MEETING THE NUTRITIONAL REQUIREMENTS OF PIGS IN HOT CONDITIONS

W.H. CLOSE

SUMMARY

The thermal components of the environment, through their effect on the animal's heat exchange, influence growth, metabolismand voluntary feed intake. The environmental components with the biggest effect on voluntary feed intake are air temperature, either constant or fluctuating, relative humidity, group size, stocking density and aerial pollution. For growing pigs a 1°C change in temperature reduces ME intake by 0.76 MJ/day, whereas for the other components it is between 0.36 and 0.65 MJ/day. Various management and husbandry devices may be employed to maintain voluntary feed intake and manipulation of the specification and composition of the ration may help to ensure that the energy and protein needs of all classes of pigs for optimum performance are achieved.

INTRODUCTION

It has been demonstrated in many species that the environment within which the animal lives has a major influence on its productivity since it influences both feed intake and the use that the animal makes of the nutrients in the feed for both maintenance and production. These effects are mediated through the animal's heat exchange and are best illustrated in relation to environmental temperature at a fixed energy intake. Under cold conditions the animal's rate of heat loss is high and since more dietary energy is used for thermoregulation, less is available for retention within the body. As the environmental temperature is reduced, heat output is also reduced until a range of temperatures is reached where it is at a minimum. This range is called the thermoneutral range, with the lower and upper limits called the lower and upper critical temperatures, respectively. Within this zone energy retention is optional. Above the zone, and as environmental temperature is increased, the animal's body temperature begins to rise with a concomitant increase in heat production, resulting in incipient hypothermia. If steps are not taken to cool the animal, it will eventually die (Fig. 1).

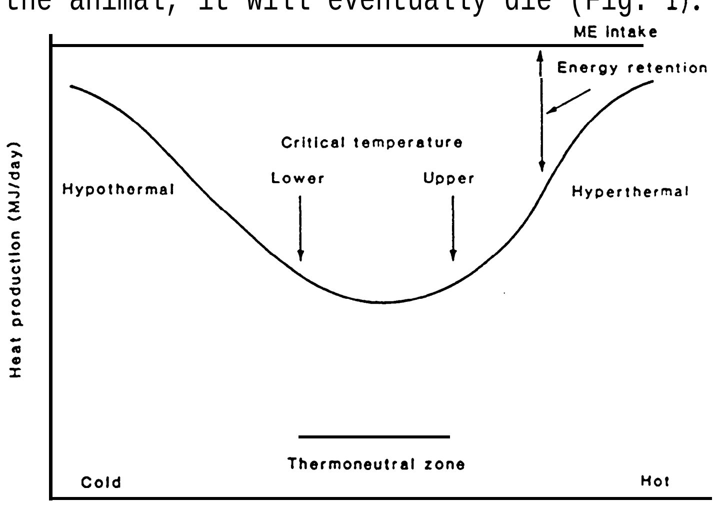

Fig. 1. Diagrammatic representation of the influence of environmental temperature on the rates of heat production and energy retention in growing pigs at a fixed metabolizable energy (ME) intake

The therinal neutral zone is analogous to the zone of optimum productivity and estimates of the lower and upper critical temperature represent estimates of the minimum and maximum temperature at which optimum efficiency of feed utilisation occurs. It is therefore important to know what factors influence critical temperature, to establish how animals adapt to varying environmental circumstances and to determine the consequences for the nutrition and production of pigs if kept outside their zone of thermal neutrality.

The purpose of this paper is therefore to review the primary factors which influence the zone of thermal neutrality, to examine those environmental factors which influence voluntary feed intake and to assess the consequences for the animal's growth and metabolism when the balance between energy intake and energy expenditure varies according to both the nutritional and environmental demands,

FACTORS INFLUENCING LOWER CRITICAL TEMPERATURE

(i) Animal These include body weight, thermal insulation, group size and animal conditions. For example, the new-born piglet has little subcutaneous fat to act as insulation and has an LCT of around 34°C. As the animal increases in size and fatness its Tc decreases to about 28°C at weaning, to 21°C at 20 kg and 18°C at100 kg body weight, respectively. These values refer to pigs kept individually; for groups of pigs they would be some 2° to 5°C lower. Pregnant sows under normal feeding conditions have Tcs of 20°C when kept individually in stalls or 15°C when kept in groups.

(ii) Nutrition Level of feeding is the most important nutritional characteristic influencing Tc so that the higher the dietary energy intake the lower the Tc. Thus pigs fed to appetite have a lower Tc than those fed restrictedly. To reduce the Tc by 1°C, feed intake should be increased by approximately 4 g and 2 g per day per kg body weight, for pigs of 20 and 100 kg body weight, respectively. Type of feed may also be important, with diets containing more energy as fat inducing a lower heat increment of feeding and hence necessitating a higher Tc than those with high fibre content where heat arising from the digestion of fibre may be used to compensate for some of the extra thermoregulatory heat demanded and hence result in a reduction in Tc. The extent to which dietary energy intake influences the thermoneutral zone for all classes of pigs is presented in Table 1.

TABLE 1 The calculated ranges of temperatures appropriate to the thermoneutral zone of pigs of several body weights and different feed intakes (Holmes and Close, 1977)

		ME Intake		
		M	2M	3M
	Body weight (kg)	Thermoneutral zone (°C)		
Growing pig	2	31–33	29–32	29–31
	20	26–33	21–33	17–30
	60	24–32	20–30	16–29
	100	23–32	19–30	14–28
Pregnant sow	(140)			
	Thin	20–30	15–27	11–25
	Fat	19–30	13–27	7–25

(iii) Environment Many environmental factors influence Tc, the most important being the rate of air movement, radiant temperature, relative humidity and floor type. The extent to which variations in any one of these factors influence the environmental requirement, and hence Tc, are presented in Fig. 2. In this example for a group of 60 kg pigs kept under different husbandry and management conditions, at constant feed intake, the range in Tc is between 8 and 25°C; for groups of early-weaned piglets at normal feed intake, the equivalent range is between 23 and 33°C. Since the magnitude of the animals' response to the various thermal components of the environment is known it may be used to calculate the critical temperature of animals living under different housing conditions (Table 2). If the air temperature for each particular set of housing conditions is less than that indicated then energy from the feed is used to compensate for the temperature deficit. This leads to a reduction in growth rate and a deterioration in feed conversion efficiency. More comprehensive reviews on the regulation of heat exchange and factors influencing the critical temperature of pigs are provided by Mount (1968), Close (1981, 1987), and Holmes and Close (1977).

TABLE 2 The lower critical temperature of groups of pigs in relation to differing housing conditions. values appropriate to a feeding level of 3M (M = 440 kJ ME/kg$^{0.75}$ per day)*

	Body weight (kg)		
	20	60	100
Summer – Insulated house – no draughts	14	12	7
– Uninsulated house – no draughts	17	15	11
Winter – Insulated house – no draughts	18	16	13
– Uninsulated house – no draughts	23	20	17
Summer – Insulated house – straw bedding	10	8	2
Winter – Uninsulated house – cold/wet concrete	29	25	22

* A value of 3M corresponds to feed intakes of 1.0, 2.2 and 3.3 kg/day for pigs of 20, 60 and 100 kg body weight, respectively. (1 kg feed = 13.5 MJ DE)

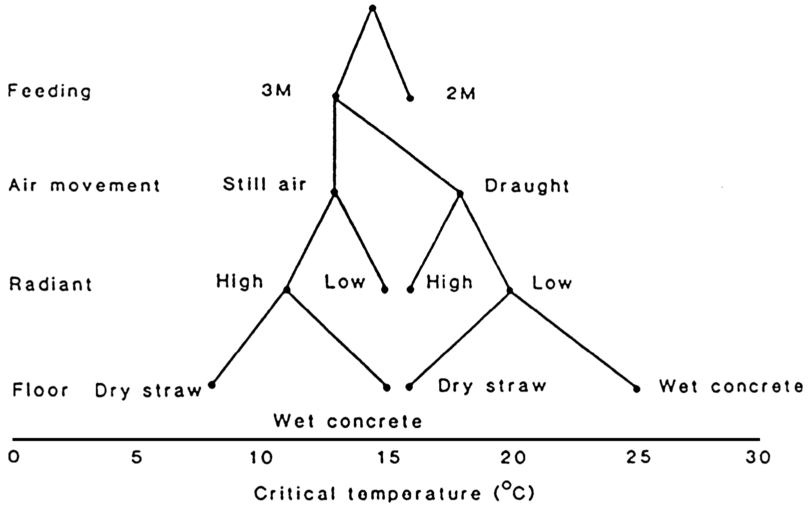

Fig. 2. Adiagrammatic representation of nutritional and environmental factors influencing the critical temperature of a group of 60kg pigs (From Close, 1981, courtesy of Butterworths)

ENVIRONMENT AND FEED INTAKE

(i) Temperature Within the zone of thermal neutrality, the implication is that additional energy is not required to maintain body temperature and hence feed intake is relatively stable. Below the zone, where heat loss increases linearlywith decrease in environmental temperature, feed intake also increases linearly with the additional energy consumed compensating for the increased thermal demand of the cold environment. Above the zone, body temperature begins to rise, and in order to avoid hyperthermia, feed intake declines steeply with increase in temperature and in some instances may fall to zero in animals subjected to thermal stress. As a result of these varying metabolic needs, voluntary feed intake tends to decrease linearly with increase in environmental temperature. For the growing-finishing pig, Verstegen, Brascamp and van der Hel (1978) concluded that feed intake declined at the relatively uniform rate of 21 g/day per 1°C increase in temperature between 5 and 20°C and this represented a 0.8% decrease in feed intake for each 1°C increase in temperature. Between 20 and 25°C, the rate of decline was only 7 g/day per 1°C, equivalent to a 0.3% change per 1°C change in temperature. NRC (1987) included additional data sets, thereby extending the original temperature range of Verstegen et al. (1978) to 30°C, and determined that feed intake decreased by 1.65% for each 1°C change in temperature between 5 and 30°C. From a series of experiments, Close (1989) has determined the relationship between voluntary feed intake, environmental temperature and body weight to be:

$$Y = 9.61 + 0.0(75x_1 + 0.52x_2 - 0.012x_1\, x_2 \quad (R=0.93) \qquad (1)$$

where y is the calculated ME intake (MJ/day), x_1 is the environmental temperature (°C) and x_2 is the animal's body weight (kg). Thus the animal's voluntary feed intake was both temperature- and weight-dependent and over similar temperature ranges decreased by 0.16, 0.64 and 1.12 MJ ME/day per 1°C increase in temperature atbodyweights of 20, 60 and 100 kg, respectively.

Temperature has a greater effect on the voluntary feed intake of the lactating sow than on the growing pig. Lynch (1977) exposed lactating sows to environmental temperatures of 21 and 27°C over a 4-week period and found that feed intake was reduced by 21% at the higher temperature, equivalent to 1.5 MJ ME/day per 1°C change in temperature, More recently Stansbury, McGlone and Tribble (1987) reported that lactating sows consumed less feed and lost more bodyweightat 30°C than at either 25 or 18°C, 4.20 comparedwith 6.46 and 6.13 kg/day, respectively. The calculated rate of dietary energy change between 18 and 30°C was 2.3 MJ ME/day per 1°C. In both experiments the reduced feed intake not only resulted in a greater body weight loss of the sows but also a lower piglet weaning weight even though creep feed was available. This suggests a reduction in milk yield of the sow at the higher temperatures.

unlike the older animal, the newborn piglet cannot increase its energy intake if it becomes cold, even though a high intake of colostrum is vital to ensure sufficient energy supply for thermogenesis. At an ambient temperature of 18-20°C, newborn piglets consumed 37% less colostrum than their littermates at 30-32°C (Le Dividich and Noblet, 1981). The cold conditions therefore impaired the development of thermostability and induced hypothermia in the piglets. This, in turn, dimished the vigour of the piglets leading to less aggressive nursing behaviour. Passive antibody protection was also reduced as a result of the reduction in colostrum-derived immunoglobulin and both mortality and the incidence of diarrhoea were increased (Blecha and Kelley, 1982). This demonstrates the complexity of arranging the environment within the farrowing house to meet the needs of both the sow and the suckling piglet and has lead to the development of localised, thermally-controlled creep areas for the piglets.

The above values relate to environmental temperatures which have been maintained constant throughout each experiment. In practice, temperatures may 'fluctuate and it is important to know to what extent voluntary feed intake may vary under these conditions. The results of Bond, Kelly and Heitman (1963) and Morrison, Heitman and Givens (1975) would suggest that animals can tolerate reasonable temperature variations when the mean of the temperature variation is at their LCT. When the mean temperature is maintained above the animal's optimal temperature, then both feed intake and performance was reduced. It is therefore suggested that too large temperature fluctuations are detrimental and although it is desirable to keep animals within thermal neutrality, fluctuations more than ±5°C around the mean should be avoided especially at the lower end of the thermoneutral zone. Younger animals are more sensitive to temperatute fluctuations than larger animals. Temperatures as high as the higher critical temperature are tolerable, but behavioural characteristics may change and may lead to an increase in vices and in poor pen facilitation.

Since pigs have a marked diurnal pattern of heat production (McCracken and Caldwell, 1980) with the lowest heat production rates occurring at night, it has been suggested that they can tolerate and, indeed, prefer cooler surroundings at night (Carter and Morris, 1982). The practice of reducing night time temperatures has therefore been used in an attempt to stimulate the intake and growth of piglets. Brumm, Shelton and Johnson (1985) exposedweaned piglets to either a constant temperature regime or one where the temperature from 1900 h to 0700 h each day was reduced by 5°C below the daytime temperature. Over the 5-week period of the investigation they recorded a 10% improvement in both the voluntary feed intake and performance of the piglets kept at the reduced nocturnal temperature compared with the constant temperature. The varying temperatures appeared to impose an additional stress on the animals since there was a higher incidence of dead or sick animals. In a subsequent trial Brumm and Shelton (1988) confirmed this increase in voluntary feed intake with reduced nocturnal temperatures. The lack of difference in the overall feed:gain ratio in both experiments may indicate that the diurnal temperature variations did not alter the weaned piglets' need for metabolic heat from dietary sources. Possibly the diurnal temperature regimes may have matched more closely the pig's diurnal variation in body temperature and hence its temperature preferences.

(ii) Other environmental variables An increase in air movement increases heat loss through convection and increases critical temperature. At fixed levels of feeding it has been calculated that each 5 cm/sec increase in windspeed above the boundary layer of air surrounding the animal has the equivalent effect on an individually-housed 30 kg pig as a 1°C decrease in temperature (Mount and Ingram, 1965; Close, Heavens and Brown, 1981). For an individually-housed 60 kg pig the equivalent thermal effect was 10 cm/sec whereas for groups of pigs it was 20 cm/sec (Verstegen and van der Hel, 1974). From the results of Bond, Heitman and Kelly (1965), who exposed ad-libitum fed groups of pigs to different temperature/windspeed combinations, it may be calculated that each 1 cm/sec increase in windspeed at 20°C resulted in a 4 g increase in voluntary feed intake, that is 52 kJ ME/day. Applying the thermal equivalent of 20 cm/sec per 1°C change in temperature (Verstegan and van der Hel, 1974), this equates to a 1.04 MJ/day increase in ME intake and compares with the mean increase of 0.65 MJ/day per 1°C decrease in temperature previously calculated.

Because the pig relies to a great extent on evaporation at high ambient temperatures, relative humidity becomes increasingly important under hot conditions. Ingram (1965) has shown that under hot conditions the rate of evaporative heat loss from the skin of a pig wetted with mud or water was increased to a rate at which all the heat produced by the pig could have been dissipated by evaporation from only a part of the pig's total surface. Morrison, Heitman and Bond (1969) exposed ad-libitum fed, group- housed, 68 kg pigs to various combinations of environmental temperatures and relative humidity and showed that at an environmental temperature of 22°C an increase in relative humidity between 50 and 95% had no effect on voluntary feed intake or growth. However, both feed intake and performance decreased with increasing relative humidity at both 28 and 33°C, with the effects becoming greater as environmental temperature. At these temperatures each 10% increase in relative humidity increased feed intake by 36 g/day, that is 0.47 MJ/day. Holmes and Close (1977) suggested that with respect to its thermal effect, an 18% increase in relative humidity was equivalent to a 1°C increase in temperature. On this basis a 1°C change in temperature associated with a change in relative humidity would decrease voluntary feed intake by 0.84 MJ/day.

There are many reports in the literature indicating the extent to which both group size and space allocation influence voluntary feed intake and performance of pigs. These have been reviewed by Kornegay and Notter (1984) and NRC (1987). Kornegay and Notter (1984) established quadratic equations to determine the relationship between daily feed intake and space allocation for weanling, growing and finishing pigs. From this it may be calculated that each 0.1 m^2 reduction in space allocation results in 50 g/day reduction in feed intake, and assuming a conventional diet containing 13 MJ ME/kg, this is equivalent to a 0.65 MJ/day reduction in ME intake. The space allowance for optimum feed utilisation was 0.4 m^2 for weaned piglets, 0.6 m^2 for growing pigs and 1.0 m^2 for fattening pigs (NRC, 1987). It was similarly calculated that for weaned piglets each additional pig in the pen decreased feed intake by 0.92%; the corresponding values for growing and fattening pigs were 0.25 and 0.32%, respectively.

It is generally recognised that the high levels of obnoxious gases and dust may have detrimental effects upon pig performance, some of which may be mediated through effects associated with a reduction in voluntary feed intake. Stombaugh, Teague and Roller (1969) found significant depressions in the food intake of pigs as ammonia in the air was increased up to 145 ppm. The mean reduction in intake was 3.0 g feed/l ppm increase in concentration, equivalent to 0.36 MJ ME/10 ppm ammonia. Similar results were reported by Drummond, Curtis, Simon and Norton (1980) except that the percentage depression in growth was about double that measured by Stombaugh et al. (1969). Curtis, Anderson, Simon, Jensen, Day and Kelly (1975), on the other hand, employed lower atmospheric concentrations of ammonia and hydrogen sulphide more appropriate to those found in practice, but were unable to detect any difference in either rate of gain or change in tissue structure of the respiratory tract.

Although it is possible that other environmental factors such as the type of floor, absence or presence of bedding, feed receptacle, feed presentation, radiant environment and pen design may influence voluntary feed intake there is little information available to allow their effects to be quantified. The extent to which the major thermal components of the environment influenced voluntary feed intake of the growing pig is summarised in Table 3.

TABLE 3 The extent to which some thermal components of the environment influence the voluntary feed intake of 60 kg growing pigs (Close, 1989)

Environmental component	Change in ME intake (MJ/day)
Air temperature (1°C)	0.65
Air movement (10 cm/sec)	0.52
Relative humidity (10%)	0.47
Ammonia concentration (10 ppm)	0.36
Space allocation (0.1 m^2/pig)	0.65

TEMPERATURE, ENERGY METABOLISM AND GROWTH

Environmental temperature influences the extent to which ME intake is utilised within the body; for maintenance, on the one hand, and energy retention or growth, on the other. At any given intake, exposure to temperatures outside the zone of thermal neutrality increases the animal's energy requirements for maintenance, and when energy intake is fixed, reduces the energy available for retention. However, under ad-libitum feeding conditions, it is possible that the extra energy consumed under cold conditions may more than compensate for the extra thermoregulatory heat demanded. In 35 kg pigs, Close, Mount and Brown (1978) showed that the maximum rate of energy retention, and both protein and fat deposition, was attained at 10°C, the lowest temperature they investigated (Fig. 3). Between 10 and 30°C, ME intake was reduced by 38 $kJ/kg^{0.75}$ per day, but heat loss by only 12 $kJ/kg^{0.75}$ per day, so that the minimum rates of energy retention, and protein and fat deposition, were recorded at 30°C. Thus maximum and minimum growth rates were attained at 10°C and 30°C, respectively. under these ad-libitum feeding conditions the net efficiency of energy utilisation, that is $\Delta ER/\Delta ME$, was 0.68, a value similar to that determined within the zone of thermal neutrality for pigs (ARC, 1981). The maximal gross efficiency of energy utilisation (ER/ME) was measured as 0.49 at 10°C, and this value is similar to that determined by Fuller and Boyne (1972) and Nienaber, Hahn and Yen (1987). It is therefore interesting to note that the maximum gross efficiency of energy utilisation in the pig does not exceed 50% and this is only obtained under conditions of ad-libitum feeding and is independent of environmental temperature.

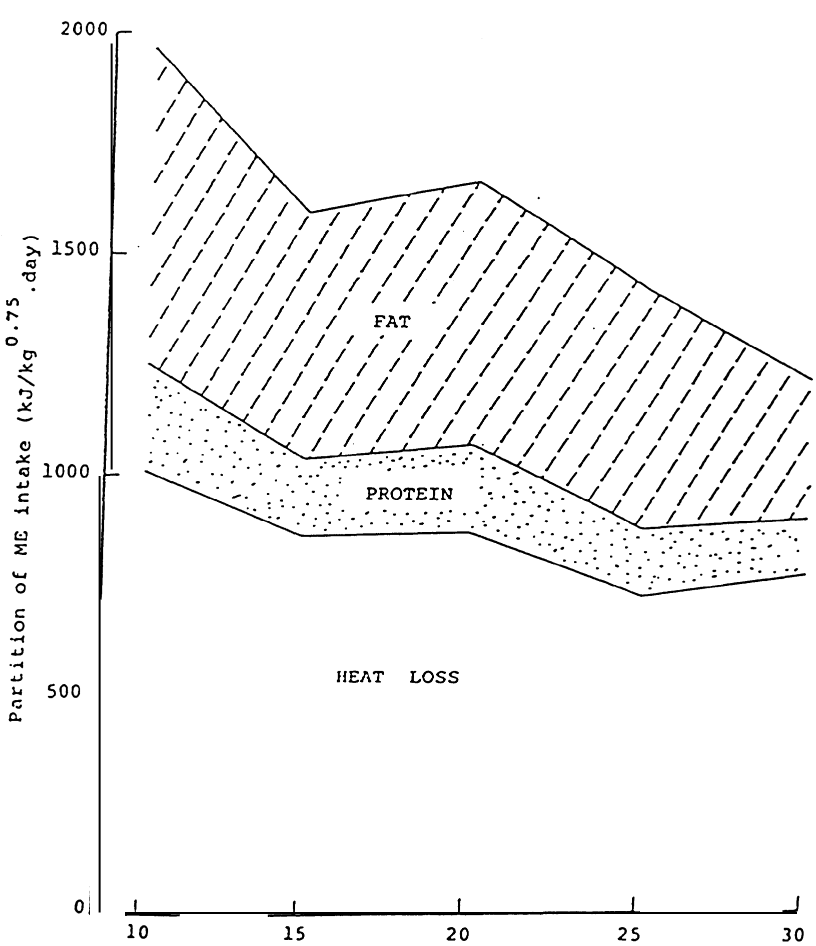

Fig. 3. The influence of environmental temperature on the partition of ME intake in 35 kg pigs fed ad-libitum (Close, 1988)

The changes in the rates of protein and fat deposition Which occur as a 'consequence of exposure to differing environmental temperatures are naturally reflected in the growth and body composition of the animals. Since the deposition of protein is proportionately less retarded by environmental factors than that of fat, it is to be expected that animals will be fattest in a thermoneutral environment and that departures from the zone of thermal neutrality will result in leaner animals. Thus Fuller (1965) showed that after 8 weeks of exposure to different air temperatures, young pigs had maximum rates of both fat and fat-free tissue within the range 20-30°C. Over the growth period 40-90 kg, Nienaber, Hahn and Yen (1987) found under ad-libitum feeding conditions that the carcase fat and protein reached respective minimum and maximum values at 30°C. Conversely, highest fat and lowest protein in the carcase was achieved at 15°C. In this experiment environmental temperature was also shown to significantly influence the weight of the various body organs, and this finding is in accordance with those of Dauncey and Ingram (1983). Campbell and Taverner (1988), on the other hand, have suggested that protein retention is only independent of temperature when pigs are given a protein-deficient diet. Under conditions of protein adequacy, protein deposition is a function of energy intake and therefore dependent upon the extent to which energy is needed for thermoregulatory purposes.

With pigs, the relation between environmental temperature, feed intake and growth rate is of considerable economic importance. Buildings are designed to maintain temperatures which allow the most rapid growth rate consistent with acceptable carcase quality. Figure 4 shows the results of the 4 experiments used to establish the relationship between body weight, voluntary feed intake and ME intake, presented in equation (1). The results of Verstegen, Brascamp and van der Hel (1978) are provided for comparison. In each trial there was a clearly defined range of temperatures within which the pigs grew most rapidly. For the younger animals, the range was between 20 and 25°C; for the older animals it was between 10 and 20°C. It is interesting to note that the lower the temperature at which maximum growth rate occurred, the higher the animals' feed intake, indicating a lowering of the thermoneutral zone with increasing feed intake. Below the optimum there was a varied response in the growth rate of the pigs from the different experiments to environmental temperature. At temperatures above the optimum, growth rate decreased at a rate independent of the body weight of the pigs.

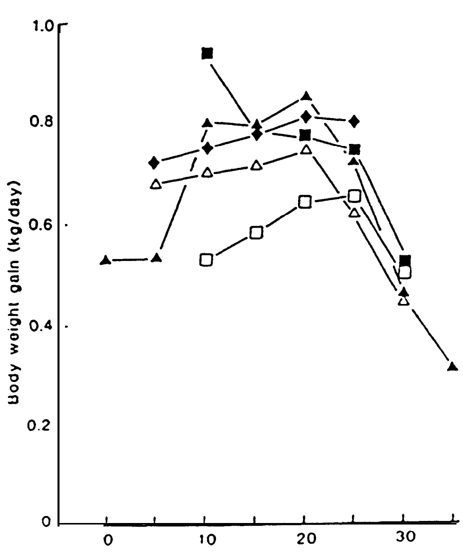

Fig. 4. The influence of the environmental temperature on the body weight gain of ad-libitum fed pigs (Close, 1989)

MEETING THE NUTRITIONAL, REQUIREMENTS OF THEANIMAL

It is generally accepted that most modern pig genotypes can be fed to appetite without major deleterious effects upon carcase fatness, although the propensity to over-fatness in the later periods of growth can be overcome by restriction of feeding. However, it has been established that the thermal components of the environment influence the voluntary feed intake of all classes of pigs to a considerable and variable degree. In practice, the question arises as to how voluntary feed intake may be increased and what are the consequences for productivity should it be limited. This is not a problem under cold conditions, where the animal has the capacity to consume additional feed intake to meet the its extra thermoregulatory demand. under hot conditions, on the other hand, when the air temperature exceeds the upper critical temperature, the primary reaction of the animal is to reduce its feed intake. Since the requirement is to increase evaporative heat loss, the use of such practices as shades, wallows, hoses, automatic sprinklers and the control of relative humidity have been employed under tropical conditions to improve both voluntary feed intake and productivity (Culver, Andrews, Conrad and Noffsinger, 1960; Garrett, Bond and Kelly, 1960; Hsia, Fuller and Koh, 1974; Morrison and Heitman, 1982; Morrison, Heitman, Givens and Bond, 1972; Vajrabukka, Thwaites and Farrell, 1987). Increasing the rate of air movement may also be beneficial since the effect of the high rate of air movement will be to increase the animal's critical temperature to that of its surrounding environment. The beneficial effects of some of these practices on the voluntary feed intake of sows is presented in Table 4.

TABLE 4 The effect of management procedures on the voluntary feed intake and body weight change of lactating sows during heat stress on partially slatted concrete floors
(McGlone, Stansbury and Tribble, 1988)

Water drip	Snout cooler	Feed intake (kg/day)	Body weight change (kg/28 day)
OFF	OFF	3.99	-19.8
OFF	ON	4.86	-14.3
ON	OFF	5.29	-10.8
ON	ON	5.84	-2.0

Nutritionally it may also be possible to influence the voluntary feed intake of pigs under hot conditions by varying dietary composition and there is evidence to suggest that the higher the DE content of the ration, the higher the animal's energy intake. Thus fat has been included in pig diets to improve not only energy concentration, but, since it has a lower heat increment of feeding than carbohydrate, to reduce metabolic heat production, improve intake and indeed increase animal comfort (Britt, 1976; Coffey, Seerley, Funderburke and McCampbell, 1982; Pettigrew, 1981; Stahly and Cromwell, 1979; Stahly Cromwell and Aviotti, 1979). Fibrous diets, on the other hand, have a high heat increment of feeding and this them more suitable for feeding under cold conditions since the additional heat may be used to compensate for some of the extra thermoregulatory heat demanded of the animal (Noblet, Le Dividich and Bikawa, 1985).

Adjustments must be made to the diet to ensure an adequate protein intake by the animal, but there are indications that too high a dietary protein content may also reduce intake. For example, Lynch (1989) fed lactating sows diets containing 160 and 200 g protein/kg diet at both 16 and 28°C and observed 'that sows ate less of the high-protein diet at 28°C but more at 16°C. These results are consistent with those reported by Stahly, Cromwell and Aviotti (1979). This suggests that only highly available sources of protein or the inclusion of synthetic sources of amino acids should be used in diets for pigs in hot environments. Similarly, levels of vitamins and minerals have to be increased if the animal's needs for good growth and reproduction are to be met.

The behavioral responses of animals change to living in a hot environment. Feeding behaviour also changes and in an attempt to reduce the additional energy associated with the digestion and assimilation of nutrients, and activity, animals may eat on a 'little and often' basis rather than a few discreet meals throughout the day. Whatever the circumstances and under conditions where feed intake is variable, the objective must be to sustain as high a level of animal performance as is possible. This may necessitate the formulation of 'nutritional packages' dependent upon the environmental conditions to which the animals are exposed.

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