) 1	Treatment 2	Treatment 3	Treatment 4	LSD	Level of significance
Preliminary		1865 ± 71 2)	1799 ± 47	1738 ± 74	1714 ± 59	(183; 250)3)	
Feed restriction	1	1830 ± 74	1719 ± 52	1575 ± 75	1477 ± 49	(178; 244)	**
	2	1842 ± 76	1808 ± 58	1504 ± 69	1424 ± 36	(172; 235)	***
	3	1831 ± 73	1690 ± 58	1477 ± 67	1418 ± 42	(181; 247)	***
Recovery	4	1876 ± 77	1791 ± 53	1673 ± 65	1714 ± 68	(186; 255)	
	5	1864 ± 66	1794 ± 55	1670 ± 68	1718 ± 62	(172; 235)	
	6	1828 ± 69	1781 ± 55	1689 ± 69	1700 ± 56	(190; 260)	

1)Treatment 1 is an *ad libitum*-fed control group; treatments 2, 3 and 4 are 80, 60 and 40 % feed restriction; 2) mean ± SEM body weight (g) calculated from individual weighing of 7 birds/treatment; 3) Least Significant Differences ($P = 0.05$; $P = 0.01$); **, $P < 0.01$; ***, $P < 0.001$; no asterisk, non-significant result ($P > 0.05$).

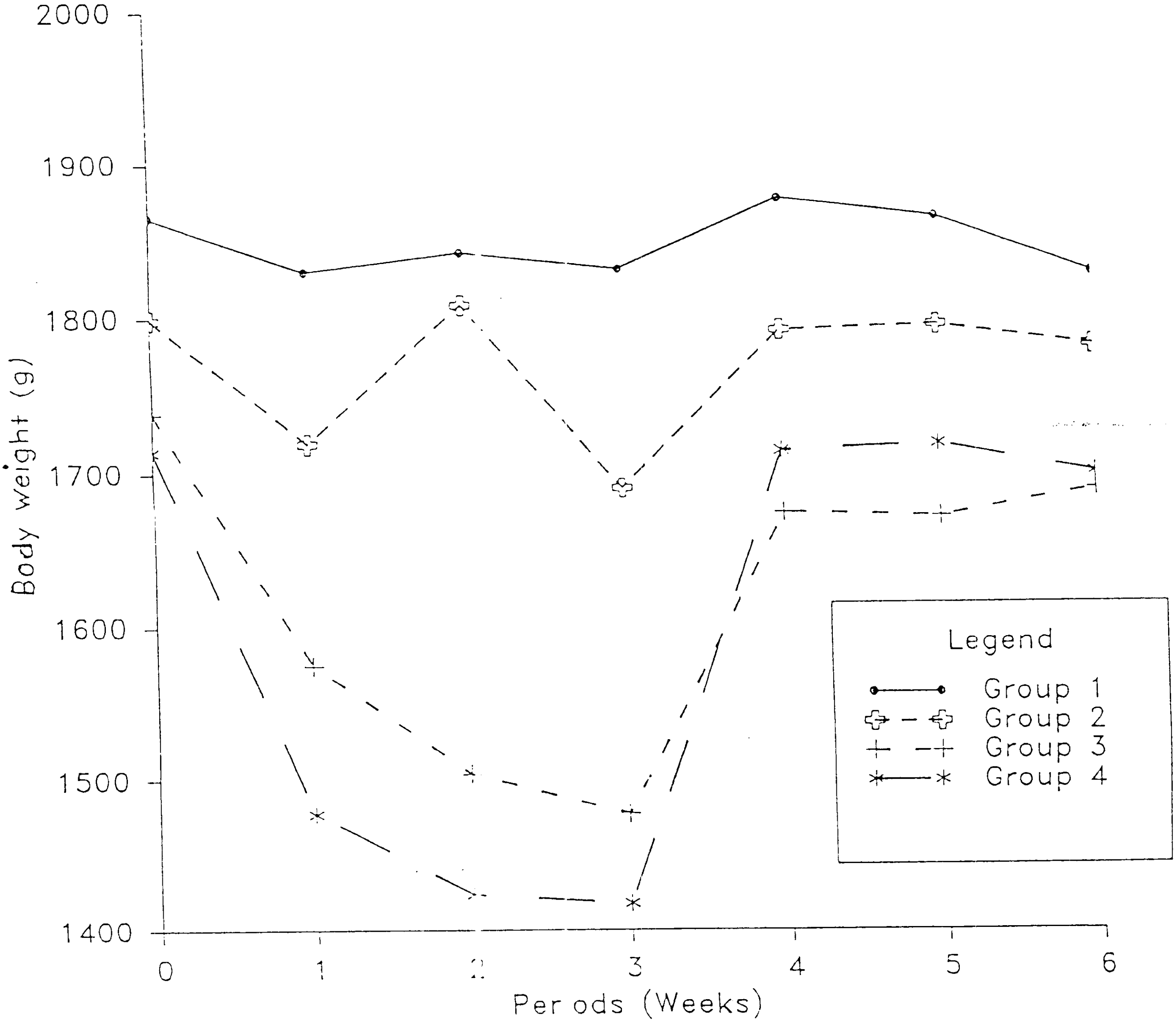

Figure 2. **The body weight of hens in Experiment 6.**

The reduction of body weight with time increased progressively with the severity of feed restriction The mean body weight of birds on treatment 3 declined from 1738 g in the preliminary period to 1575, 1504 and 1477 in weeks 1, 2 and 3 respectively (an overall loss of 15 %), whereas in the birds on treatment 4 it decreased from 1714 g in the preliminary period to 1477, 1424 and 1418 in weeks 1, 2 and 3 respectively (an overall loss of 17 %). These body weight results from treatments 3 and 4 indicate that restricting the feeding of hens to 60 and 40 % respectively of their *ad libitum* intake did not provide sufficient nutrients for the birds to maintain body weight.

The depression of body weight by feed restriction observed in Experiment 6 is in agreement with the results of Singsen *et al.* (1959), Jalaludin (1969, cited by Auckland and Fulton, 1973) and Al-Khazarji *et al.* (1970), all of whom found that restricting the feed intake of laying hens resulted in loss in body weight. These data are however, in disagreement with findings of Heywang (1940), who restricted the feed intake of White Leghorn hens over a period of one year to 87.5 and 75 % of the amount consumed by the control-group fed on *ad libitum* basis, and found that feed restriction had no significant effect on the mean body weight of the feed-restricted hens in comparison to the hens fed *ad libitum.* It is possible that the ability of birds to improve their feed utilisation over time (as they became accustomed to a diet) may explain this different results.

Although the current results provide evidence that restricted feeding is an effective method of reducing the body weight of laying hens, levels of restriction down to 60 and 40 % were clearly too severe for the birds to maintain body weight under conditions of Experiment 6, and would presumably be unsustainable in the long term, particularly for egg production (see Table 35).

In contrast, in weeks 4 and 5, the period of recovery, all restricted groups gained weight, presumably largely through re-alimentation, and at each of these weeks weighed approximately the same (particularly the birds on treatment 4 at week 4) as they had at week 1 of the preliminary period. Body weight was fully recovered in all groups within 3 weeks. The gain in body weight of the feed-restricted birds during the recovery period was apparently the result of increased feed consumption resulting in an excess feed intake (Table 33) compared to those on *ad libitum* feeding. Over the 3-week recovery period, body weight did not differ significantly among the four groups (Table 32 and Figure 2).

The data in Table 33 represent the amount of feed consumed by birds of the four treatments groups. The feed intake of all restricted groups was highly significantly (P < 0.001) less than that of the control group during the restriction period. From an economic point of view, this type of reduction in feed intake becomes of greater importance as the price of eggs is lowered (Kari *et al.*, 1977)

Table 33. Mean feed intake (g) ± SEM of hens during feed restriction and a subsequent recovery period in Experiment 6.

Period	**Week**	**Treatment[1] 1**	**Treatment 2**	**Treatment 3**	**Treatment 4**	**LSD**	**Level of significance**
Preliminary		118.0 ± 3.0[2]	122.3 ± 3.4	123.0 ± 5.9	116.3 ± 4.7	(12.9;17.7)[3]	
Feed restriction	1	106.7 ± 3.3	92.6 ± 2.2	70.8 ± 3.7	44.7 ± 1.8	(8.4; 11.5)	***
	2	110.3 ± 4.0	95.1 ± 2.3	71.9 ± 5.4	44.8 ± 1.7	(9.4; 12.9)	***
	3	109.3 ± 4.6	95.7 ± 4.5	71.8 ± 3.6	44.9 ± 1.7	(9.8; 13.5)	***
Recovery	4	113.0 ± 3.8	123.6 ± 4.0	130.3 ± 6.4	129.5 ± 9.5	(19.1; 26.1)	
	5	105.7 ± 6.3	113.1 ± 2.8	115.5 ± 7.6	111.6±10.7	(23.7; 32.5)	
	6	99.5 ± 7.5	111.0 ± 3.5	117.0 ± 5.2	122.0 ± 4.2	(16.8; 23.0)	

[1] Treatment 1 is an *ad libitum*-fed control group; treatments 2, 3 and 4 are 80, 60 and 40 % feed restriction; [2] mean ± SEM feed intake (g) calculated from individual feed intake of 7 birds/treatment; [3] Least Significant Differences (P = 0.05; P = 0.01); ***, P < 0.001; no asterisk, non-significant result (P > 0.05).

In contrast, after 3 weeks feed restriction, the return to *ad libitum* feeding in the recovery period resulted in rapid growth and a very high consumption of feed, notably in the 4th week. A possible explanation for this result is reported by Pym and Dillon (1974), who found that the extent of the increase in feed intake was related to the severity of prior feed restriction and body weight retardation.

In general, both the body weight (Table 32) and feed intake data (Table 33) of Experiment 6 are congruent with observations made by Robinson *et al.* (1978), who found that there is a positive relation between weight gain and feed intake in the laying period. Thus, the increased feed intake and compensatory growth observed during the recovery period immediately after feed restriction ceased in Experiment 6 were as expected if it is assumed that body weight was effectively reduced but not impeded.

This compensatory growth by all types of undernourished chickens and turkeys after return to an adequate diet has been reported previously (Osbourn and Wilson, 1960; Gardiner and MacIntyre, 1962; Auckland and Morris, 1971; Pym and Dillon, 1974; Moran, 1979; Brody *et al.*, 1980; Proudman and Opel, 1981; Johnson *et al.*, 1984). Plavnik and Hurwitz (1985) and Plavnik *et al.* (1986) in their studies with broiler chickens have also suggested that compensatory growth occurs after a short period of feed restriction, as occurred in the current work.

There was no significant difference ($P > 0.05$) between the mean water intakes of the birds restricted in feed intake during either the period of feed restriction or the recovery (Table 34). It is noteworthy that there was no consistent effect of feed restriction on water intake of these laying hens; this does not agree with the work of McFarland (1965) with Barbary doves, and Anderson and Hill (1968) with two light-bodied strain of layers (Thornber 606, 707 and Shaver 288), who both observed that reduction in feed intake of birds was accompanied by a significant reduction in water intake. These conflicting findings may be explained on the basis of strain differences.

Table 34. Mean water intake (ml) ± SEM of hens during feed restriction and a subsequent recovery period in Experiment 6.

Period	**Week**	**Treatment[1] 1**	**Treatment 2**	**Treatment 3**	**Treatment 4**	**LSD**	**Level of significance**
Preliminary		200 ± 12[2]	213 ± 10	223 ± 6	199 ± 9	(28; 38)[3]	
Feed restriction	1	193 ± 12	191 ± 10	192 ± 5	166 ± 14	(35; 47)	
	2	197 ± 15	199 ± 12	178 ± 10	186 ± 23	(44; 60)	
	3	193 ± 14	210 ± 22	167 ± 10	214 ± 37	(70; 95)	
Recovery	4	203 ± 16	227 ± 15	221± 14	228 ± 19	(52; 71)	
	5	199 ± 16	211 ± 16	197 ± 17	200 ± 21	(55; 75)	
	6	181 ± 15	201 ± 16	192 ± 15	228 ± 14	(42; 58)	

[1] Treatment 1 is an *ad libitum*-fed control group; treatments 2, 3 and 4 are 80, 60 and 40 % feed restriction; [2] mean ± SEM water intake (ml) calculated from individual water intake of 7 birds/treatment; [3] Least Significant Differences (P = 0.05;
P = 0.01); no asterisk, non-significant result (P > 0.05).

The mean egg numbers and hen-day egg production of both the restricted and control groups are summarised in Table 35. When comparing the percentage of hen-day egg production during the 3-week feed restriction period, hens of treatments 1, 2 and 3 had significantly (P < 0.001) higher figures than did those of treatment 4, with treatment 2 being higher than treatments 1 and 3 in the 3rd week of the experiment. Among treatments 1, 2 and 3, hen-day egg production was the same for treatments 1 and 3, but was higher in treatment 2.

Table 35. Mean egg numbers ± SEM (%) of hens during feed restriction and a subsequent recovery period in Experiment 6.

Period	Week	Treatment[1] 1	Treatment 2	Treatment 3	Treatment 4	LSD	Level of significance
Preliminary		4 ±0.7[2](57)[3]	5 ± 0.4 (71)	6 ± 0.6 (86)	5 ± 0.3 (71)	(1.7; 2.3)[4]	
Feed restriction	1	5 ± 0.5 (71)	5 ± 0.4 (71)	5 ± 0.5 (71)	4 ± 0.7 (57)	(1.7; 2.3)	
	2	5 ± 0.2 (71)	5 ± 0.4 (71)	5 ± 0.4 (71)	1 ± 0.2 (14)	(1.1; 1.5)	***
	3	4 ± 0.5 (57)	5 ± 0.5 (71)	4 ± 0.5 (57)	2 ± 0.4 (29)	(1.3; 1.8)	**
Recovery	4	5 ± 0.4 (71)	5 ± 0.4 (71)	4 ± 0.7 (57)	2 ± 0.3 (29)	(1.6; 2.2)	*
	5	5 ± 0.3 (71)	5 ± 0.7 (71)	6 ± 0.4 (86)	3 ± 0.7 (43)	(1.6; 2.2)	*
	6	4 ± 0.3 (57)	5 ± 0.3 (71)	6 ± 0.5 (86)	5 ± 0.8 (71)	(1.5; 2.0)	

[1] Treatment 1 is an *ad libitum*-fed control group; treatments 2, 3 and 4 are 80, 60 and 40 % feed restriction; [2] number of eggs/7birds/week; [3] % hen-day egg production/week/treatment; [4] Least Significant Differences (P = 0.05; P = 0.01); ***, P < 0.001; **, P < 0.01; *, P < 0.05; no asterisk, non-significant result (P > 0.05).

It is of interest that although the body weights of birds on treatment 3 were lower as compared to treatments 2 and 1, the percentage of hen-day egg production was the same as in the control group during the 3-weeks of feed restriction. This evidence agrees with the observation of Sykes (1972), who found that laying hens can maintain egg production under conditions which cause moderate loss of body weight.

The cause of the lower hen-day egg production exhibited by treatment 4 when compared with the other treatments appears to have been the reduction in feed intake and body weight. The first effect agrees with Connor *et al.* (1977), who found that birds on restricted feeding required less feed for egg production than did birds fed *ad libitum*. The shift in the pattern of egg production with reduced body weight is in agreement with Singsen *et al.* (1959) and Al-Khazarji *et al.* (1970), who both showed that birds that lose body weight also very quickly suffer a reduction in egg production.

From a consideration of body weight and hen-day egg production, the degree of feed restriction used in this study (notably treatment 4) seemed to be too severe. The depression of body weight and hen-day egg production in the 40 % feed restriction treatment was consistent with the results of Donaldson and Millar (1962) and McMahon *et al.* (1974), who found that more severe restrictions during laying may depress body weight and egg production.

In contrast, during the 3-week period of recovery with *ad libitum* feeding, birds in the 40 % feed-restricted groups tended to compensate by gaining more body weight and laying more eggs than less restricted individuals. Hen-day egg production of the 40 % group at week 6 of the recovery period was the same as it had been in the preliminary period, that is, 71 % as compared to 57 % in the control group.

The various results available in the literature indicate that the magnitude of the responses to short-term feed restriction are related to the strain of the bird used (Robinson and Sheriden, 1982), and it is thus not surprising that restricting the feed intake of the Leach 'Reds' strain (New Hampshire x Single Comb WL) used in this experiment to 80 and 60 % of that consumed by an *ad libitum* control group resulted in no loss in egg production, but at the expense of body weight.

The mean egg weights recorded are given in Table 36; no significant differences ($P > 0.05$) were noted between groups or between the feed restriction and recovery periods. Although restricted feeding had no significant influence on the egg weight, there was a small decrease in the mean egg weight of the feed-restricted birds during the entire experiment. In contrast, in weeks 4 to 6, the period of recovery, egg weights of both restricted and control groups were higher than they had been in the 3-week feed restriction and the preliminary week.

Table 36. Mean egg weight (g) ± SEM of hens during feed restriction and a subsequent recovery period in Experiment 6.

Period	Week	Treatment[1] 1	Treatment 2	Treatment 3	Treatment 4	LSD	Level of significance
Preliminary		62.4 ± 1.6[2]	66.0 ± 3.0	61.0 ± 1.6	62.5 ± 1.7	(6.1; 8.3)[4]	
Feed restriction	1	62.2 ± 1.0	64.9 ± 3.3	60.2 ± 1.6	60.2 ± 1.5	(6.6; 9.1)	
	2	62.4 ± 1.0	64.3 ± 2.8	60.0 ± 1.7	59.3 ± 1.6	(5.7; 7.9)	
	3	62.8 ± 1.2	63.9 ± 2.8	60.1 ± 1.7	60.1 ± 1.3	(5.9; 8.2)	
Recovery	4	63.0 ± 1.1	66.1 ± 2.8	61.9 ± 1.7	65.0 ± 1.7	(6.8; 9.4)	
	5	63.2 ± 1.3	64.9 ± 3.3	64.2 ± 1.7	64.0 ± 2.0	(6.6; 9.1)	
	6	63.4 ± 1.0	65.2 ± 2.2	63.8 ± 2.0	65.7 ± 1.7	(5.4; 7.5)	

[1] Treatment 1 is an *ad libitum*-fed control group; treatments 2, 3 and 4 are 80, 60 and 40 % feed restriction; [2] mean ± SEM egg weight (g) calculated from individual weighing of eggs/treatment; [3] Least Significant Differences (P = 0.05; P = 0.01); no asterisk, non-significant result (P > 0.05).

A possible explanation for the decrease in egg weights during the 3-week feed restriction period is reported by Donaldson and Millar (1962) : lowered egg weight may reflect an attempt by the hen to maintain reproductive capacity under conditions of restriction by allotting less nutrient to each egg. Another one is that the depression in body weight (Walter and Aitken, 1961) and in egg production (Heywang, 1940; Sherwood and Milby, 1961; Al-Khazarji *et al.*, 1970; Jackson, 1970; Polin and Wolford, 1972; Bell and Moreng, 1972) caused by feed restriction in the laying period would tend to decrease egg weight.

In discussing the former, Kwakkel *et al.* (1991) concluded that egg weight is dependent primarily on body weight. Hence, the increase in egg weight of both restricted and control groups during the recovery period (Table 36) is supported by the data of body weight (Table 32), feed intake (Table 33) and egg numbers (Table 35), which indicated that egg weight is not only dependent on body weight, but also dependent on feed intake and egg numbers.

Generally, this lack of an effect of feed restriction on egg weight is in agreement with the data of Heywang (1940), Walter and Aitken (1961) and Jalaludin (1969, quoted by Auckland and Fulton, 1973), all of whom found that feed restriction in the laying period had no effect on egg weights, but disagrees with the data of Combs *et al.* (1961), who showed that egg weights were highly significantly reduced when feed was restricted.

The mean specific gravity of eggs as influenced by feeding treatment is shown in Table 37. Restricting the feed intake of hens to 80, 60 and 40 % for a 3-week period had no statistically significant ($P > 0.05$) effect on the specific gravity of eggs. This lack of an effect of feed restriction on specific gravity of eggs is in agreement with the data of MacIntyre and Aitken (1959) and Gardiner and MacIntyre (1962), all of whom found that specific gravity of eggs was not influenced by feed restriction.

Although the differences in specific gravity of eggs were not significant, there was a tendency for the mean values in feed-restricted birds to be higher than the *ad libitum*-fed controls. The actual magnitudes of such increases, however, were very small and not likely to be of any commercial significance. This conclusion is consistent with Horn (1978), who reported that eggs with a specific gravity below 1.080 g/ml have a shell thickness problem, while eggs with specific gravity of 1.040 g/ml or less are of very poor quality. The cause of the low values of egg specific gravity (1.029 to 1.042 g/ml) observed in Experiment 6 can perhaps be attributed to the advanced age of the hens (Petersen, 1965; Wolford and Tanaka, 1970; Washburn, 1982), or to possible upthrust from the water on the egg cradle. Exactly the the same method was used as before; irrespective of these low values it is considered that the between group comparisons are valid.

Table 37. Mean egg specific gravity (g/ml) ± SEM of hens during feed restriction and a subsequent recovery period in Experiment 6.

Period	**Week**	**Treatment$^{1)}$ 1**	**Treatment 2**	**Treatment 3**	**Treatment 4**	**LSD**	**Level of significance**
Preliminary		1.029±0.002$^{2)}$	1.034 ±0.005	1.030±0.001	1.029±0.002	(0.007; 0.010)$^{4)}$	
Feed restriction	1	1.035±0.002	1.037±0.002	1.032±0.002	1.037±0.002	(0.005; 0.007)	
	2	1.037±0.001	1.036±0.002	1.037±0.002	1.037±0.002	(0.005; 0.007)	
	3	1.038±0.002	1.039±0.002	1.035±0.002	1.033±0.002	(0.006; 0.009)	
Recovery	4	1.037±0.002	1.039±0.001	1.039±0.002	1.042±0.003	(0.006; 0.008)	
	5	1.036±0.001	1.041±0.002	1.041±0.002	1.035±0.004	(0.008; 0.010)	
	6	1.035±0.001	1.037±0.001	1.040±0.003	1.039±0.003	(0.007; 0.010)	

$^{1)}$ Treatment 1 is an *ad libitum*-fed control group; treatments 2, 3 and 4 are 80, 60 and 40 % feed restriction; $^{2)}$ mean ± SEM specific gravity of eggs (g/ml) calculated from specific gravity values of eggs/treatment $^{3)}$ Least Significant Differences (P = 0.05; P = 0.01); no asterisk, non-significant result (P > 0.05).

The mean FCR's of both restricted and control groups are shown in Table 38, and indicate that the birds fed restricted were highly significantly (P < 0.001) more efficient, in terms of g feed intake/g egg weight, during the 3 weeks of the feed restriction period, than the controls.

Table 38. Mean FCR (g feed intake/g egg weight) ± SEM of hens during feed restriction and a subsequent recovery period in Experiment 6.

Period	**Week**	**Treatment$^{1)}$ 1**	**Treatment 2**	**Treatment 3**	**Treatment 4**	**LSD**	**Level of significance**
Preliminary		1.9 ± 0.03$^{2)}$	1.9 ± 0.10	2.0 ± 0.08	1.8 ± 0.07	(0.2; 0.03$^{4)}$	
Feed restriction	1	1.7 ± 0.03	1.4 ± 0.07	1.2 ± 0.06	0.7 ± 0.02	(0.02; 0.02)	***
	2	1.8 ± 0.05	1.5 ± 0.06	1.2 ± 0.06	0.7 ± 0.03	(0.02; 0.02)	***
	3	1.8 ± 0.05	1.5 ± 0.07	1.2 ± 0.06	0.8 ± 0.03	(0.02; 0.02)	***
Recovery	4	1.8 ± 0.06	1.9 ± 0.10	2.0 ± 0.05	2.3 ± 0.05	(0.02; 0.03)	***
	5	1.7 ± 0.09	1.7 ± 0.10	1.9 ± 0.04	1.9 ± 0.05	(0.02; 0.03)	
	6	1.5 ± 0.11	1.8 ± 0.03	1.8 ± 0.05	1.9 ± 0.06	(0.02; 0.03)	**

$^{1)}$ Treatment 1 is an *ad libitum*-fed control group; treatments 2, 3 and 4 are 80, 60 and
40 % feed restriction; $^{2)}$ mean ± SEM FCR (g feed intake/g egg weight) calculated from individual FCR of 7 birds/treatment $^{3)}$ Least Significant Differences (P = 0.05; P = 0.01); ***, P < 0.001; **, P < 0.01; no asterisk, non-significant result (P > 0.05).

The better FCR of the feed-restricted hens compared to the *ad libitum*-fed ones, is in agreement with the results of Singsen *et al.* (1959), Jackson (1970), Polin and Wolford (1972), Bell and Moreng (1972), Snetsinger *et al.* (1973), Watkins *et al.* (1973) and Connor *et al.* (1977), all of whom found that restrictedly fed birds recorded FCR's that were significantly better than *ad libitum*-fed controls.

The mean water : feed intake ratios data for Experiment 6 is shown in Table 39; expressed in terms of ml drunk/g feed intake, the ratios were significantly (P < 0.001) greater for the feed-restricted birds than for the controls during each of the 3 weeks of feed restriction. Comparing the results in Tables 38 and 39 indicates a positive relationship exists between FCR and the ratio of water to feed intake. This conclusion is supported by Van Kampen (1983), who also showed that hens with a high water : feed intake ratio have a superior feed utilisation efficiency.

The present results indicate that the efficiency of feed utilisation progressively increased with increasing severity of feed restriction, an association which is in accordance with the conclusion of Brody (1945), who reviewed data which showed that animals on low planes of nutrition utilised nutrients more efficiently due to increases in digestibility, metabolisability and assimilability.

Table 39. Mean water : feed intake ratios (ml water drunk/g feed intake) ± SEM of hens during feed restriction and a subsequent recovery period in Experiment 6.

Period	**Week**	**Treatment[1] 1**	**Treatment 2**	**Treatment 3**	**Treatment 4**	**LSD**	**Level of significance**
Preliminary		1.7 ± 0.09[2]	1.8 ± 0.10	1.8 ± 0.09	1.7 ± 0.08	(0.3; 0.4[4])	
Feed restriction	1	1.8 ± 0.08	2.1 ± 0.11	2.7 ± 0.12	3.8 ± 0.33	(0.6; 0.9)	***
	2	1.8 ± 0.09	2.1 ± 0.13	2.5 ± 0.19	4.0 ± 0.54	(0.8; 1.1)	***
	3	1.8 ± 0.10	2.2 ± 0.20	2.3 ± 0.16	4.7 ± 0.74	(1.2; 1.6)	***
Recovery	4	1.8 ± 0.10	1.8 ± 0.08	1.7 ± 0.07	1.8 ± 0.11	(0.3; 0.4)	
	5	1.9 ± 0.11	1.8 ± 0.12	1.7 ± 0.07	1.8 ± 0.10	(0.3; 0.4)	
	6	1.8 ± 0.08	1.8 ± 0.13	1.6 ± 0.08	1.9 ± 0.11	(0.2; 0.4)	*

[1] Treatment 1 is an *ad libitum*-fed control group; treatments 2, 3 and 4 are 80, 60 and 40 % feed restriction; [2] mean ± SEM water : feed intake ratios (ml water drunk/g feed intake) calculated from individual water : feed intake ratios values of 7 birds/treatment [3] Least Significant Differences ($P = 0.05$; $P = 0.01$); ***, $P < 0.001$; *, $P < 0.05$; no asterisk, non-significant result ($P > 0.05$).

Bird No. 6 in treatment 4 of Experiment 6 died suddenly in the 2nd-last week of the recovery period. *Post mortem* findings indicated that this bird had suffered from Marek's Disease and that the death was unrelated to experimental conditions. The one item of missing data of this bird was estimated using the Neva program of Burr (1982).

Linear regressions of water intake and feed intake of hens in Experiment 6 are presented in Table 40. Because neither intercepts nor slopes were significantly ($P > 0.05$) different between treatments, overall regressions covering both the feed restriction and recovery periods of the experiment, week by week, are presented.

Table 40. Regression equations of water intake (dependent variable, Y) on feed intake (independent variable, X) of hens in Experiment 6.

Period	Week	r	Regression equation	P
Preliminary		0.363	$Y = 86.5 + 0.156 X$ (16.58) (0.079)	0.058
Feed restriction	1	0.393	$Y = 17.9 + 0.328 X$ (28.23) (0.150)	0.038
	2	0.233	$Y = 51.5 + 0.153 X$ (24.29) (0.125)	0.233
	3	0.044	$Y = 76.7 + 0.019 X$ (17.53) (0.086)	0.823
Recovery	4	0.688	$Y = 59.9 + 0.292 X$ (13.51) (0.060)	0.000
	5	0.769	$Y = 46.2 + 0.326 X$ (10.92) (0.053)	0.000
	6	0.683	$Y = 60.4 + 0.259 X$ (11.12) (0.054)	0.000

r is the correlation between water intake and feed intake. Standard deviations of the coefficients are in brackets.

The analysis of variance (Table 40) showed that, on a week by week basis, the regressions of water intakes on feed intakes approached significance in the preliminary period, and were significant ($P < 0.05$) in the 1st week of feed restriction, but during the 2nd and 3rd weeks of restriction, however, the regressions were not significant ($P > 0.05$), indicating that these 2 parameters were poorly related at those times. By contrast, in the 3-week recovery period of *ad libitum* feeding and drinking, the birds showed significantly positive correlations between water intake and feed intake, as also suggested by the highly significant regressions ($P < 0.001$) between these two parameters (Table 40).

Comparison of the present results (mean weekly values of all treatment groups) with the only available literature in which water and feed intakes were provided *ad libitum*, and from which a comparable relationship can be calculated, (*ad lib.*: $Y = 54.55 + 0.27 X$, $r = 0.73$, $P < 0.05$; Savory, 1978), as plotted in Figure 3, indicates very similar relationships in the two sets of data.

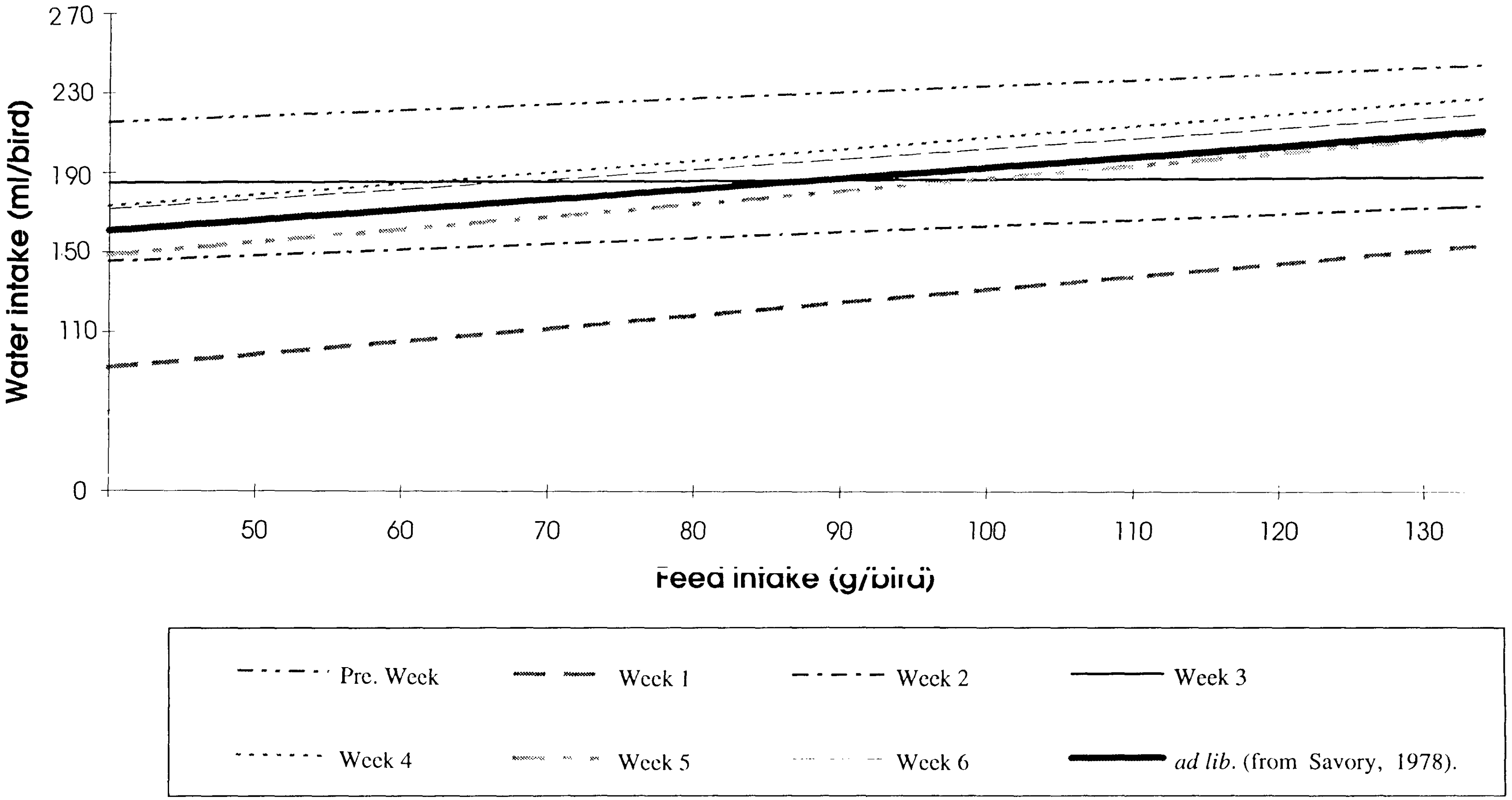

Figure 3. **The relationships between water and feed intakes within weeks in Experiment 6 as compared to the relationship under *ad libitum* conditions reported by Savory (1978).**

In summary, restricted feeding of laying hens has some benefits for egg production that may be of value to producers in areas such as West Timor, Indonesia, where the feed is limited, especially in the period immediately before harvest, and because what is available is imported, and expensive. When feed is in short supply for limited periods (e.g. before harvest), the present results indicate that hens have the capacity to recover quickly, provided full feeding is available for the recovery. However, verification of the effects of feed restriction with a larger number of birds and over a longer period is necessary before estimates of the actual economic advantages of feed restriction can be made for commercial producers.

3.3.4. **Experiment 7 - The effects of water restriction at 20 °C.**

3.3.4.1. **Introduction.**

Improving efficiency of feed utilisation is a universal goal in all animal production systems, and in laying hens is generally expressed as a feed conversion ratio (g feed intake/g egg weight; Katle, 1992). It has always been an important factor in commercial egg production (Hunton, 1992). From an economic viewpoint, the continually increasing cost of poultry rations has intensified the search for means to improve feed conversion efficiency (Spiller *et al.*, 1973).

As feed represents the greatest single cost in most systems of poultry production (i.e. it represents an average of 70 % of total variable costs; McMahon *et al.*, 1974; Lee, 1977; Elson, 1979; Wilson and Emmans, 1979; Emmans and Charles, 1989; Behrends, 1990; Wei, 1992), enhanced utilisation of feed offers real potential in reducing production costs for commercial egg producers (Kari *et al.*, 1977).

Undoubtedly, water restriction has consistently resulted in an improved feed utilisation (Maxwell and Lyle, 1957; Hill, 1969; Hill and Richards, 1969, 1975; Spiller *et al.*, 1976). Besides that, the economic implications of restricting water intake of hens are to prevent wet droppings and to save water in layer operations (Maxwell and Lyle, 1957). However, the effect that water restriction has on egg production is controversial. Salverson (1959), Muir and Gerry (1976) and Goan (1977) reported no effect on egg production; Maxwell and Lyle (1957) and Wilson *et al.* (1965) indicated increased egg production and Hill and Richards (1969) and Spiller *et al.* (1976) found decreased egg production as a result of water restriction in laying hens. The fact that most of these authors used time-restricted watering rather than restricting water to laying hens by volume, which is no doubt the most accurate method of water restriction (Bailey, 1990), could account for some of the discrepancies.

Even so, there is little information available on the performance of laying hens after short-term water restriction (Adams, 1973; Summers and Lesson, 1976). In view of the beneficial effects and conflicting reports outlined above, the effects of short-term water restriction on the laying performance of hens kept at an environmental temperature of 20 °C were investigated in the current experiment.

3.3.4.2. **Experimental hypothesis and design**.

The hypothesis developed was that restricted watering of laying hens instead of allowing them to drink *ad libitum* will have beneficial effects on the efficiency of feed conversion that could be of benefit to producers in areas such as West Timor, Indonesia, where the availability of water for poultry (and other animals) is severely limited during the final months of the annual dry season (April - November). A similar experimental design was used as in Experiment 6; differences being that in this case water intake was restricted to 85, 70 and 65% of *ad libitum* intake.

3.3.4.3. **Results and discussion**.

The mean results of all aspects of hen performance collected from Experiment 7, together with the respective SEM's, are presented separately in Tables 41 to 49. The regressions of water intake (dependent variable) on feed intake (independent variable) for Experiment 7 are presented in Table 49 and illustrated in Figure 5.

The mean body weights in Table 41 show that this parameter was not significantly ($P > 0.05$) affected by watering treatments in either the period of water restriction or the recovery. Although restricted watering had no significant influence on the body weight of the four groups of hens in Experiment 7, there was a reduction in their mean body weights during the 3-week water restriction.

The overall losses in body weight of hens in treatments 2, 3 and 4 were 4.7, 8.6 and 10.9 % respectively as compared to 1 % for the *ad libitum*-watered control group Return to *ad libitum* watering in the 3-week recovery period resulted in an increase in the mean body weights of the four groups (Table 41 and Figure 4). The current results support those obtained by Wilson and Edwards (1953) who deprived laying hens of water for 24, 48 or 72 h and reported the percentage of losses in body weight for the 1st, 2nd and 3rd d were 10 15 and 19 %, respectively. They also found that it took approximately 1 week after giving water *ad libitum* before body weight was restored to that of the control group.

The shift in the pattern of body weight as affected by water restriction is in agreement with the work of Heywang (1941), who studied the effect of air temperature, body weight and egg production on the water intake of White Leghorn and Rhode Island Red hens during a period of one year and reported that increases or decreases in water intake were followed by corresponding increases or decreases in body weight and egg production.

Table 41. Mean body weight (g) ± SEM of hens during water restriction and a subsequent recovery period in Experiment 7.

Period	**Week**	**Treatment[1] 1**	**Treatment 2**	**Treatment 3**	**Treatment 4**	**LSD**	**Level of significance**
Preliminary		1649 ± 45[2]	1824 ± 82	1707 ± 44	1830 ± 79	(204; 279)[3]	
Water restriction	1	1657 ± 42	1763 ± 77	1630 ± 32	1725 ± 74	(178; 243)	
	2	1649 ± 39	1747 ± 78	1580 ± 34	1631 ± 64	(171; 235)	
	3	1632 ± 46	1738 ± 78	1561 ± 42	1630 ± 60	(178; 243)	
Recovery	4	1682 ± 43	1840 ± 83	1713 ± 52	1805 ± 82	(208; 285)	
	5	1693 ± 40	1880 ± 77	1738 ± 67	1839 ± 89	(229; 314)	
	6	1713 ± 41	1894 ± 91	1745 ± 65	1865 ± 91	(223; 306)	

[1] Treatment 1 is an *ad libitum*-watered control group; treatments 2, 3 and 4 are 85, 70 and 65 % water restriction; [2] mean ± SEM body weight (g) calculated from individual weighing of 7 birds/treatment; [3] Least Significant Differences (P = 0.05; P = 0.01); no asterisk, non-significant result (P > 0.05).

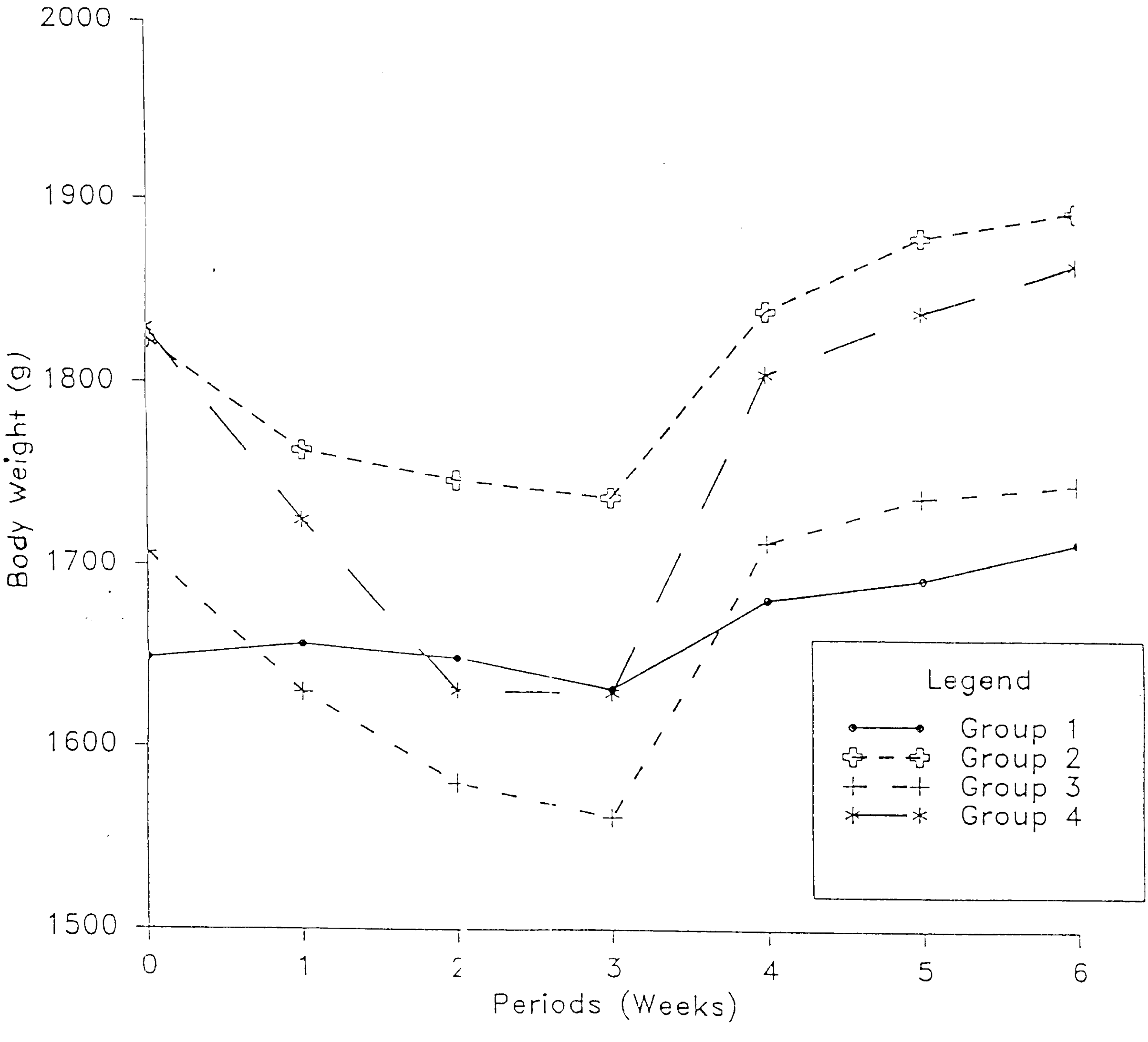

Figure 4. **The mean body weight of hens in Experiment 7.**

The reduction in body weight of the water-restricted birds during the 3 weeks of water restriction is presumed to also be partly the result of the reduction in their feed intake (see Table 42). This suggestion is consistent with the work of Wilson and Edwards (1953), who concluded that a loss in body weight and a reduction in feed intake occurred in laying hens when their water was restricted. Bierer *et al.* (1965a, 1966b) also observed that feed intake declined in broiler chickens, turkeys, guinea pigs and mice when their water was restricted, and, conversely, that their water intake declined when their feed was restricted.

In general, this lack of an effect of water restriction on body weight is similar to the results of time-restricted watering reported by other workers (Muir and Gerry, 1976, 1978; Goan 1977), all of whom found that restricting watering time of laying hens depressed body weight but the differences were not statistically significant ($P > 0.05$).

However, the above results are dissimilar to the results of Savory (1978), who showed that Brown Leghorn hens actually gained body weight ($P < 0.05$) during 6 weeks of water restriction. Strain differences in water requirements, as inferred by Malik (1965) and Hill and Powell (1977), may have contributed to these variable results, but the most likely cause is a difference in the level of water restriction. In the current work, birds were individually restricted to 85, 70 and 65 % of their previous *ad libitum* intakes. These levels are in fact lower than those of Savory (1978), who restricted the daily water supply of each hen by volume to only 90 % of its previous mean daily *ad libitum* intake.

The mean feed intakes of control and restricted birds are shown in Table 42. Both restricted and control birds showed a decrease in feed intake during the 3 weeks of water restriction, and the extent of the depression in intake increased as did the degree of water restriction. The overall decreases in feed intake of hens in treatments 2, 3 and 4 were 18.3, 19.1 and 29.6

% respectively as compared to 12.1 % for the *ad libitum*-watered control group.

The reason for the decline in feed intake in control birds (which had *ad libitum* access to both feed and water) would appear to be social facilitation. They were housed in the same room as the treated ones, and the cages were allocated at random, so the depressed feed intake (and hence, presumably, frequency and/or duration of feeding) of treated birds could well have also influenced the controls. The increase in feed intake in controls during the recovery period for treated hens is consistent with this suggestion.

Table 42. Mean feed intake (g) ± SEM of hens during water restriction and a subsequent recovery period in Experiment 7.

Period	**Week**	**Treatment 1**[1]	**Treatment 2**	**Treatment 3**	**Treatment 4**	**LSD**	**Level of significan**
Preliminary		111.7 ± 4.8[2]	123.1 ± 5.5	104.6 ± 7.4	110.1 ± 4.5	(17.0; 23.3)[3]	
Water restriction	1	104.3 ± 6.0	100.5±11.2	79.4 ± 9.6	77.3 ± 5.0	(24.9; 34.1)	
	2	98.9 ± 5.2	103.3 ± 5.9	87.0 ± 4.0	73.8 ± 5.2	(16.3; 22.4)	**
	3	98.2 ± 5.2	100.6 ± 6.7	84.6 ± 5.7	77.5 ± 4.3	(15.9; 21.8)	**
Recovery	4	107.8 ± 2.3	127.6 ± 4.9	120.8 ± 5.8	123.9 ± 6.6	(16.6; 22.7)	*
	5	106.8 ± 2.6	123.9 ± 3.8	116.0 ± 6.0	119.6 ± 5.3	(14.3; 19.6)	
	6	101.3 ± 2.8	116.6 ± 3.1	106.8 ± 4.3	113.1 ± 4.9	(12.4; 17.0)	

[1] Treatment 1 is an *ad libitum*-watered control group; treatments 2, 3 and 4 are 85, 70 and 65 % water restriction; [2] mean ± SEM feed intake (g) calculated from individual feed intake of 7 birds/treatment; [3] Least Significant Differences (P = 0.05; P = 0.1);
**, P < 0.01; *, P < 0.05; no asterisk, non-significant result (P > 0.05).

The current result, that restricted water intake led to a reduction in feed intake, is in agreement with the work of Wilson and Edwards (1953), who indicated that restricting water intake of laying hens automatically limits their feed intake. The influence of water restriction on feed intake observed in the current work is also similar to the results of time-restricted watering reported by other workers (Hill, 1969; Hill and Richards, 1969; Al-Khazarji *et al.*, 1970; Spiller *et al.*, 1973, 1976).

Working with Barbary doves, for example, McFarland and Wright (1969) concluded that the reason for the birds eating less when subjected to water restriction was a need to conserve water. Depression of feed intake conserves water both directly, by reducing faecal water loss, and indirectly, by causing a reduction in body temperature and hence in the need for evaporative water loss. Presumably this also explains why hens reduced their feed intake in response to water restriction in Experiment 7.

Routine subjective, visual observations made on the incidence of 'wet droppings' during Experiment 7, which indicated that the droppings under the cages of all restricted birds were drier than those of the control birds, support the concept of reduced faecal water excretion when water intake is restricted. The results of the present study are thus consistent with other more detailed studies on the effectiveness of restricted water intake for the prevention of wet droppings in layer houses (Maxwell and Lyle, 1957; Wilson *et al.*, 1965; Al-Khazaaji *et al.*, 1970).

With regard to the moisture content of the hens' faeces, data were unfortunately not collected in the current work, but Okumura *et al.* (1977) found that the water content in the droppings of hens is higher when the birds are kept at temperatures higher than 25 °C and when the mean water intake is higher than 250 ml/d. Neither of those conditions applied in Experiment 7.

Generally, water intake is positively and highly significantly correlated with both body weight and feed intake in laying hens (Bordas *et al.*, 1978). The effect of water restriction on body weight and feed consumption has also been studied in broiler chickens by Kellerup *et al.* (1965), who observed that chicks receiving 10, 20, 30, 40 or 50 % less water than *ad libitum* controls experienced reduced levels of feed consumption and growth rate which were proportional to the degree of water restriction. Comparison of the current results with the results from that study indicates, indeed, that the reductions observed in the current work in both the feed intake (Table 42) and body weight (Table 41) of hens were proportional to the degree of water restriction employed.

The mean actual water intakes of each group are presented in Table 43. The water intake of the restricted groups was significantly (P < 0.01) less than that of controls in all cases except group 2 in week 2 (187 cf. 181 ml/bird), that slight reversal of trend being a function of the experimental design.

Table 43. Mean water intake (ml) ± SEM) of hens during water restriction and a subsequent recovery period in Experiment 7.

Period	Week	Treatment 1) 1	Treatment 2	Treatment 3	Treatment 4	LSD	Level of significance
Preliminary		189 ± 12 2)	229 ± 16	195 ± 15	185 ± 18	(51; 69) 3)	
Water restriction	1	182 ± 12	181± 16	132 ± 14	119 ± 11	(43; 58)	
	2	181 ± 9	187 ± 11	136 ± 11	120 ± 12	(36; 49)	**
	3	186 ± 11	180 ± 11	136 ± 11	118 ± 11	(37; 50)	**
Recovery	4	228 ± 15	285 ± 12	311 ± 26	301 ± 29	(66; 90)	*
	5	190 ± 10	250 ± 21	222 ± 10	234 ± 27	(48; 65)	
	6	187 ± 15	240 ± 26	196 ± 10	208 ± 21	(43; 59)	

1) Treatment 1 is an *ad libitum*-watered control group; treatments 2, 3 and 4 are 85,
70 and 65 % water restriction; 2) mean ± SEEM feed intake (g) calculated from individual water intake of 7 birds/treatment; 3) Least Significant Differences (P = 0.05;
P = 0.1); **, P < 0.01; *, P < 0.05; no asterisk, non-significant result
(P > 0.05).

Thus, controls were watered *ad libitum*, and their intakes ranged from 189 in the preliminary period to 181 ml/bird/d (P > 0.05) in week 2. The treated groups were, however, restricted to a percentage of their intake in the preliminary period. In the case of group 2, this value averaged 229 ml/bird/d. The values for group 2 in Table 43, namely 181, 187 and 180 ml/bird/d, indicate that these birds did not drink all the water allotted to them.

The birds on all 3 restricted treatments showed a dramatic increase in water intake during the 1st few days of the 1st week of the recovery period (Table 43). This resulted in the water-restricted birds having a mean water intake higher than that of the controls in the 4th week; thereafter, and until the end of the recovery period, the differences between the four groups were not statistically significant (P > 0.05).

The mean egg numbers and hen-day egg production data for Experiment 7 are shown in Table 44. The percentage of egg production on a hen-day basis was numerically higher for the water-restricted birds than for the controls, but these differences were not statistically significant (P > 0.05) during either the water restriction or recovery periods. The fact that water restriction had no significant (P > 0.05) effect on egg numbers in the current work may have been because the birds were poor egg producers (a function of their advanced age) or because the water restriction period was too short. A third possible cause is the small group size available to the author.

Examination of Table 44 indicates that all groups produced either 4 or 5 eggs/bird/week during treatment, except group 4 in the week 3. With a large group size the differences between 4 and 5 eggs/bird/week may have been significant. Normally the water requirements of laying hens are closely related to their egg output (Heywang, 1941; Jull, 1949), so it is very likely that water restriction would eventually cause a decline in egg numbers of layers.

Table 44. Mean egg numbers ± SEM (%) of hens during water restriction and a subsequent recovery period in Experiment 7.

Period	Week	Treatment[1] 1	Treatment 2	Treatment 3	Treatment 4	LSD	Level of significanc
Preliminary		5 ± 0.6[2](71)[3]	5 ± 0.7(71)	4 ± 0.2(57)	5 ± 0.3(71)	(1.6; 2.1)[4]	
Water restriction	1	4 ± 0.7(57)	5 ± 0.4(71)	5 ± 0.7(71)	4 ± 0.6(57)	(1.5; 2.2)	
	2	4 ± 0.4(57)	5 ± 0.1(71)	4 ± 0.5(57)	4 ± 0.6(57)	(1.5; 2.1)	
	3	4 ± 0.8(57)	5 ± 0.8(71)	4 ± 0.7(57)	3 ± 0.5(43)	(2.2; 3.0)	
Recovery	4	5 ± 0.6(71)	5 ± 0.4(71)	5 ± 0.5(71)	5 ± 0.4(71)	(1.3; 1.9)	
	5	5 ± 0.4(71)	6 ± 0.3(86)	6 ± 0.4(86)	5 ± 0.3(71)	(1.0; 1.4)	
	6	4 ± 0.7(57)	5 ± 0.5(71)	5 ± 0.4(71)	5 ± 0.5(71)	(1.4; 1.9)	

[1]Treatment 1 is an *ad libitum*-watered control group; treatments 2, 3 and 4 are 85, 70 and 65 % water restriction; [2] mean ± SEM egg numbers calculated from individual collection of eggs/treatment; [3] % hen-day egg production/week/treatment; [4] Least Significant Differences (P = 0.05; P = 0.01); no asterisk, non-significant result (P > 0.05).

In the current study the restriction of water did not harm egg production, confirming the findings of Salverson (1959), Knight (1970), Muir and Gerry (1976) and Goan (1977), but disagreeing with the results of many other workers (Maxwell and Lyle, 1957; Bierer *et al.*, 1965a; Wilson *et al.*, 1965; Hill and Richards, 1969; Al-Khazarji *et al.*, 1970; Adams, 1973; Hill and Richards, 1975; Spiller *et al.*, 1973, 1976). These dissimilar results, which have been noted previously (Bailey, 1990), are probably due to the differences in water restriction methods. In other words, most of these authors used time-restricted watering in their studies, and this technique inevitably leads to variation between hens.

The mean egg weights as influenced by watering treatment are presented in Table 45, which show that there were significant differences (P < 0.05) between restricted and control birds only during the 1st week of the treatment (week 1). Thereafter, and until the end of the recovery period, the differences between groups were not statistically significant (P > 0.05), although group 4 continued to produce the smallest eggs.

The most striking feature of these results is that birds which were moderately water-restricted (i.e. 70 and 85 % water restriction) maintained a slightly higher average egg size as compared to the control birds, whereas the birds on treatment 4 (65 % water restriction) had a mean egg weight lower than the controls during the 3 weeks of restriction. Such results suggest that a critical level, in terms of water restriction, lies between the 75 and 65 % treatment levels. From an animal welfare viewpoint, the results thus vindicate the initial decision not to include a 55 % water-restricted group.

Table 45. Mean egg weight (g) ± SEM of hens during water restriction and a subsequent recovery period in Experiment 7.

Period	**Week**	**Treatment 1) 1**	**Treatment 2**	**Treatment 3**	**Treatment 4**	**LSD**	**Level of significance**
Preliminary		62.2 ± 0.8 2)	62.8 ± 2.7	65.3 ± 1.5	67.7 ± 0.7	(5.1; 6.9 3))	
Water restriction	1	61.0 ± 1.2	67.9 ± 2.6	63.5 ± 1.3	60.4 ± 1.2	(5.2; 7.1)	*
	2	62.2 ± 0.6	66.6 ± 1.8	62.8 ± 1.7	60.9 ± 1.7	(4.6; 6.4)	
	3	62.0 ± 0.9	67.8 ± 2.6	62.1 ± 1.8	61.2 ± 1.3	(5.7; 7.8)	
Recovery	4	61.2 ± 0.9	67.3 ± 2.4	64.7 ± 1.4	63.1 ± 1.5	(4.9; 6.8)	
	5	62.5 ± 1.1	68.4 ± 2.6	65.0 ± 1.6	63.3 ± 1.0	(5.1; 7.0)	
	6	62.8 ± 1.3	69.8 ± 3.6	65.2 ± 1.6	63.6 ± 0.7	(6.2; 8.5)	

1)Treatment 1 is an *ad libitum*-watered control group; treatments 2, 3 and 4 are 85, 70 and 65 % water restriction; 2) mean ± SEM egg weight (g) calculated from individual weighing of eggs/treatment; 3) Least Significant Differences (P = 0.05; P = 0.01); *, P < 0.05; no asterisk, non-significant result (P > 0.05).

The increased egg weights recorded in the moderately restricted birds in the current work (particularly group 2) support the results obtained by Muir and Gerry (1976), who conducted two trials in which they restricted watering time to 15, 8 and 15 min either 4 times or 8 times/d. The size of eggs from layers watered four times/d was significantly greater than for those receiving 8 watering periods in the 1st trial, but not in the 2nd one. Spiller *et al.* (1976) also found that restrictedly watered hens laid heavier eggs than did controls. The lack of consistency in egg weight in treatment 2 of Table 45 is attributed to the small number of birds/treatment.

The mean specific gravities of the eggs of the layers in Experiment 7 are presented in Table 46. Because the birds used in this experiment were the same as in Experiment 6, but correspondingly older, the egg specific gravity values presented in Table 46 are also numerically lower than the standard values described by Horn (1988). Possible reasons for this have been suggested previously (see page 124).

Table 46. Mean specific gravity of eggs (g/ml) ± SEM of hens during water restriction and a subsequent recovery period in Experiment 7.

Period	**Week**	**Treatment1) 1**	**Treatment 2**	**Treatment 3**	**Treatment 4**	**LSD**	**Level of significanc**
Preliminary		1.036±0.0032)	1.037±0.002	1.040±0.002	1.035±0.001	(0.007; 0.0103)	
Water restriction	1	1.037±0.004	1.037±0.002	1.034±0.003	1.031±0.002	(0.008; 0.011)	*
	2	1.036±0.002	1.035±0.003	1.039±0.001	1.035±0.001	(0.006; 0.009)	
	3	1.036±0.003	1.037±0.002	1.036±0.002	1.033±0.002	(0.007; 0.009)	
Recovery	4	1.035±0.003	1.039±0.003	1.039±0.002	1.038±0.001	(0.006; 0.009)	
	5	1.035± 0.002	1.036±0.002	1.040±0.001	1.037±0.002	(0.007; 0.009)	
	6	1.034±0.003	1.037±0.003	1.038±0.002	1.038±0.002	(0.008; 0.011)	

1)Treatment 1 is an *ad libitum*-watered control group; treatments 2, 3 and 4 are 85, 70 and 65 % water restriction; 2) mean ± SEM specific gravity (g/ml) of eggs calculated from specific gravity values of eggs/treatment; 3) Least Significant Differences (P = 0.05; P = 0.01); no asterisk, non-significant result (P > 0.05).

As shown in Table 46, restricting the water intake of hens to 85, 70 and 65 % for a 3-week period had no statistically significant (P > 0.05) effect on the specific gravity of eggs, nor were any obvious trends present. This means that shell quality, as measured in terms of egg specific gravity determined by using the suspension weighing technique, was not influenced by any of the restricted water treatments in Experiment 7. The current results agree with the research of Goan (1977) and disagree with the results of Bierer *et al.* (1965b) and Spiller *et al.* (1976). Strain, age of bird and the method used to determine egg specific gravity could account for this dissimilarity in results.

Working with White Leghorn hens which had been in lay for approximately 5 months, for example, Spiller *et al.* (1976) found that eggs from restrictively watered hens had significantly higher egg specific gravity values than controls when the specific gravity was determined by using salt solutions scaled from 1.052 to 1.104 g/ml in increments of 0.004. It is possible that in the current work, because of advanced age, the specific gravity of eggs had already declined to a very low level below which any further reductions were difficult to achieve.

The effects of water restriction on the FCR of hens in Experiment 7 are presented in Table 47. A major effect was an increase in the mean FCR of the two most severely restricted groups of birds (i.e. 70 and 65 % water restriction), while those restricted to only 85 % of *ad libitum* water intake maintained a FCR similar to that of the controls. The FCR values of groups 1 and 2 were lower than for groups 3 and 4 throughout the treatment period, but this difference was significant (P < 0.01) only in week 1.

Table 47. Mean FCR (g feed intake/g egg weight) ± SEM of hens during water restriction and a subsequent recovery period in Experiment 7.

Period	**Week**	**Treatment 1)** **1**	**Treatment 2**	**Treatment 3**	**Treatment 4**	**LSD**	**Level of significance**
Preliminary		1.7 ± 0.08 2)	1.8 ± 0.06	1.6 ± 0.11	1.7 ± 0.07	(0.2; 0.3 3))	
Water restriction	1	1.7 ± 0.11	1.7 ± 0.07	1.3 ± 0.11	1.2 ± 0.11	(0.3; 0.4)	**
	2	1.6 ± 0.08	1.6 ± 0.07	1.4 ± 0.09	1.3 ± 0.05	(0.3; 0.4)	
	3	1.5 ± 0.11	1.6 ± 0.14	1.4 ± 0.06	1.3 ± 0.10	(0.3; 0.4)	
Recovery	4	1.7 ± 0.05	1.9 ± 0.08	1.9 ± 0.06	1.9 ± 0.12	(0.2; 0.3)	
	5	1.8 ± 0.05	1.8 ± 0.08	1.8 ± 0.09	1.9 ± 0.06	(0.2; 0.3)	
	6	1.7 ± 0.06	1.7 ± 0.09	1.7 ± 0.05	1.8 ± 0.08	(0.2; 0.3)	

1)Treatment 1 is an *ad libitum*-watered control group; treatments 2, 3 and 4 are 85, 70 and 65 % water restriction; 2) mean ± SEM FCR (g feed intake/g egg weight) of eggs calculated from individual FCR of 7 birds/treatment; 3) Least Significant Differences (P = 0.05; P = 0.01); **, P < 0.01; no asterisk, non-significant result (P > 0.05).

After 3 weeks of water restriction, a return to *ad libitum* watering conditions resulted in a reduction in the FCR of all restricted birds (P < 0.05), but the differences between the four groups were not statistically significant (P > 0.05). Obviously, the reduction in the efficiency of feed utilisation by the restrictively watered hens during the 3-week recovery period was a consequence of the fact that their feed intake (Table 42) increased proportionally more than their egg weights (Table 45) and numbers (Table 44).

Conversely, the greater feed efficiencies recorded by the restrictively watered hens of treatments 3 and 4 when compared to treatments 2 and 1 were a result of their proportionally large reductions in feed intake (Table 42). Because of the higher feed efficiency concomitant with a lower feed intake, it is apparent that the lower body weight (Table 41) of the 70 and 65 % water-restricted birds was also associated with their lower feed intake. In general, the feed efficiency data on 70 and 65 % water restriction treatments *per se* support the results obtained by previous workers (Maxwell and Lyle, 1957; Hill, 1969; Hill and Richards, 1969, 1975; Spiller *et al.*, 1976), all of whom reported that water restriction consistently resulted in an improved feed utilisation by laying hens.

The results summarised in Table 48 are presented to show the effect of water restriction on the ratio between ml water drunk and g of feed consumed. The restricted birds generally showed a higher ratio than the controls during the 1st week of restriction, though this was not significant ($P > 0.05$).

During the 2nd week, the ratio in the birds on treatment 2 (85 % water restriction) was equal to that of controls, whereas the other treatments (i.e. 70 and 65 % water restriction) maintained lower ratios. Again, however, these differences were not significant ($P > 0.05$). In the 3rd week of water restriction the same pattern was maintained, although in this case the treatment effect was significant ($P < 0.05$).

Table 48. Mean water : feed intake ratios (ml water drunk/g feed intake) ± SEM of hens during water restriction and a subsequent recovery period in Experiment 7.

Period	**Week**	**Treatment**[1)] **1**	**Treatment 2**	**Treatment 3**	**Treatment 4**	**LSD**	**Level of significance**
Preliminary		1.7 ± 0.04[2)]	1.9 ± 0.11	1.9 ± 0.09	1.7 ± 0.15	(0.3; 0.4[3)]	
Water restriction	1	1.5 ± 0.06	1.7 ± 0.18	1.8 ± 0.10	1.9 ± 0.06	(0.3; 0.4)	
	2	1.8 ± 0.03	1.8 ± 0.08	1.6 ± 0.10	1.6 ± 0.10	(0.2; 0.3)	
	3	1.9 ± 0.12	1.8 ± 0.02	1.6 ± 0.11	1.5 ± 0.11	(0.3; 0.4)	*
Recovery	4	2.1 ± 0.13	2.2 ± 0.04	2.5 ± 0.15	2.4 ± 0.17	(0.4; 0.6)	
	5	1.8 ± 0.07	2.0 ± 0.14	1.9 ± 0.09	1.9 ± 0.14	(0.3; 0.4)	
	6	1.9 ± 0.17	2.0 ± 0.21	1.8 ± 0.10	1.8 ± 0.11	(0.3; 0.5)	

[1)] Treatment 1 is an *ad libitum*-watered control group; treatments 2, 3 and 4 are 85, 70 and 65 % water restriction; [2)] mean ± SEM water : feed intake ratios (ml water drunk/g feed intake) calculated from individual water : feed intake ratios values of 7 birds/treatment; [3)] Least Significant Differences (P = 0.05; P = 0.01); *, P <0.05; no asterisk, non-significant result (P > 0.05).

The current work thus showed an overall pattern of reduced water : feed intake ratios when the water intake was restricted, though the trend was generally non-significant. It would seem that this lack of statistical significance was largely the result of the small numbers of birds available to the author.

If the trend indicated can be verified in later work, it has two major areas of practical significance. Firstly, through association with feed conversion efficiency, birds on restricted water intakes might be expected to be more efficient than fully watered ones. In intensive production systems, therefore, there is scope to improve feed efficiency by limiting water intake, so long as the birds' essential needs (especially for thermoregulation) are met.

At the same time, the relative severity of water restriction necessarily imposed in areas such as the author's home region, West Timor, Indonesia, is unlikely to be a detrimental factor, at least in terms of feed conversion efficiency. Secondly, a lower water : feed intake ratio could be expected to yield drier faeces, and restricted watering has the added advantage then of helping to avoid (or control) the occurrence of wet droppings, and the consequent problem with odours, flies, disease and difficulty of removal of faeces from the poultry house

The regressions of water intake (dependent variable) on feed intake (independent variable) of hens in Experiment 7 are summarised in Table 49. Highly significant ($P < 0.001$) regressions were obtained for water and feed intakes during both the periods of water restriction and recovery; but as with Experiment 6, there were no significant differences in intercepts or slopes among the treatments.

The resulting regressions for Experiment 7 were also plotted with the relationship calculated from Savory's (1978) data in Figure 5. As for feed restriction in Experiment 6, the regression lines of the water-restricted birds in weeks 1, 2 and 3 (Figure 5) were below those of Savory (1978) and of *ad libitum* watered hens in Experiment 7; that is, during water restriction, hens drank relatively less water/unit of feed intake.

Table 49. Regression equations of water intake (dependent variable, Y) on feed intake (independent variable, X) of hens in Experiment 7.

Period	**Week**	**r**	**Regression equation**	**P**
Preliminary		0.695	$Y = 61.1 + 0.257\ X$ (10.62) (0.052)	0.000
Feed restriction	1	0.919	$Y = 13.3 + 0.503\ X$ (6.76) (0.042)	0.000
	2	0.846	$Y = 33.1 + 0.370\ X$ (7.34) (0.457)	0.000
	3	0.792	$Y = 39.7 + 0.326\ X$ (7.89) (0.049)	0.000
Recovery	4	0.732	$Y = 70.9 + 0.175\ X$ (9.18) (0.032)	0.000
	5	0.729	$Y = 74.8 + 0.187\ X$ (7.89) (0.034)	0.000
	6	0.493	$Y = 86.8 + 0.109\ X$ (8.08) (0.038)	0.008

r is the correlation between water intake and feed intake. Standard deviations of the coefficients are in brackets.

Here too, it is perhaps of practical significance to note that the slopes of the regressions during water restriction (weeks 1 to 3) were lower than during *ad libitum* watering. Again, there was a progressive change from week 1 to weeks 2 and 3. If subsequently confirmed in more extensive experiments, this difference would suggest that at a low level of water intake, restricted birds eat less than *ad libitum*-watered ones, and vice versa at higher (above about 200 - 250 ml/d) water intakes.

Birds currently being kept on restricted amounts of water during the dry season in Timor, Indonesia, for example, might thus be suffering an induced depression in feed intake. In any further work to examine these phenomena, ambient temperature should also be taken into account. The current work was conducted at 20 °C; poultry in the tropics would typically live at 25 - 32 °C and might be expected to have further elevated water intakes (Vohra, 1982). Overall, the current results confirm the previous studies of Anderson and Hill (1968), Wood-Gush and Horne (1970), Hill and Powell (1977), Savory (1978) and Hill *et al.* (1979), which established that there is a positive relationship between water and feed intakes when both are provided *ad libitum*.

It is concluded that although restricted watering of laying hens has little beneficial effect on feed conversion and egg production, it may offer some added advantages related to the so-called 'wet droppings' problem, and indeed saving of water in layer operations. Thus, it may be of value to impose in areas such as West Timor, Indonesia, where water is limited in availability during the dry season. However, the small number of birds and the short period of time in Experiment 7 suggest that water restriction in laying hens requires further investigation. Conversely, it seems unlikely that the forced restriction in water intake which occurs in West Timor late in the dry season would have significant effects on egg production, although field trials to confirm this are obviously required.

3.4. **General discussion**.

The seven experiments reported in this thesis were carried out (1) to obtain information on the practical application of choice feeding to laying hens in a single feeder at different environmental temperatures; and (2) to study the effects of short-term feed and water restriction programs on the laying performance of hens fed on a complete diet at a constant normal temperature.

As mentioned in Chapter 1, this information is considered to have immediate application in solving the three particular nutritional problems of feeding laying hens in the author's home country, West Timor, Indonesia, namely: (1) the high cost of processed (protein) feedstuffs (all of which are currently imported), (2) seasonal shortages of feedstuffs (particularly in the period immediately before a new harvest), and (3) seasonal shortages of drinking water (particularly during the "dry" season, April - November). The two parts of this section will discuss further the practical application of all results obtained in the current work. The first part will focus on the choice feeding experiments and the second on the work on the feed- and water-restriction.

3.4.1. **Choice feeding**.

From the foregoing discussions of the first five experiments of this thesis, it can be seen that laying hens choice fed *ad libitum* in a single feeder generally performed as well as those given a single complete diet. Collectively, these experiments quite clearly indicated that choice-fed hens not only consumed less feed in total, but also converted feed more efficiently to eggs and even laid eggs at a similar rate to those fed the complete diet when they were kept at a constant 'normal' environmental temperature of 20 °C (Experiments 1 and 4).

The results of these experiments suggest that improvements in efficiency of laying hens on choice feeding can be expected, and this improvement in the feed efficiency would represent an additional saving in feed costs because the birds fed in this way are able to self-select the appropriate feedstuffs related to their physiological status and level of egg production. However, type of feedstuffs and the form of protein sources are very important in affecting the pattern of feed intake and performance of the choice-fed birds.

The fact is that the overall saving in total feed intake in Experiment 1 (10.4 %; based on whole wheat plus a protein pellet) was greater than in Experiment 4 (2.9 %; whole maize plus a protein meal). These differences support the field work of other workers (e.g., Karunajeewa, 1978a; Desmayati *et al.*, 1983), who indicated that the response of laying hens to choice feeding varied between the types of cereal grains offered. The former author further explained that differences in the CP contents of the grains used may have contributed to the differences in the saving of total feed intake. The same explanation could apply in the current work where savings were greatest with wheat which had the highest CP content (13.0 vs 8.6 %); energy levels were very similar in the two grains (13.2 vs 13.9 MJ ME/kg respectively).

Although there was only a small saving in the mean total feed intake of the choice-fed hens in Experiment 4, the use of whole maize plus a protein source in the meal form is considered to have immediate application in areas such as West Timor, Indonesia, where there is lack in the supply of electricity to process feeds to pellets. Indeed, the grinding process requires 20 KW h/tonne of grain, while processing the feeds to pellets requires another 20 KW h/tonne of feed, plus the energy expenditure for the steam generation necessary for these procedures (Petersen, 1976).

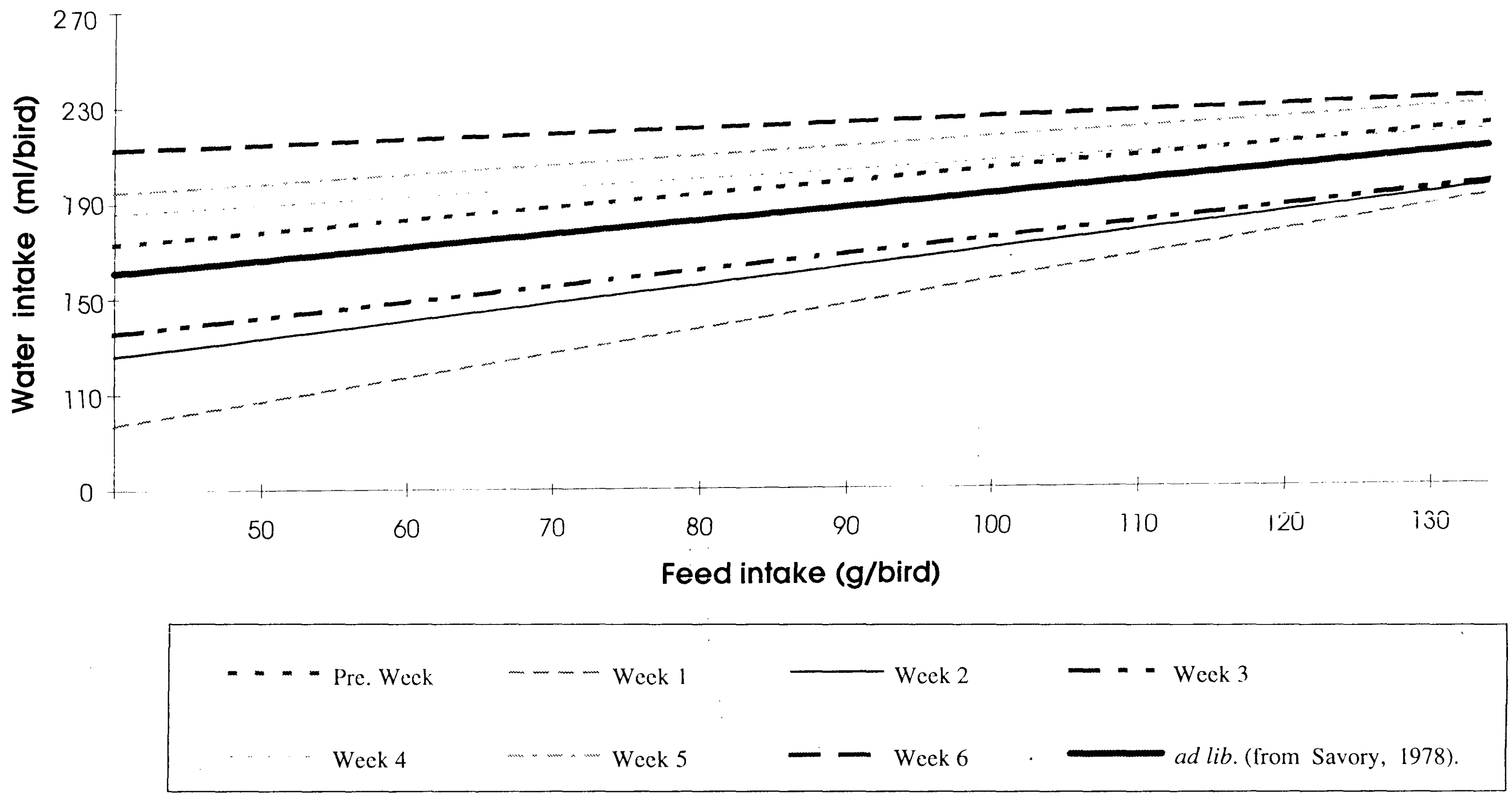

Figure 5. **The relationships between water and feed intakes within weeks in Experiment 7 as compared to the relationship under *ad libitum* conditions reported by Savory (1978).**

The results of Experiments 2 and 5 indicate that at high temperatures, choice feeding can help in solving the problems of decreasing nutrient intake and poor performance that are commonly experienced by laying hens fed a complete diet in the hot environments of the tropics. This occurs because birds fed by self-selection can balance their nutrient intake to more correctly meet their nutrient requirements and thus maintain adequate performance. The current results indicate that birds are able to do this in either a constant high temperature (32 °C; Experiments 2 and 5) or a cyclical hot-temperature regime (e.g. 16 h/d at 20 °C and 8 h/d at 32 °C; Experiment 3). However, any improvement in the choice-fed birds' performance at temperatures such as these has been shown to be dependent mainly on whether they are experienced in choice feeding or not (Mastika, 1987; Forbes and Shariatmadari, 1994). The exact nature and extent of any such "training" needed in choice-feeding is an area which requires further research.

While the cost savings and improved feed efficiency associated with the choice feeding of laying hens at 'normal' temperature, and their maintenance of adequate performance at high temperature, could be of considerable importance in modern layer operations where all-mash diets are normally fed *ad libitum*, choice feeding can offer even more to small-holder farmers in many developing countries in the tropics, especially in South and South-east Asia (including Indonesia), who do not have ready access to chemical analyses of the raw ingredients offered to their birds, and to whom the high cost of processed diets is a considerable burden. Choice feeding allows birds to choose their own nutrient mix, and thus obviates the need for chemical analysis, and as pointed out by (Cumming *et al.*, 1987) there is no longer any need for mechanical feed grinding and mixing. Capital costs can thus be considerably reduced. An additional practical outcome is in a more assured supply of feedstuffs, since home-produced ingredients can readily be utilised.

In West Timor, Indonesia, in particular, where feed, transport and feed-milling facilities are scarce and the need to contain costs is great, choice feeding is thus considered to have the most immediate, and widespread application as an alternative to the use of complete diets for laying hens. Moreover, as oyster-shell grit proved to be a better Ca source than limestone in the current work (Experiment 4) and since it is readily available in West Timor at a lower cost than limestone, the use of oyster-shell grit can further benefit the small-holding poultry farmers in this area. However, the results of Experiments 1 and 2 suggest that further studies are required to improve the shell quality of eggs produced by hens fed oyster-shell grit as a Ca source in the choice-feeding system.

In general , the five experiments quite clearly suggest that choice feeding offers an interesting economic advantage to complete diets because laying hens fed in this way will reduce feed costs, since grinding, mixing and many of the handling procedures associated with mash production are then unnecessary (Karunajeewa, 1978b; Kiiskinen, 1987; Tauson *et al.*, 1991). These experiments also demonstrated that individual hens offered feed ingredients (whole grain, protein pellets and oyster-shell grit) *ad libitum* by choice feeding in a single feeder are able to self-select from those ingredients to compose their own diet, presumably according to their actual needs and production capacity (Emmans, 1975, 1977 and 1982; Karunajeewa, 1978a; Hughes, 1984; Leeson and Summers, 1991; Rose and Kyriazakis, 1991).

3.4.2. **Feed and water restriction.**

From the foregoing results and discussions of Experiments 6 and 7, it can be seen that, when being subjected to feed and water intake restriction for the same short period of time (i.e.: 3 weeks), hens were more responsive to feed restriction than to water restriction. Thus, the improvement in FCR (g feed intake/g egg weight) and water : feed intake ratios (ml water drunk/g feed intake were greater for the birds restricted in feed intake than for those water-restricted

In Experiment 6, the improvement in FCR was greatest in the birds which suffered the most severe feed restriction, and these benefits of feed restriction on feed efficiency support the field reports of Sherwood and Milby (1961). This apparent improvement in feed efficiency would be further enhanced for practical egg producers because restricting the feed intake in commercial sheds also leads to a lowered feed wastage. Feed wastage was not a factor in the current work, where deep feeders with anti-spill lips and side flaps were provided to individual birds as shown in Plate 1.

Since the birds in Experiment 7 showed an overall pattern of reduced water : feed intake ratios when their water intake was restricted, the results of the current study offer an added advantage to producers in improved control of the so-called 'wet droppings' syndrome and consequent problems with odours, flies, disease and difficulty of removal of faeces from the poultry house. Thus restrictedly watered birds could be expected to produce drier faeces, and lead to savings in water costs in layer operations. Thus, it may be of value to impose a limited form of water restriction on hens in areas such as West Timor, Indonesia, where water is often limited in availability during the later stages of the annual dry season.

However, the small number of birds used, and the short period of time of Experiment 7, suggest that the effects of water restriction in laying hens require further investigation. Future experiments should be of at least several month's duration, should include groups of larger size, and if possible should be conducted under practical, field conditions so that feeding, housing and climatic conditions are those actually used by the industry.

As a consequence of water restriction having relatively less effect on feed conversion and egg production than feed restriction, and also because of the generally low cost and ready availability of water in the majority of intensive production areas, there has as yet been no practical application of water restriction to laying hens under commercial conditions. But, as discussed above, it may be of value for controlling the body weights of hens in order to prevent excessive fat accumulation, and it may assist in preventing the "wet-droppings' syndrome.

From a passive point of view, the current results indicate that transitory restrictions in water intake, as might occur during natural day periods, are likely to be of limited influence on egg production as long as intakes do not drop below 80 % of the *ad libitum* level. In contrast, feed restriction has long been a common practice with many commercial egg producers because of its economic advantages in their enterprise through improving feed efficiency and through savings of feed. In addition, any disadvantage of excessive fat deposition in laying birds resulting from over-eating can be prevented by applying feed restriction.

According to Gleaves (1989), feed efficiency has received more attention from egg producers in recent years because of the relatively high cost of feed compared with other production costs. The improvement in feed efficiency was greater in the current work for birds restricted in feed intake than those water-restricted, and as a consequence restricted feeding may be of value to producers in areas such as West Timor, Indonesia, where the feed is often limited, especially in the period immediately before harvest, and because what is available is imported, and indeed expensive.

When feed is in short supply (e.g. before harvest), the results of Experiment 6 also indicate that hens have the capacity to recover quickly, provided full feeding is available for the recovery. However, verification of the effects of feed restriction with a larger number of birds and a longer period of treatment is necessary before estimates of the actual economic advantages of feed restriction can be made and before any practical significance can be attached to the current observations.

As regards the relationships between water and feed intakes, the results clearly indicated that the two parameters were most closely correlated when the water, rather than the feed, intake of birds was restricted (r = 0.79-0.91 vs 0.04-0.39; Tables 49 and 40). These results suggest that restricting water intake of laying hens may be a good way either to control or to reduce the mean feed intake of individual birds to a desired level. Since there was only one previous report (Savory, 1978) available on the relationships between these two parameters under conditions when water intake was restricted, the results of the current study are of special importance. However, further research using a larger number of birds and a longer period of time is needed to study these relationships in detail before practical recommendations can be made.