EARLY POSTNATAL MAMMALIAN GROWTH: PROTEIN AND LIPID SYNTHESIS AS DETERMINED IN VIVO

by

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ABSTRACT

The body composition of twelve piglets during early postnatal growth on two planes of nutrition was determined sequentially *in vivo* by isotope dilution to investigate the pattern of early mammalian growth. Animals were reared artificially from twelve hours after birth on a diet of condensed milk; six animals at a level (high plane) commensurate with rapid growth and six animals at a level of seventy percent of the high plane. At eight weeks of age, the low plane animals were realimented and the subsequent effects of growth and composition were assessed.

Phasic properties of growth and development were investigated as changes in gross body weight, protein, lipid and ash constituents of the body.

A distinct phasic pattern of early protein growth was observed and its interrelationships with phasic changes of body weight discussed. A modified mathematical treatment of growth curves and composition curves is presented and assessed. Daily synthesis of new protein was quantified on a daily basis and its efficiency estimated. Efficiencies of liveweight gain were calculated. Energetic efficiencies of protein and lipid gain were assessed in relation to nutritional plane.

Fundamental control of protein synthesis appears to operate relatively independently of nutritional plane and in a phasic manner as an extension into postnatal life of phasic embryonic growth and development. Control of the growth processes are briefly discussed.

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INTRODUCTION

An appreciation of the growth and compositional changes of the young mammal is an essential requirement in evaluating its nutritional needs during this period.

Throughout recorded history, because of his dependency on animals for food, Man has been indirectly aware of the effects of various environmental influences on the composition of his domestic animals. To the Greeks and Romans, the external form of the human body took precedence over its internal features; however, the development of anatomy first as an art form (circa 15th Century), and three centuries later as a science in its own right, threw much light on the distribution and integrity of tissues and organs and prompted the realization that discrete types of biological materials exist which are common both to Man and to the animals.

Anatomical dissection of animals larger than rodents to evaluate their body composition has often been described as "heroic" because of the extreme care and patience which must be applied. It involves the physical separation of anatomically defined components and has proved to be a valuable tool (Hammond 1921; McMeekan 1941; Palsson and Verges 1952 a, b).

As Alchemy lost some of its mystery and leaned towards respectability and some degree of standardisation in its methodology, it became possible to divide the body into chemically defined compartments relatable to those defined anatomically, and thus relieving some of the extreme tedium and expense of the dissection technique. In 1858,

Lawes and Gilbert killed ten domestic animals and chemically analysed the carcasses. The experiment was classical not only because they were probably the first to use this technique but also because they were the first to realise that the correct nutritional treatment of a growing animal requires an understanding of weight gain in terms of the biochemical composition of the gain. This method, the slaughter technique, has been the principle means employed in obtaining information about changes in the composition of the bodies of animals in the years since Lawes and Gilbert (Moulton 1923; Mitchell and Hamilton 1929; Pomeroy 1941; Spray and Widdowson 1950). It determines the absolute values on which any indirect methods of measurement must be based and the comparison by which indirect methods must be judged. The usefulness of the slaughter experiments in the determination of body composition is limited by the necessity of killing the animal. If sequential changes throughout a growth period are to be measured, then a large number of animals must be employed. Groups of these must then be killed at various chronological (or physiological) times for analysis, and conclusions must be based on averaged results from each group making the assumption that animals of an older group are genetically identical with, or nearly the same animals as, those of a younger group. This technique has proved very useful for noting general changes and differences arising from environmental influences, especially when two or three animals from the same litter can be distributed in each group. But in terms of quantifying the changes occurring during growth, the comparison of one animal with another of the same age or of a different

age leads to serious errors.

Differences between littermates originate in the reproductive tract of the mother. The nutrition of the mother, especially in late pregnancy, influences size at birth. In man, only severe undernutrition will reduce the birth weights of infants (Widdowson 1950). Other factors in the uterine environment contribute to differences at birth. Most noticable in the case of multiparous species are the number of foetuses, the position in the womb, size of placenta and nutrient supply of the maternal circulation, time of fertilization, prematurity and other complex and interrelated factors (Widdowson 1968).

In the application of body conformation measurements to humans, the slaughter technique is obviously unacceptable except when cadavers become available for analysis; unfortunately, the cause of death is often a pathological condition severely affecting the "normal" composition of the body hence information about this aspect of human development is quite limited (Widdowson and Dickerson 1964).

An accurate method of indirect estimation of body composition is useful not only as a means of following changes in experimental animals and humans in relation to health and nutritional status, but might also be useful, as Pearson (1963) has pointed out, in breeding superior strains of meat animals and might even find application in the market value of farm animals.

Indirect measurement in the form of visual appraisal has been employed to judge the "form" of livestock (and humans!) since

Biblical times, and the natural extension of taking various external measurements has been applied to human (Keys and Brozek 1953) and animal (Brody 1945) growth and form. While these anthropometric measurements have yielded much useful information about skeletal growth, some of the interpretations concerning muscle mass and particularly fat distribution have been questioned (Keys and Brozek 1953). Similarly, visual evaluation even to the trained eye leads to inaccurate estimation of an animal's performance (Williams 1952), and has hardly been improved by the age-old practice of filling livestock with water on the way to market.

From the point of view of food production, the practical nutritionist is concerned with the rapid growth and economic production of an acceptable carcass in a reasonably short period of time. Since the value of a carcass is determined in part by the ratio of fat to muscle to bone, the body compositional changes accompanying growth and their relationship to the nutritional environment must be carefully elucidated. A review of the literature (e.g. Reid et al 1968) concerning body composition of the young growing mammal reveals that it is nearly all based on the slaughter technique and therefore compositional differences at different ages represent averages and tend to eliminate the growth and compositional patterns of the individual. The alternative to such methods is to use an indirect method of measuring composition in vivo in the individual animal. Such an approach is a refinement over the slaughter technique only if the error associated with the indirect method is less

than that with the averaging process and analytical error of the slaughter method.

Groves (1960) undertook a study of the growth and composition of suckling pigs using the deuterium oxide dilution method of estimating total body water in a sequential manner as the animals grew. The technique facilitated study of the growth and compositional changes of each individual animal. Good agreement was achieved between body composition determined in vivo by prediction equations derived from total body water and body composition determined shortly afterwards in the same animals by in vitro methods. The study of the individual animal is a technique which tended to lose favour after the introduction and popularisation of statistical techniques and while it is acknowledged that statistics have proved to be of great use when applied properly, there is still the case for detailed study of the individual; averaging processes, for example, often obscure very real individual differences. Some of the results from Groves's work (1960) illustrate compositional changes during growth which are not discernible by slaughter studies and which are not necessarily reflected in the growth curve. A phasic nature of protein growth and cyclic pattern of fat composition were salient features noted in his study. Since the early growth pattern is extremely susceptible to nutritive influences, it is important to discover whether and to what extent changes in body weight and conformation are determined by the amount and composition of the diet. From the point of view of rapidly producing an acceptable animal for slaughter,

the upper limit of rate of growth would appear to be most economical since the faster the gain in weight, the less feed is required, and the overhead cost of maintaining and housing the animal are reduced. Such an approach, however, does not take into consideration the compositional changes; the final carcass may be of lower value due, for example, to excessive fat deposition. Alternatively, nutrient limitations will impose certain compositional changes.

If one can control the environment, particularly the nutrient environment, of the young animal, and measure the resulting growth and composition, then a cause and effect rationale may be applied. In the case of animals weaned normally then isolated from the dam, this is relatively easy, and controlled conditions have provided much useful information of energy metabolism (e.g. Armstrong and Blaxter 1957); however the new born presents many additional problems. It is usually very dependent on the dam, first for disease resistance via colostrum, and then for food. It is desirable that a rapidly growing mammal be chosen for study so that growth changes are definitive, yet the fact that the most rapidly growing species are the most immature at birth renders removal from the dam difficult. Previous nutrition affects growth and body composition; therefore to control the nutritive environment of the animal, it must be separated from the dam.

In this study, the pig was the animal of choice being by far the most immature of the domestic animals at birth and exhibiting very rapid growth during the first few weeks of life. Its growth and

composition is of obvious importance as a food commodity and its size permits laboratory handling while not being too small to be affected by the analytical techniques imposed upon it. It is possible by careful husbandry to grow isolated piglets from several hours after birth. Since rapid early growth is economically important, it is of interest to explore near-maximal growth rates.

When applied to mammalian early postnatal growth, the dilution technique predicts body composition fairly accurately (Wood and Groves 1963). Therefore, this thesis attempts to detail developmental growth as determined in vivo in individual animals and to relate these observations to the nutritional conditions employed.

GROWTH AND DEVELOPMENT

> "The body contains four constituents .... blood, yellow bile, black bile, phlegm. These are the things that make up its constitution and cause its pain and health."
>
> Hippocrates 450-400 B.C.

Mammalian growth is usually considered to start at conception and end when the mature characteristics of the species have been attained. The period from maturity to death is usually considered as senescence.

Although traditionally, growth is considered as a change in size and weight with age, numerous studies from the nineteenth century to the present have shown it to be an extremely complex process which involves not only an increase in body size but also associated changes in form and function of the different parts of the body. Brody (1945) defined growth as "a relatively irreversible time change in the measured dimension" thus allowing for conformational changes (as well as gross changes) by choice of the "measured dimension". Hammond (1952 a) stated:

> "As an animal grows up, two things happen: (i) it increases in weight until mature size is reached; this we shall call growth, and (ii) it changes in its body conformation and shape, and its various functions and faculties come into full being; this we shall call development."

The growth in liveweight of most species when plotted against time appears to follow a sigmoid curve; however most studies involve the imposition of a limited environment, particularly of nutrients, and there is evidence for a phasic pattern of liveweight change

similar to that exhibited by the embryonic chick (Romanoff 1935; Brody 1945) and the deer after puberty (Wood et al 1962). The human growth curve is unique in approximating a double sigmoid shape characterised by a long period of relatively slow growth during adolescence. The chemical synthesis of living material progresses by cell multiplication, enlargement and absorption of material from the environment, the coordination of the growth processes being regulated by the endocrine system. Cells become organised into tissues so that the liveweight gain is the gross expression of combined changes in muscle, bone, fat, organs, viscera and gut fill. Growth therefore represents the interaction between the genotype and the environment. The most important environmental factor limiting the genetic potential is availability of nutrients.

The changes of form of the body accompanying growth are believed to have evolved in land animals for several reasons: gravitational effects necessitate the growth of supporting organs and tissues to enable movement. The development of fat both for thermal regulation and for energy reserves is responsible for major changes in carcass composition while the size, length and surface area of the digestive tract influences the proportions of the viscera in the body. In contrast, the fish has a similar external form and proportions from shortly after hatching to death (Hecht 1916: Groves 1970). The changes in the form and composition of the body is brought about by the differential growth rates of different tissues and parts (Robbins et al 1928; Widdowson 1950). Changes in the

composition of the whole body during growth may reflect: a) similar changes in composition of all tissues; b) different alterations in different tissues; and c) changes in the amount of fat in the body tissues (Macy and Kelly 1961). The different organs of the body develop in an order that appears to be related to their functional necessity. The organs essential for life processes develop first, then the organs associated with post-natal development, and later still, those serving for the storage of nutrient reserves and reproduction. Early in foetal life, the brain and spinal chord develop most rapidly followed by the liver, kidneys, heart and lungs. The alimentary tract develops more in the late foetal stage and early post-natal life. Throughout post-natal life, the carcass is developing more rapidly than the viscera. Hammond (1932 a) using the results of dissection studies of sheep, outlined the fundamental principles of differential or heterogonic growth which account for the changes in conformation of the animal from birth to maturity. Later workers (McMeekan 1940, 1941; Verges 1939 a, b; Palsson and Verges 1952; Wallace 1948) confirmed and extended the theory. In general, the main carcass tissues, bone muscle and fat, attain maximum growth rates in a regular sequence with advancing age in the order bone, muscle, then fat. The theory maintains that growth proceeds as a primary wave anterior-posterior and that a secondary wave starts at the lower parts of the limbs spreading out towards the digits and in towards the lumbar region which is the latest maturing part of the animal. Similarly, within tissues, differential growth occurs following an ordered sequence according to

the heterogonic growth theory. For example, adipose tissue deposits having a physiological significance other than energy storage develop at an earlier stage than storage depots.

The dominant change with age in an animal is the change in overall body size. Therefore it is logical to note the changes in parts and tissues in relation to body size. Huxley (1932) studied the regular changes which take place in the different parts and organs of growing animals from birth to maturity and showed that a useful qualitative description of many of the changes was represented by the allometric equation $Y = ax^b$. This expression indicates that the relative growth rates of the different parts and tissues of the body bears a proportionate relationship to the body as a whole, implying that the form and development of an animal depends solely on its absolute size and not upon the length of time it has taken to reach that size. For this to hold true, it is necessary to make an important distinction between "true" growth of the fat-free body and the deposition of fat. The deposition of fat is for the most part (intrinsic involvement in structural tissues excepted) considered to be a quite separate process to that of true growth, being a process designed to deal with surplus energy. Huxley has shown that this basic relationship applies over a wide range of species and environmental conditions and has put it forward as the allometric theory of relative growth. The relationship of these theories to the effects of nutritional plane on the development of the animal is reviewed later.

The chemical composition of the body changes throughout life from conception to death in a way which substantiates the phasic development of the tissues. Thus, in general, chemical growth is characterised by consecutive phases of mineral, nitrogen and lipid deposition. The most marked change with age is the rapid decrease in the proportion of water in the body. The percentage of protein and ash in the live weight declines only slowly as growth proceeds. The almost inverse relationship between the water and fat content of the body reflects the lower water content of fat (about 10%) compared with that of muscle (about 75%). Friis-Hansen (1958) has partitioned body water into intracellular fluid (ICF) and extracellular fluid (ECF). Studies on the development of the human foetus (Widdowson 1968) indicate that when the ovum is fertilised, the organism is entirely cellular but when the blastocyst is formed 10 days after fertilisation, the extra-cellular fluid forms an important part of it. Foetuses of less than one gram which have been analysed contained 93% to 95% water (Widdowson 1968). After twenty weeks gestation, the total water amounts to 90% of the body weight of which nearly 70% is outside the cells (ECF). By parturition, the total water is about 69% of the body weight or 82% in the lean body mass and about 50% of the total water can be accounted for as ECF (Friis-Hansen 1958). These changes noted in the human fit the hypothesis that post-natal growth occurs mainly through an increase in cell size. The percentage of water in the body at birth depends upon the degree of fatness of the body. Species which have the most fat contain the

least water. Fat is the outstanding variable in the composition of the newly born mammal. The mouse, rat, rabbit and cat contain 1% to 2% fat, the pig about 1%, the guinea pig about 10% while the human baby varies between 11% to as high as 28% (Widdowson 1950). Those species containing little fat are virtually poikilothermic during the first few days of life until subcutaneous fat deposition permits some degree of insulation; the pig is notable in this respect. The deposition or absence of fat during foetal development may be related to the length of the gestatory period; for example, the human and guinea pig have comparatively long periods of development in utero. Since fat appears to be deposited mainly in the latter part of gestation, the nutrient supply to the foetus may exceed its requirements for growth resulting in lipid deposition. In addition, control of maternal circulating lipid levels (Boyd 1935) and placental properties (Widdowson 1950) may be involved. In the foetal pig, the percentage of total lipid remains constant at a low level during most of the gestational period (Gortner 1945). In their ability to survive, the guinea pig and pig are more mature at birth than the rat, mouse and rabbit and less mature than the foal and ruminant offspring; however in terms of physiological age the pig is much less mature than the guinea pig. The concepts of physiological and chronological aging have been considered by Carrel (1931) and Brody (1945). Chronological time is measured in hours, days and years and assumed to flow at the rate of solar time. Carrel (1931) wrote:

"Each human (animal) constitutes a relatively independent

> world in a state of continuous transformation ... The living organism undergoes two classes of changes: rhythmical and reversible, or progressive and irreversible ... The process of aging starts simultaneously with embryonic life. It is expressed by irreversible changes progressing during the entire span of our existence."

He also noted that the rate of physiological aging decreased over the life span. Brody (1945) showed the great similarity in occurrence of physiological events during the life span of different species when plotted on axes of equivalent scale. Since generally, moisture content decreases as protein concentration increases, tending toward a constant value at maturity, Bailey et al (1960) suggested that the protein to water ratio is valid as an index of physiological age in mammals.

In mammals, birds and amphibia, Von Berzold (1857, 1858) noted a decrease in body water until maturity and an increase in organic material which was most rapid in the period immediately following birth or hatching. Murray (1922) concluded that the composition of the fat-free body was constant and Moulton (1923) suggested that on a fat-free basis, the concentrations of water, protein and ash change until a point of "chemical maturity" is attained at which the change becomes rather less as nearly constant composition results. He also noted that animals reach chemical maturity at different ages but that these ages are fairly constant relative to the total life span. However Spray and Widdowson (1951) pointed out that the concentrations of some of the constituents of the body cease to increase before those of other constituents, and

therefore the concept of chemical maturity of the body as a whole can only be applied when all the components have reached a constant level. Pace and Rathbun (1945) claimed that the percentage water content of the fat-free body was constant in guinea pigs, but their conclusions were criticised, (Keys and Brozek 1953; Siri 1956) and fat-free water values appear to range from 72% to 76% (Pearson 1963). After chemical maturity, there is a slight decrease in the water content of the fat-free body with age and a slight increase in percentage of ash and protein.

In studies of the mature and aged mammal, most of which have been restricted to man since animals are normally slaughtered before reaching mature weight, important changes in body composition occur. Complex changes in gross body weight accompany increases of some tissues, notably fat, and decrease of others (Steele et al 1950; Berges et al 1950). Such changes account for the changes in basal metabolic rate which occur during maturity (Keys and Brozek 1953).

Nutrition is generally the dominant environmental feature influencing the expression of growth potential. Whilst reference to micronutrient variation of the diet will be dealt with in a separate section, it seems pertinent at this point, following a review of general growth and composition patterns, to consider the effects of quantitative variation of the diet upon body composition.

The two major macronutrients of a diet are protein and energy. Considering a more or less balanced diet, it is obvious that if an animal is fed less, it grows less rapidly. Evidence of the influence of plane of nutrition on development is based mainly on

the work of Hammond (1932) and his co-workers at Cambridge: McMeekan (1940; 1941) and Pomeroy (1942) in the pig; Palsson and Verges (1952) in the sheep.

It is agreed that the plane of nutrition of an animal influences a) its rate of liveweight gain, b) its rate of development; that is, animals on a high plane of nutrition grow faster than those on a lower plane and furthermore the sequence of developmental changes is accelerated in the former and retarded in the latter. This relationship between rate of liveweight gain and rate of development is to be expected since it is generally agreed that developmental changes are closely associated with overall changes in body weight. Palsson (1955) states:

> ".... a low plane of nutrition during a certain time interval or during the entire growing period not only retards growth and prolongs the growing period, but also distorts the animal's form to a varying extent depending at what stage of development and to what degree it was subjected to under-nutrition."

On a low plane of nutrition the later developing parts and tissues develop only slowly at a much later age and a potentially early maturing animal on a low plane of nutrition becomes late maturing. Child (1920) postulated that body parts, organs or tissue having the highest metabolic rate have the highest priority for nutrients. The descending order of priority for nutrients was generalised by Hammond (1932) as nervous tissue, bone, muscle, and fat. Hammond, applying his theory of heterogonic growth, proposed that by manipulating the nutritional environment of the young animal, it was possible

to change the proportions of the body as a whole and the carcass in particular, and that at any age, restricted nutrition has the greatest retarding effect on those organs and tissues which have their growth intensity at that age. Similarly, Hammond (1932) proposed that if nutrient restriction is very severe, to the extent of a submaintenance ration, the different body parts and tissues are utilised for the maintenance of life in the reverse order of their maturity; therefore fat is lost most readily and then muscle may be depleted to supply nutrients for maintenance. Initially these tissues will be depleted first from the latest maturing depots and regions of the body. Dramatic examples of nutritional deprivation leading to teratogenic effects have been cited by Asling (1969). Not only has the occurrence of defective offspring been related to specific nutritional deprivation of the mother but it has been shown that in pregnant rats on a deficiency diet, when a supplement was given, the timing of administration of this supplement affected the malformations resulting in the young. The extreme of nutritional deprivation before pregnancy is the failure to conceive and during early pregnancy results in reabsorption of the foetus.

It is agreed that nutrition has a general effect on the rate of body development and also a differential effect on the development of fat relative to fat free tissues; however the view that gross changes in conformation can be achieved by retarding or accelerating growth was challenged by Wallace (1948), Wilson (1952; 1954 a), Elsley, McDonald and Fowler (1964), Tulloh (1964), Allden (1968 a, b), and Reid et al (1968). These workers provided evidence that restricted

nutrition causes a more or less uniform retardation of development in agreement with Huxley's allometric theory of growth (1932). In other words, a precise description of the effects of nutrition on growth must make a distinction between the effects of nutrition on the growth of body parts relative to age, and the effects relative to fat-free body weight. Therefore the major influence of variation in nutritional plane is on a) the rate of growth of the body as a whole reflecting mainly the growth of its structural parts, and b) the relative development of fat on the one hand and structural fat-free tissues on the other. Comparisons of growth changes on a chronological age basis tend to confuse these two processes whereas comparisons on the basis of fat-free body weight reveal the effects of nutrition on body composition independent of variation in fatness.

These two approaches can be illustrated by reference to the classical work on the pig by McMeekan (1940) and work on the sheep by Palsson and Verges (1952). These experiments involved the imposition of differences in the plane of nutrition at different stages during the growth of the animals. McMeekan (1940) divided the growth period he studied into two portions and imposed four distinctive nutritional patterns: high-high, high-low, low-high, low-low. The changeover age from one treatment to the other (where applicable) was chosen as sixteen weeks. Several animals were slaughtered at sixteen weeks and others when they reached 200 pounds live weight. Feed restriction between birth and sixteen weeks had a much greater effect on the late maturing tissues and joints than

on those that were early maturing. Many of the differences were between low and high plane pigs at sixteen weeks obviously associated with the large weight differences between the two treatments. However these differences between treatments persisted in animals slaughtered at the same liveweight (200 lbs). In general, the high-high and low-high treatments produced pigs with a greater proportional development of the late maturing fat and a smaller development of the early maturing bone and muscle compared with the high-low and low-low treatments; the animals which received the low plane of nutrition in early life showed these effects to the most marked extent. The experiments of Palsson and Verges (1952) with sheep were similar in design and produced comparable results but the differences were of a smaller magnitude because the lambs varied less in fatness than the pigs.

However, Elsley et al (1964) have compared the results of McMeekan and Palsson and Verges both in the way they were originally expressed as a percentage of total carcass weight, and also after adjustment for the effects of large differences in fat content by relating each tissue component to fat-free body weight. Huxley's allometric equation was found suitable for standardising the measurements. For pigs, there are large differences between treatments in the weight of fat both in relation to total weight and fat-free body weight; but on adjustment for fat free weight, the treatment differences in bone and muscle weight were reduced from 23.5% and 29.3% respectively on a total weight basis, to 4% and 1.3% respectively.

The effect in sheep was similar. Therefore when the effects of variation in fat content were eliminated, little evidence was found of any effect of plane of nutrition on the relative weights of bone and muscle for a given weight of bone and muscle together.

Tulloh (1964) studied the published data on sheep, cattle and pigs based on carcass dissection and found that irrespective of nutritional history, the relation of each of the components to empty body weight can be described by linear regression equations using log values for the variables. When the fat component was regressed, there were greater variations than for muscle and bone. Elsley et al (1964) noted with animals subjected to extreme planes of nutrition that there appeared to be changes in the proportions of a few; he stressed the need for a growth hypothesis to explain the differential effects on conformation of either gross undernutrition or gross overnutrition. Recently, Bryden (1969) following studies on the elephant seal, has postulated that differential development of muscle and bone may occur to meet a functional requirement but that once functional significance has been permanently established, body components conform to the allometric theory. Winik and Noble (1966) suggest that growth consists essentially of two phases. First, cell division predominates, but gradually gives way to cell enlargement, and the change from one phase to the next occurs at different times in different parts and tissues. Therefore, the effect of an imposed nutritional plane on composition and the permanency of the effect depends upon the

phase of cellular growth at that time, essentially in agreement with Hammond (1932).

The pattern of growth markedly influences the shape of the animal's body. This effect on shape is related partly to differential fatness but is also the influence of nutrition on skeletal extension on one hand and muscle development on the other. Waters (1908) showed that when animals are not growing or even losing weight, skeletal extension continues. Therefore although nutrition may not have a differential effect on bone and muscle weight, it may influence the relationship between bone extension and muscle weight. McCance (1960, 1968) noted that in pigs kept at almost constant weight from ten days old to one year that some differential growth of skelton occurred, especially the head and teeth.

To summarise the preceding review, current thought favours Huxley's theory of allometric growth in which body composition appears to be mainly dependent on fat free body weight and largely independent of age and nutritional history, but when food is either restricted to such an extent that bone growth continues at the expense of other tissues, or available to such an extent that fat deposition occurs early, the shape of the animal may be altered to a slight degree.

It is important to distinguish between malnutrition and undernutrition relative to plane of nutrition. Malnutrition may be induced by an unbalanced nutrient intake; undernutrition implies an adequately balanced diet but in deficient amounts. These terms

are by no means exclusive; when undernutrition is severe enough to cause imbalances it is correctly termed malnutrition. It is not proposed to enter into a discussion of malnutrition except to note that protein deficiency in its severest form coupled with a sufficiently good caloric intake results in the disease Kwashiorkor, while severe undernutrition, marasmus, can be described as "an insufficiency of all food" (McCance 1968). These deficiencies are extensively reviewed by McCance and Widdowson (1968).

The degree to which the protein and caloric contents of a diet influence body composition is determined by the protein-calorie ratio. At any specified level of energy intake, if muscle growth is restricted by the inadequacy of the quantity (and balance) of amino acids supplied as dietary protein, animals increase in fatness. If the energy content of the diet is limiting, then the amino acids of dietary protein will be deaminated in the liver and carbon skeleton utilised as an energy source. McKenzie (1964) studied the growth and body composition of rats fed diets containing different energy levels and different protein levels at each energy level. The diets ranged from low protein to high protein at each energy level and the energy levels ranged from low to high. The body composition data indicated an increase in fatness with increasing energy level at any one protein:calorie ratio, and an increase in fatness with decreasing protein:calorie rations at one energy level. McCance (1960, reviewed 1968) maintained young growing pigs at almost constant weight shortly after birth for a period of twelve months.

Some were kept protein deficient, others calorie deficient. Those fed small amounts of a diet containing 18% protein, i.e. calorie deficient, grew very little but showed some differential growth of head and teeth. The pigs subjected to protein deficiency but unlimited calories (as sugar) grew a little at first because the protein-sparing effect of the carbohydrate enabled use of the little protein available to be made. These conditions represent extremes and their usefulness to the student of body composition lies in establishing upper and lower limits of growth of the young animal and confirming certain nutrient priorities.

MATERIALS AND METHODS

I. Animals

Twelve newborn Landrace X Wessex piglets of both sexes were used in two experiments involving five and seven animals respectively. Initially it was planned to study six littermates in each experiment, three on a high plane of nutrition and three on a lower plane; however the death of two piglets, one a "reserve", at the beginning of the first experiment reduced the litter to five, two on a high plane, three on a lower plane. An extra piglet was therefore raised on a high plane during the second experiment. Facilities at present do not allow greater than seven of these animals to be handled comfortably.

After having access to the dam for approximately nine hours after birth to obtain antibody protection, piglets from a single litter were randomly chosen, tranquilised, (acepromazine maleate: 0.5 mg per lb body weight; intramuscular), and transported to the laboratory. The animals were housed in an animal room individually in stainless steel rabbit cages to a body weight of about eight kilograms and then transferred to larger aluminum cages built for the purpose, which allow comfortable growth to twenty-five kilograms. In the second experiment, they were transferred directly to the larger cages. The design specifications of these larger cages are illustrated in Figure 1. Two slits cut in the side of each compartment enabled the raising and lowering of a feeding trough (Figure 1a). The air was changed ten times each hour

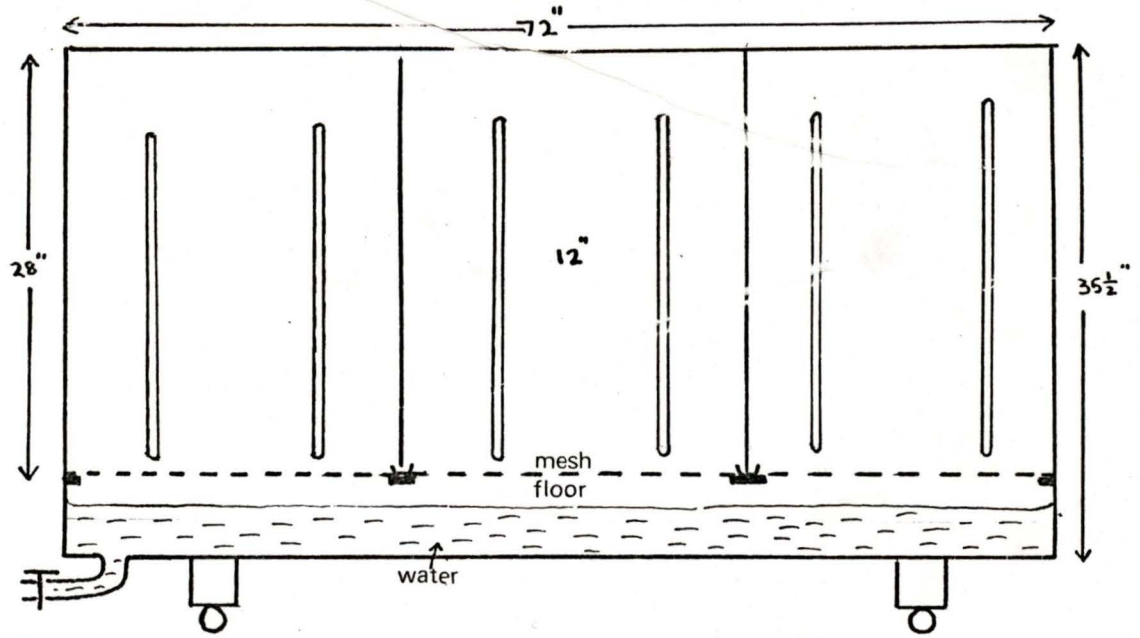
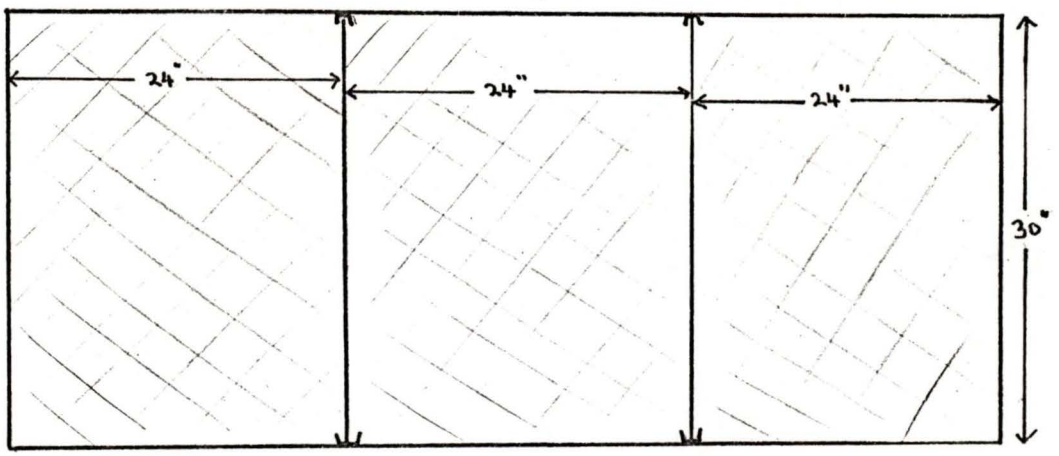


Figure 1. Three-animal housing unit. Side and top elevations.



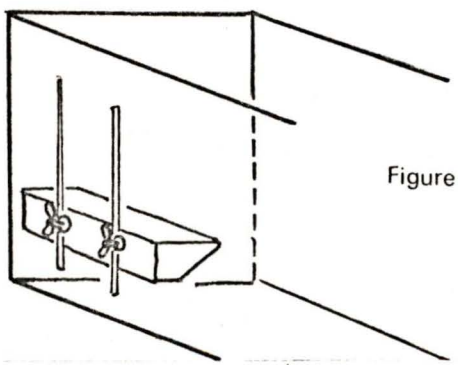


Figure 1a. Feeding arrangement

in the animal room by means of a large extractor fan; this did not however create a draught.

Allocation to nutritional plane was random. Those allocated to a high plane were designated the prefix H while those on a lower nutritional plane are referred to by the prefix L. Therefore, piglets L_1, L_2, L_3, H_1, H_2 were involved in experiment I and L_4, L_5, L_6, H_3, H_4, H_5, H_6 in experiment II.

For normal health and efficiency, body temperature of the homeotherm must be kept within certain limits. The further that body temperature is displaced from normal, the greater is the interference with animal function until if displacement reaches certain limits, breakdown and death occur. The environmental temperature range over which the animal's heat production stays at a minimum, the zone of thermoneutrality, is narrow in the young pig. The newborn pig possesses no brown adipose tissue and is apparently incapable of non-shivering thermogenesis (Leblanc and Mount 1968). Holub (1957) showed that up to 6 days of age, the baby pig is lacking in its capacity to respond to cold by increasing its heat production. At birth the piglet possesses very little subcutaneous fat, and although fat is quickly laid down during the first few weeks, the major means of thermoregulation shortly after birth are contact with the sow and huddling with others of the litter (Mount 1968). In this study, isolated piglets were subject to up to twelve hours of starvation before drinking milk from a trough. It was therefore necessary

to ensure an adequate environmental temperature. The lower critical temperatures of the pig at several body weights are shown in Table I.

TABLE I: LOWER CRITICAL TEMPERATURES OF THE PIG AT SEVERAL BODY WEIGHTS (after Smith 1968; Mount 1969)

Body weight (kg)	Nutrition	Lower critical temperature (°C)
1.5	suckling	+34
4.0	"ad lib" creep	+29
10.0	"ad lib" creep	+19
200.0	adult maintenance	-12

Braude et al (1970) noted no effects on performance when individual piglets were grown from two days of age to twenty eight days at 20°C, or at 30°C gradually reducing to 20°C during the first fourteen days. However it was noted in preliminary experiments by this author that pigs, particularly those of smaller birth weight, showed symptoms of temperature stress when the ambient temperature was maintained at 20°C, and declined to drink milk for several days which occasionally resulted in death by starvation; the metabolic interrelationships and results of some preliminary work related to this is dealt with briefly in a later section. Taking these considerations into account, it was decided to maintain the environmental temperature at 30°C for the first week, then reduce it to 24°C until the end of the second week when it was lowered to 20°C for the remainder of the experiment.

It is desirable when one is measuring compositional changes during growth, to obtain a detailed description of the weight growth curve so that body weight and composition may be compared. Each animal was weighed daily before the morning feed. Piglets up to a body weight of 5 kg were weighed[1] to an accuracy approximately ± 10 g and thereafter[2] to an accuracy of ± 50 g. Throughout the growth period studied, any signs of infection or scouring were treated with penicillin-streptomycin (intramuscular)[3] and oral administration of sulfathiazole.

A body weight of twenty five kilos at 56 days (8 weeks) was considered after perusal of the literature, preliminary experiments and farm data to be a near maximal growth rate. In practice, four pigs on the high-plane of nutrition reached 22 kilos in eight weeks while the remaining two which were affected by several days of scouring reached the same weight several days later. Those on the lower plane of nutrition were realimented at 57 days and grown to weights comparable to the 56 day weights of the high plane pigs. Piglet L_1 weighed 2 kg at birth and although raised on a low plane of nutrition, succeeded in achieving a 56-day weight of 20 kg.

[1]Mettler P10 - Mettler Analytical and Precision Balances, CH-8606 Greifensee-Zurich, Switzerland.

[2]Toledo Scale Co. Ltd. Windsor, Ontario.

[3]20,000 I.U. penicillin G procaine per kilogram of body weight. 1 cc contained 200,000 I.U. penicillin G procaine with 0.25 g streptomycin sulphate.

It is of interest to compare such growth rates with the performance of market pigs, and to this end the figure published by the U. S. National Research Council (1968) for evaluation of growth is reproduced in Figure 1h. The graph

> "is based on published scientific data on feed intake and gains of market pigs"

and

> "indicates the variability actually found, and hence to be expected, in the ages of pigs reaching specific liveweights. The variability results from differences among breeds and groups of pigs, differences among individual pigs and between sexes, and differences in environment".

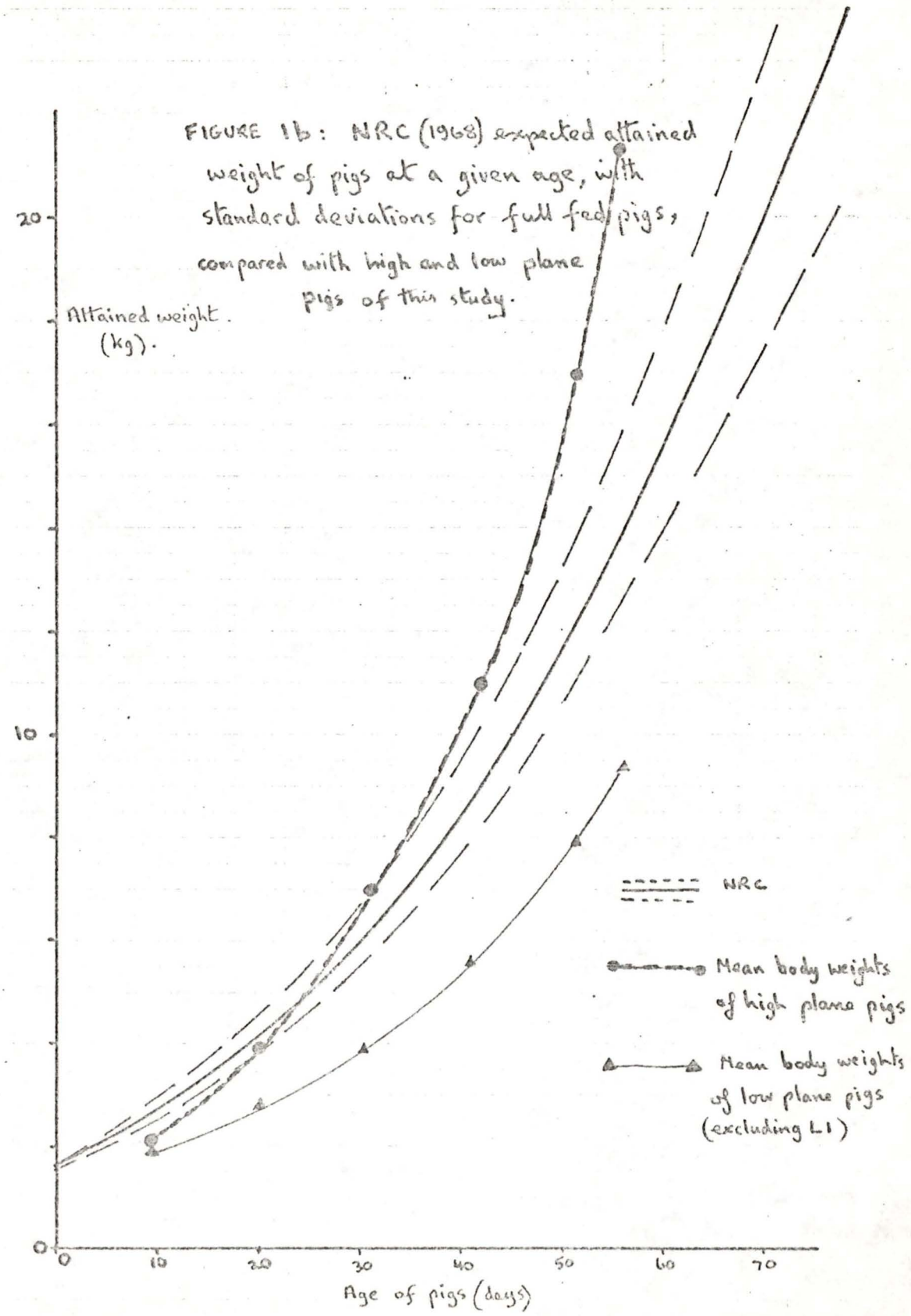
This author feels justified in claiming that the high plane of nutrition employed in this study was indeed near maximal.

Each week, and occasionally after a six day interval, the total body water of individual piglets was measured by the deuterium oxide dilution technique and used to determine body composition.

II. NUTRITION

It has been a general observation that the milk of any one species is especially adapted to the growth of the young of that species (Lusk 1928). This may be true as a general statement, but since the potential for growth is genetically determined by both parents while the milk is provided by only one, and since in many species the amount of milk produced even under ideal conditions does not allow maximum growth of the young, then the corollary, that the growth of the young is adapted to

FIGURE 1b: NRC (1968) expected attained weight of pigs at a given age, with standard deviations for full fed pigs, compared with high and low plane pigs of this study.



the milk of the species may in many instances be valid. The pig is a useful illustration. During the first week or so of suckling the sow, the growth rate of the piglet is extremely high; however, as lactation progresses, a point is reached when the milk yield of the sow is energetically inadequate for the continued rapid growth of its young. Such energetic inadequacy, combined with a condition of hypoferrous anaemia, may result in cessation of growth during this period (Waldern 1954).

In terms of composition, sow's milk is an excellent source of energy and protein and it would seem logical that a diet to provide near maximal growth should approximate the composition of sow's milk. The formulation of synthetic and semi-synthetic diets of high caloric density for young pigs is confounded by the inability of the digestive enzymes to handle dextrins and starches these contain until two to three weeks of age (Bailey et al 1956; Kitts et al 1956). Cow's milk has often been used as a replacement for sow's milk but contains only about one half the energy per unit volume. This problem can partly be overcome by the use of evaporated cow's milk. A comparison of cow and sow milk is presented in Table II. In the last few years, attention has been focussed on the inadequacy of expressing nutrient requirement as a percentage of feed or as a requirement per day. Since most nutrients are related to energy utilisation and those which are not are probably of minor importance, the expression of nutrient

requirement per unit of gross, digestible, or metabolisable energy has been advocated (Lucas and Lodge 1961; Blaxter 1962). Most values in Table II are therefore presented on a per kcalorie basis calculated from data presented by Kon and Cowie (1961).

TABLE II: THE COMPOSITION OF BOVINE AND PORCINE MILK

	average data		
	Cow	Sow	NRC[4]
Total solids (g/100 g)	13.0	20.1	--
Fat (g/100 g)	3.7	8.5	--
Energy (Kcal/litre)	680	1200	3500
Energy (Kcal/kg dry matter)	5090	5970	4375
Protein (mg/Kcal)	50.5	48.3	63.0
Casein (mg/Kcal)	40.1	32.5	--
Ash (mg/Kcal)	11.1	7.8	--
Lactose (mg/Kcal)	68.2	40.0	--
Iron (mg/Kcal)	0.0004	0.0015	--
Magnesium (mg/Kcal)	0.15	--	--
Calcium (mg/Kcal)	1.80	2.20	2.30
Phosphorus (mg/Kcal)	1.47	1.33	1.70
Vitamin A activity (i.u./Kcal)	2.28	0.83	0.63
Vitamin D (i.u./Kcal)	0.029	0.039	0.063
Thiamine (µg/Kcal)	0.59	0.57	0.37
Riboflavin (µg/Kcal)	2.57	1.20	0.86
Nicotinic acid (µg/Kcal)	1.18	7.08	6.30
Pantothenic acid (µg/Kcal)	5.15	3.33	3.70
Vitamin B_6 (µg/Kcal)	0.51	0.17	0.43
Biotin (µg/Kcal)	0.03	0.01	--
Vitamin B_{12} (µg/Kcal)	0.007	0.002	--
Ascorbic acid (mg/Kcal)	0.03	0.11	--
Arginine (mg/Kcal)	1.82	2.83	--
Histidine (mg/Kcal)	1.18	1.33	--
Isoleucine (mg/Kcal)	3.12	2.08	--
Leucine (mg/Kcal)	5.24	3.38	--
Lysine (mg/Kcal	3.78	4.15	--
Methionine (mg/Kcal)	1.28	0.93	--
Phenylalanine (mg/Kcal)	2.54	1.73	--
Threonine (mg/Kcal)	2.24	1.73	--
Valine (mg/Kcal)	3.35	2.90	--
Tryptophan (mg/Kcal)	0.74	0.49	--
Cystine	0.16	0.67	--

[4]U.S. N.R.C. Recommendations: (5-10 kilograms body weight)

It can be seen from Table II that on a per Kcalorie basis, sow's milk adequately supplies essential micronutrients with the possible exceptions of nicotinic and ascorbic acids. Evaporated cow's milk[5], suitably supplemented, was the diet of choice. In terms of caloric density per unit of dry matter, cow's milk is on average inferior to sow's milk, but it was noted from dry matter determinations and from data supplied by the processor that the average caloric density of the evaporated milk used in this study approximated 5300 Kcalories per kilogram dry matter. Evaporated milk is cow's milk after removal of half the water and therefore the nutrient content per kilocalorie is the same as for cow's milk (see Table II). During the preparation of evaporated milk, vitamins C and D are destroyed, but are added back to the commercial product at the rate of 0.61 i.u. vitamin D_3 and 0.09 mg vitamin C per Kcalorie. Both cow and sow's milk is very low in iron and copper and unless supplemented, iron deficiency in the form of hypoferrous anaemia develops. In its most severe form in young piglets this disorder leads to what is commonly known as "thumps"; rapid deep breathing caused by anoxia resulting from the inability of the blood to transport enough oxygen to meet tissue requirements. The anoxia is usually caused by depletion of iron stores, their non-repletion by the diet, and a subsequent inadequate supply of iron to support optimal erythropoiesis in the developing red cell mass. In the rapidly growing piglet, when the total blood volume must be

[5]Pacific Milk Division, Vancouver, B. C.

doubled during the first months with an accompanying great increase in haemoglobin, the piglet literally "bleeds into its own increasing blood volume" (Heath and Patek 1931). Sub-optimal haemoglobin levels lead to limitation of growth by restricting the rate at which oxygen is supplied to the tissues and therefore the rate of energy utilization. Under normal production conditions, depletion of iron reserves occurs after three to eight days. Most iron is received via the placenta before birth. At birth, the newborn pig has a haemoglobin level ranging from 6 to 12 grams per 100 ml blood (grams per cent). It often drops to below 5 grams per cent after a few days (Waldern 1954). By adequate supplementation of iron and copper, haemoglobin values of 12 to 14 g per cent can be established (Waldern 1954; this study) which appear optimal for rapid growth. Woodruff (1958) has pointed out that in many instances of iron deficiency in infants, excessive milk consumption to the exclusion of other foods is the underlying fault. It was therefore necessary to establish an adequate mineral supplement.

The National Academy of Sciences (1968) recommendations of iron for swine varies between 60 mg per kg diet for fortified cow's milk to 12.5 mg per kg of synthetic casein-type diet. Levels in excess of 5 g per kg may be toxic by reducing serum inorganic phosphate and femur ash. For "normal" growth, newborn pigs are reported to require approximately 7 mg of absorbed iron daily. It is important to note that this requirement may be insufficient for animals growing at a somewhat faster rate than "normal". Other

factors being adequate, the growth rate depends on the caloric density of the diet rather than on the mass of diet eaten and therefore mineral requirement should be based either on energy intake or on body weight both of which are more reasonable parameters than age or weight of diet. The composition of liveweight growth is also important in this respect; for example, an increase in the protein compartment of the body will lead to a larger increase of blood volume than will an isocaloric increase of the fat compartment. It is debatable whether such detailed considerations are very important in the sense that if enough iron is provided to enable optimal haemoglobin levels to be established and adequate reserves to develop without toxicity problems, then the requirements for growth are met.

Small quantities of copper are required for the normal formation of haemoglobin (Elvehjem 1935; Hamilton et al 1933), and levels above those needed to meet the metabolic needs of the pig appear to increase live weight gain and improve feed efficiency (Barber et al 1955). This effect is probably attributable to a chemotherapeutic influence on the intestinal flora and is greatest in the absence of antibodies (Woodruff 1958).

The diet used in this study was supplemented with iron (as ferric citrate), magnesium (as magnesium chloride) and copper (as cupric sulphate) at the rate of 40 mg, 270 mg, and 5 mg of the salts per thousand Kcalories of gross energy of the diet respectivly. The blood haemoglobin levels were monitored[6] during the

[6]Haden-Hausser clinical haemoglobinometer

second experiment during which they were maintained between eleven and fourteen grams per cent (Appendix Table II).

Enough evaporated milk was purchased in one batch for use throughout experiment 1 and half of experiment 2. That purchased for the latter part of experiment 2 was not significantly different on analysis from the other (Appendix Table I).

Total daily consumption was determined by the body weight before the morning feed. Milk was offered thrice daily up to a body weight of three kilograms at 09.30, 13.30 and 20.00 hours and thereafter twice daily at 09.30 and 20.00 hours. Pigs fed twice daily were offered half their daily ration at each feed. Milk samples (5 cc) were taken every day, pooled and stored preserved (mercuric chloride) at 4°C.

The baby piglets learned to drink milk from feeding troughs by having their snouts dipped into it every hour. This usually resulted in a lively interest in milk by about eight hours after receipt at the laboratory, although some refused milk for twelve hours.

High levels of milk intake during the first few days has been suggested as a major cause of digestive upsets and mortalities of very young piglets, (Weijers 1965; Braude et al 1970), and therefore the milk offered was gradually stepped up to the required plane during the first four days. While it is acknowledged that such a procedure results in a lower body weight at four days than if the nutritional plane was adhered to from

day one, it must be realised that diarrhoea ("scouring") during this period often leads to death and always leads to loss of weight, or, at best, weight stasis.

Mortality rate was no higher when low quantities of milk were offered (low plane) than when fed to appetite (high plane). Braude et al (1970) noted low mortalities when low or moderate amounts of milk were offered and a higher mortality rate when a level comparable to the high plane used in this study was offered. However, an even higher plane giving slightly better growth rates than reported in this study resulted in a lower incidence of mortality. The hypothesis that overfeeding results in an increased mortality rate requires further investigation (Braude et al 1970).

Planes of Nutrition

Maximum voluntary milk intake varies in a curvilinear manner with body weight. Attention has been drawn to the fact that the opportunity to consume milk ad libitum does not necessarily lead to maximal intake (Leche 1964). There occurs a great variation in fluid intake on consecutive days especially at higher weights. The net effect of overeating followed by refusal of part of the next feed is an overall lowered milk intake due to digestive upsets than feeding to a fixed plane. The problem is to determine a maximum intake plane. An empirical approach was employed. The curvilinear relationship of nutrient intake to body weight suggests (Kleiber 1961) that voluntary intake is related to metabolic size and can be described by an equation of the type:

Milk intake = aW^b a, b constants, W = body weight kg.

The constants were evaluated in preliminary experiments using 6 animals yielding the equation:

$$MI.cc = 255\ Wkg^{.912}.$$

This level of feeding was employed as the high plane in experiment 1. Data compiled from experiment 1 indicated that at low body weights the piglets might have eaten more, while at higher body weights part of the milk offered was refused. Such considerations resulted in a revised equation for the second experiment:

$$MIcc = 285\ Wkg^{.80}.$$

Interesting changes in the compositional growth pattern occur during the first ten kilograms of weight gain (Wood and Groves 1963; Wood 1964). It was therefore desirable for comparative purposes to grow the low plane animals to at least ten kilograms. By reduction of the constant "a" in the equations, milk intake of low plane animals is a constant proportion of the high plane. Seventy percent of the high plane intake was chosen to allow adequate gain but on a distinctly lower plane. The equations for low plane were therefore:

$$\text{experiment 1:}\quad MIcc = 178\ Wkg^{.912}$$

$$\text{experiment 2:}\quad MIcc = 200\ Wkg^{.80}.$$

In practice, slight deviations from the high feeding plane occurred, occasionally because of scouring, or because of anaesthetic after-

TABLE III: HIGH PLANE OF NUTRITION: REGRESSION EQUATIONS OF ACTUAL MILK INTAKE WITH BODY WEIGHT

Y = cc milk consumed

W = body weight, kg.

Animal	Range of W	Regression equation
H_1	$W \leqslant 6.8$	$Y = 255\ W^{.912}$
	$W > 6.8$	$Y = 375\ W^{.702}$
H_2	$W \leqslant 15.2$	$Y = 255\ W^{.912}$
	$W > 15.2$	$Y = 1345\ W^{.135}$
H_3	all	$Y = 300.8\ W^{.762}$
H_4	$W \leqslant 13.5$	$Y = 272\ W^{.802}$
	$W > 13.5$	$Y = 211\ W^{.908}$
H_5	all	$Y = 282\ W^{.808}$
H_6	all	$Y = 290\ W^{.737}$

effects, and at other times because the nutritional requirements of the animal had been met. Therefore, the actual intakes throughout the experimental period were regressed against body weight and these equations used in the calculation of efficiencies of live-weight gain and protein synthesis, and energetic efficiency. The equations are summarised in Table III. Those fed according to the low plane of nutrition adhered exactly to the standard and the equations shown above were used for calculations.

The indirect determination of body composition

Besides anthropometric methods, approaches to indirect measurement of body composition have been directed toward body density measurements and dilution methods.

Following the work of Murray (1922) and Moulton (1923) a mature animal can be considered to consist of two compartments; a fat and fat-free portion. If the density of each portion is known, an estimating equation based on body density may be derived (Rathbun and Pace 1945; Morales et al 1945; Keys and Brozek 1953). However the composition of the fat-free body is not constant in young growing animals and density measurements are less accurate in predicting the composition of the immature. Early attempts at the density method neglected lung volume (Spivak 1915), but on correction for this, the method is reasonably useful for determining fatness and leanness (Behnke et al 1942). The displacement

of air rather than water to measure density eliminates lung space correction (Wedgewood et al 1953) as does a modification of this method, helium dilution (Walser and Stein 1953; Siri 1956 a). Densitometry has had wide application in the study of obesity but its limitations have been stated (Pearson 1963) to the effect that the variation associated with predicting body composition from density measurements is too great to permit the precise determination of the composition of a single individual and therefore the method has its usefulness in detecting differences between small groups of animals.

The introduction of dilution techniques has permitted a better assessment of changes in the composition of the individual. Essentially, the dilution procedure consists of uniform incorporation of a known quantity of a tracer into the materials to be analysed followed by a precise measurement of its dilution. It has been suggested (Finlayson 1969) that tracers have done for biochemistry and its allied sciences what the microscope did for biology making accessible realms which were previously inaccessible to direct experimentation.

The technique was first used to measure the total body water of man and was prompted by the physicist H. J. Moseley over a cup of tea at the Manchester Physics Laboratory. Moseley ...

> "... then expressed the wish that an indicator might be found that would allow one to determine the fate of the individual water molecules contained in the cup of tea consumed. Even a man of the vision of H. J. G. Moseley considered this hope to be a highly

Utopian one."

(Hevesey and Hofer 1934)

These same authors were the first to try out the technique by inbibing a solute (heavy water) and measuring the concentration in urine from which they estimated the deuterium oxide space and the average rate of turnover of body water. Publication of Hevesey and Hofer's paper prompted McDougall (1934) to report the results of an experiment which had been conducted earlier to determine deuterium oxide space by assuming complete distribution of the marker one hour after its injection into the jejunal loops of two rats.

Since in this study, the total body water of each animal was determined during early growth, this aspect of the dilution technique will be explored fully; it should be borne in mind however that the dilution technique has been frequently employed to determine total cell mass by potassium dilution, and various other "spaces" including plasma volume, interstitial water and extracellular water by solutes such as sodium thiocyanate, thiosulphate and Evans blue dye.

It was perhaps logical that heavy water be chosen as the first marker for total distribution throughout the body water because of its close similarity to ordinary water. However, for measurements of body water, an "ideal" solute should possess the following characteristics:

a) Even and rapid distribution through the entire body water;

b) Non-toxicity in required doses;

c) Slow rate of metabolic turnover and low excretion;

d) Accurate and convenient estimation of its concentration in the plasma or derivative thereof;

(Soberman et al 1949)

e) Not be absorbed on, be combined with, or be destroyed by other constituents of the body.

(Keys and Brozek 1953)

Many solutes satisfy most of these criteria but for sequential determinations, none satisfies them all. Others have properties which disqualify them as useful solutes. For example, glycerol and alcohol tend to be distributed in the total body water but are metabolised very rapidly and at a variable rate. Furthermore, alcohol is soluble in water and fat and cannot therefore be used to differentiate the two body compartments. Urea tends to be distributed in body tissues in proportion to their water content (Marshall and Davies 1914; Painter 1940) and determination of the "urea space" has been used as a valid physiological index by many workers, notably McCance and Widdowson (1951), Kornberg and Davies (1952), Bradbury (1961), with reasonable results. Use of the urea space as a measure of total body water has been criticised by Pace et al (1947) and Brodie (1951) on the basis of a report that the distribution ratio of urea in the water of blood cells and plasma is not exactly unity (Ralls 1943). However, San Pietro and Rittenberg (1953) also used N^{15} labelled urea, and deuterium dilution comparisons indicate some justification in the use of urea dilution.

Several markers have been used which were thought to hold

some relationship to total body water. These include thiourea (Danowski 1944), sulfanilamide, and acetyl sulfanilamide (Painter 1940). Little use has been made of these relationships.

Of the remainder, antipyrene (Brodie et al 1949; Soberman et al 1949; Garrett et al 1959), N-acetyl-4-amino antipyrene (Brodie 1951; Reid et al 1957; 1958), tritiated water (Reid et al 1948, Pace et al 1947; Done and Payne 1957) and deuterium oxide most closely meet the requirements of the "ideal marker". N-acetyl-4-amino antipyrene is believed superior to antipyrene which has been criticised for its variable rate of metabolism, slow equilibration during obesity and selective binding by proteins (Garrett 1959). With the onset of rapid development in mass spectrometry, liquid scintillation and availability of isotopes, most solutes investigated with the exception of deuterated and tritiated water have been discarded.

Tritiated water gained popularity in compositional studies when technology developed reliable assay of small samples of radioactivity, (circa 1960). Tritium water and heavy water appear to measure the same body water volume in man. Exchange with labile hydrogen in organic constituents of the body appears to occur (Prentice et al 1952). The exchange of tritium is small in fat, greater in muscles and gut, and large in liver, kidney, and plasma solids (Keys and Brozek 1953), and leads to an overestimation of body water of 0.5 to 4.0 percent (Prentice et al 1952). Repeated use of tritiated water with its long half life makes it hazardous

and inconvenient for sequential studies. In addition, it is probable that its kinetics are more different from ordinary water than is deuterated water.

Deuterium oxide meets all the requirements of a marker for the dilution method except for its tendency to overestimate total body water. On the other hand, it has been reported that the water content by dessication was not appreciably different from that derived by deuterium dilution (Moore 1946; Reid et al 1958; Groves 1960). The possibility of error arising during dessication appears never to have been considered in the literature; the conflicting opinions as to deuterium overestimation may lie in different drying techniques.

Since it has been repeatedly shown that the heavy water dilution volume of the body corresponds closely to what might be expected from other information and reasonable assumptions, it was the solute of choice in this study. The broad pathways of research with deuterium oxide have been partitioned by Panaretto (1968):

a) Volume of distribution, equilibration time with total body water, and turnover rate determined;
b) Deuterium space was compared with other indirect methods;
c) Determination of total body water in various pathological states;
d) Energy balance studies;
e) Exchange between D and tissue H ions.

Heavy water reaches equilibrium in the body as HDO:

$$H_2O + D_2O \rightleftharpoons 2HDO$$

$$Keg = \frac{[HDO]^2}{[H_2O][D_2O]} = 3.8 \text{ at } 25°C \text{ (Washburn et al 1953).}$$

Equilibration time in man is approximately 60 minutes after intravenous injection of heavy water. In the growing pig, it appears to be a function of body weight (Groves and Wood 1965) requiring up to two hours in very small pigs (1-8 kg) and three to four hours in larger animals (up to 25 kg) when injected intraperitoneally.

Heavy water does not appear to pass across the bladder wall and this water space is not normally included in the total body water measurement, although glomerular filtration continues and via this pathway some isotope enters the bladder.

Measurement of Deuterium oxide in water

It is desirable to use a technique for the determination of deuterium oxide in blood water which is both accurate and reliable without being too expensive. Since the marker is diluted and therefore small quantities of it are measured, low errors of measurement may lead to high margins of error in the total body water. Primarily for this reason, most methods tested including freezing point elevation (Reaser and Burch 1958; Graystone et al 1967; Garry et al 1968), infra-red absorption (Graystone 1967) and gas chromatography (Mendez et al 1970), have been discarded in favour of the more accurate techniques of mass spectrometry and densitometry.

Mass spectrometry is somewhat in favour at present probably because of the increased availability of equipment and because of some of the practical difficulties associated with densitometric techniques. In this study, the falling drop method first suggested by Barbour and Hamilton (1926) and used extensively by Vogt and Hamilton (1935), and Keston, Rittenberg and Schoenheimer (1937) was used. Approximately every decade the falling drop technique is reviewed; thus Schloerb et al (1951), Hytten et al (1961) and Clarke (1969).

The density of deuterium oxide is 10.7 per cent greater than that of ordinary water and therefore a method of analysis in which purified blood water containing heavy water is permitted to fall through a non-miscible medium of a slightly lower density than water is employed. The usual medium, orthofluorotoluene, has

a middle fraction with a density of 0.9996 at 26.8°C.

The velocity of fall of a body through a non-miscible medium at a given temperature is expressed by Stoke's Law as:

$$V = \frac{2\ g\ a^2\ (\rho_1 - \rho_2)}{9\ \eta}$$

V = terminal velocity (cm per sec)
g = gravitational acceleration (cm per sec).

ρ_1 and ρ_2 are the densities of the sphere and medium respectively.

η = viscosity of the medium dyne - sec per cm^2.

Therefore the reciprocal of time of fall (seconds) is proportional to concentration of deuterium oxide in the water sample at a given temperature. It should be noted that Stoke's law is for rigid spheres moving in a boundless medium; however at low concentrations of heavy water (0 to 0.8%), the relationship of reciprocal time of fall to percent deuterium oxide in the sample assumes a linear relationship (Keston et al 1937; Clarke 1969). The range of concentrations encountered in this study was 0 to 0.30% heavy water. A standard curve at two different temperatures to demonstrate linearity under the present experimental conditions is shown in appendix Figure 1.

The falling-drop apparatus

a) Constant temperature water bath

The water bath essentially conforms to the design proposed by Popjak (1950). It consisted of a double-walled fibreglass-insulated plywood tank of overall dimensions 3 feet by 2 feet by 9 inches and capacity 200 litres. Temperature was controlled at 27°C

by two heating coils (500 W and 1000 W) attached to a Colora thermostat and cooling coil through which passed water at 13°C at the rate of approximately 1 litre per minute. A double-bladed stirrer run by a beam-mounted heavy-duty 1/2 h.p. motor ensured rapid and efficient distribution of heat throughout the medium. Into the front and rear walls were cut slit-windows, the front window for observation of the dropping tube, the rear window to facilitate its illumination. Temperature as measurable with a Beckman Thermometer was held constant at $\pm$ 0.002°C.

b) The dropping-tube

The drop was timed over a fall of 20 centimetres; however to ensure that it reaches terminal velocity before timing commences, the 20 centimetre timing range was located some 15 centimetres below the level of orthofluorotoluene in the tube. The overall length of the dropping tube was about 40 centimetres, the lower end terminating in a bulb-reservoir and stopcock to facilitate drainage. The internal diameter of the tube was 1 cm. The whole tube was enclosed in a water-tight glass tube to cushion any relatively adverse changes in bath temperature. The insides of the dropping tube was coated with Dricote[7] silicone compound preventing adhesion of the drop to the walls of the tube. The tube and its envelope were attached by rubber tubing to a Dexion steel strip which was securely bolted in a vertical position behind the front window of the bath. Orthofluorotoluene filled the dropping tube to within about 4 cm of the bath water surface.

[7]Dricote spray - Fisher Scientific Co., N. J.

c) Sample application

An Eppendorf[8] pipette with disposable tips set to deliver a volume of 10 λ at 25°C was used. This proved consistently accurate and entirely satisfactory.

Before each series of drops, linearity of the standard curve was checked and in addition the unknown was dropped between two drops of known deuterium oxide content. The time of fall over the dropping range was measured to one-hundredth of a second[9] and each sample was measured at least five times.

The level of orthofluorotoluene in the dropping tube was periodically adjusted for displacement caused by the drops.

Percentage of heavy water in an unknown was then calculated as:

$$\frac{(\text{time of fall of unknown})^{-1} - (\text{time of fall of lower standard})^{-1}}{(\text{time of fall of upper standard})^{-1} - (\text{time of fall of lower standard})^{-1}} \times$$

X difference in % heavy water of standard + % heavy water in lower standard.

Standards were made up gravimetrically using 99.74% pure deuterium oxide and doubly distilled water in 100 ml volumetric flasks. After approximately 6 weeks of use, new standards were prepared. Although pure water normally contains 0.015 atoms per cent deuterium ozide, this fraction is common to both standards and to blood waters and can therefore be neglected.

[8]Brinkmann Instruments (Canada) Ltd., Toronto.

[9]A. W. Haydon Co., Waterbury, Connecticut, U.S.A.

Although Keston et al (1937) emphasised that the axis of the dropping tube must be vertical, Schloerb et al (1951) were unable to produce any differences in dropping times up to 35° from verticality. In this study, the tube was set vertical with the aid of a spirit level.

Maintenance of constant temperature ± 0.002°C was the major factor influencing accuracy of measurement of a series of drops. By determining the unknown both from the standard curve and from two standards, temperature fluctuations could be monitored. Once the apparatus had "settled down" after two or three hours of running, temperature fluctuations over a several-hour period were rare. It is doubtful whether the slight fluctuations in water bath temperature occurred to the same degree in the dropping tube because of the air envelope surrounding it. Clarke (1969) reviewed the factors influencing accuracy of the falling drop method and pointed out the importance of low temperature fluctuation. She set a fluctuation of 0.002°C as the maximum permissible variation.

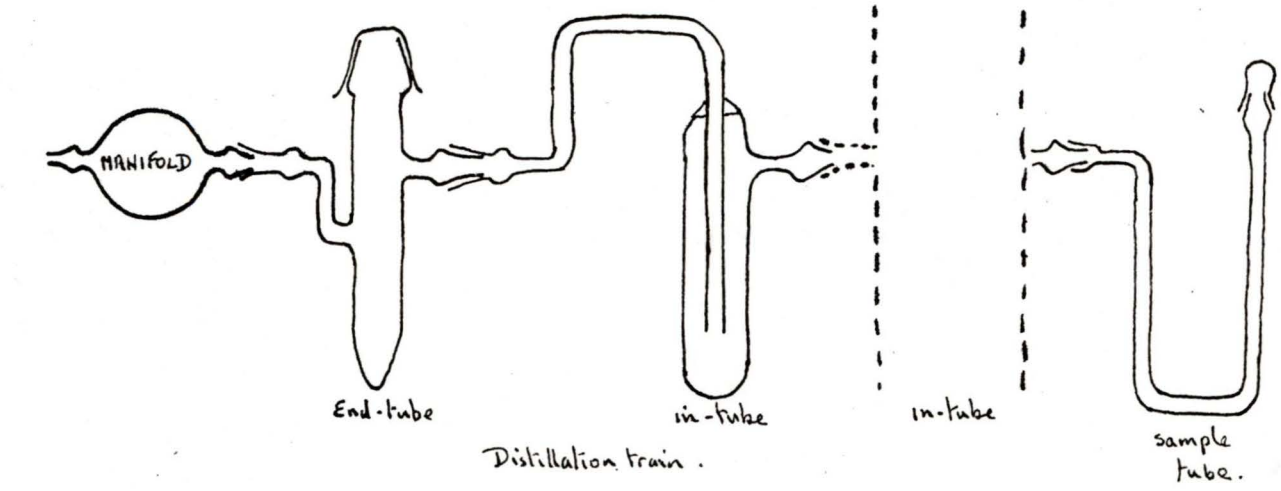
Purification of Blood Samples

Purification of water from the serum samples has to be effected prior to the measurement of deuterium oxide content. It was first thought that this step might be unnecessary, but Schloerb et al (1951) found that impurities of the order of 10^{-5} grams per hundred millilitres will cause a measurable alteration in the dropping time. There is a claim (Mendez 1970) that raw saliva samples assayed for heavy water content by gas chromatography

are not significantly different to their respective condensates obtained by lyophilisation.

The object of the purification step is to obtain an aliquot of pure water from the blood fluid without fractionating the H and D isotopes and without contamination by impurities. Vacuum distillation with various reagents including potassium permanganate, sodium peroxide, chromic oxide, powdered charcoal and calcium oxide (Finger-Eriksen et al 1936; Keston et al 1937; Cohn 1946) has been found to be no more accurate than double vacuum distillation without chemical reagents (Schloerb et al 1951). The latter method with virtually no modification was used in this study. The layout of the distillation system is shown in Figure 1c. A six-outlet manifold linked three pairs of distillation trains enabling six samples to be purified simultaneously. Each unit consisted of a glass shell containing the sample attached to an "in-tube" in series with another "in-tube" in series with an "end-tube" in which the purified sample was finally collected. The end-tube was connected directly to the manifold. Thinly greased ground glass joints connected all tubes. Between the manifold and vacuum pump was placed a liquid nitrogen moisture trap and calcium chloride dry air inlet facility.

The system was first evacuated and liquid nitrogen placed under the moisture trap. After one hour, dry air was let in and 0.5 ml of blood serum introduced into the sample shell then quickly frozen by brief immersion of the shell in



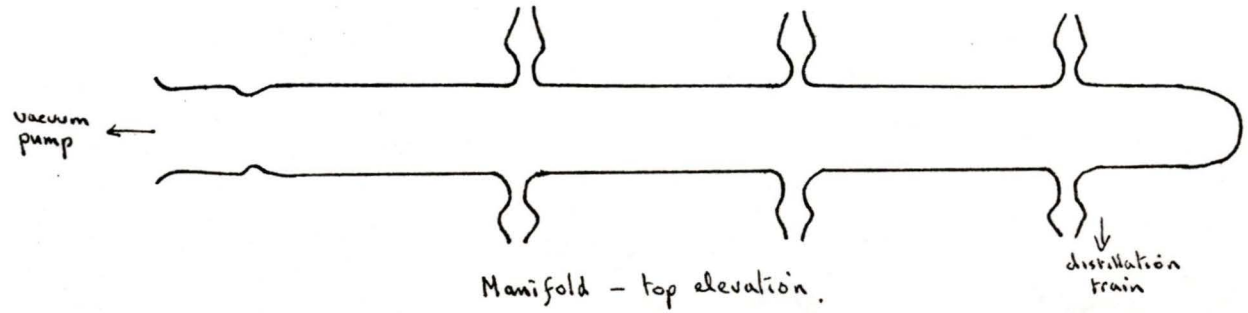


Figure 1c : Purification train for deuterium oxide analyses

(After Schloerb et al 1951)

liquid nitrogen. The system was then evacuated and the first in-tube immersed in liquid nitrogen and about half the sample vacuum distilled into the first in-tube. The freezing mixture was removed, dry air admitted and the sample melted. The sample shell was then removed and remaining sample discarded. The first in-tube was immersed in water at about 30°C and the second in-tube in liquid nitrogen. The apparatus was then slowly evacuated and the sample distilled to dryness into the second in-tube. The process was repeated, the final sample being collected in the end-tube. The sample was allowed to melt then pipetted into a vial and stored frozen until required for assay.

To ensure as little contamination as possible, all glassware was soaked in acid-alcohol then washed several times with distilled water and finally with double-distilled water before drying. The system differs from that of Schloerb et al only in that one extra in-tube per distillation train was used, and liquid nitrogen instead of ice-alcohol used as the freezing mixture.

The in-vivo determination of body water in the Piglet

The piglets were tranquilised by intramuscular injection of acepromazine maleate (Atravet 1.5 mg per kg body weight). An initial sample of blood (about 2 cc) was removed by cardiac puncture (Vacutainer[10]) up to a body weight of about 3 kg and thereafter from an ear or tail vein. A measured dose of 99.74%

[10]Vacutainer - Becton, Dickinson & Co., New Jersey, U.S.A.

deuterium oxide was then injected intraperitoneally (2 cc per kilogram estimated body water). A second blood sample was removed after equilibration of the heavy water with the total body water. Equilibration times at different body weights were followed according to Groves and Wood (1965). Blood collected was allowed to stand for several minutes, the clot ringed, spun down, and serum aspirated into screw-topped vials and frozen stored until the blood water was purified by vacuum distillation.

"Normal" turnover of body water in the human is about thirteen days (Hevesy and Hofer 1934). There is a similar rate of turnover in the young pig and therefore from week to week there is a residual carryover of heavy water from the previous week. By determining the deuterium oxide content of the initial blood sample during each assay the carryover can be determined and subtracted from the equilibrium value.

After purification from the serum, the % deuterium oxide in blood water was determined by the falling drop method. The difference in percentage of heavy water in the initial and equilibrium blood samples represents the dilution of heavy water in the total body water:

$$\text{kg total body water} = \frac{\text{cc Deuterium oxide injected X 10}}{\text{(\% deuterium oxide equilibrium - \% deuterium oxide initial)}}$$

One piglet which died during cardiac puncture after heavy water equilibration afforded the opporunity to compare tissue water

with serum water. The Thoracic cavity was quickly opened, and a sample of blood, intercostal muscle and lung tissue removed. Tissue water was obtained by heating over a water bath at 80°C in a 250 ml ground glass Erlenmeyer flask. Each flask was fitted with a cold finger beneath which was fastened an aluminium foil cup to collect condensate. Cold water was circulated through the cold finger and tissue water collected in this way was further purified by vacuum distillation. No significant differences in deuterium oxide concentration of water from different tissues was apparent. Data is presented in appendix Table

Since with some animals, blood was removed from the heart as opposed to the ear and, in a few cases, the tail, a comparison of the heavy water content of the blood from these three sites in the same pig during the same analytical run was made. Initial and equilibrium samples were removed from the tail and heart in one case and from the ear and heart in another. There were no significant differences in the content of heavy water in serum water when the ear or tail samples were compared with the heart sample (Appendix Table

The relationship of total body water to protein, ash and fat free dry matter

The composition of young piglets has been determined *in vitro* by many authors (McMeekan 1941; Spray and Widdowson 1950; Osinska 1962; Manners and McCrae 1963; Wood and Groves 1965). Wood and Groves (1965) presented data on a large number of piglets

killed between birth and sixty five days. The relationships of body water to body nitrogen (X6.25 = body protein), body water to ash, and body water to fat-free dry matter (FFDM) were determined by regression equations (log-log grid). These relationships are presented in Table IV and were used throughout this study to determine compositional changes during early growth.

Groves (1960) pointed out that FFDM appears to be more closely related to body weight than to body water; an arithmetic relationship of FFDM = 17.92% body weight gave essentially the same error term as that of the regression line. However a high or low nutritional plane may affect the FFDM at the same body weight and therefore the regression equation was used.

To establish the validity of the prediction equations, body protein and ash determined in vitro by other workers were compared with the values obtained by applying the prediction equations of Wood and Groves (1965) to the body water values reported by the various authors. Table V summarises these data.

Excellent agreement between in vitro values and those predicted by the regression equations of Wood and Groves (1963) is evident in Table V. It is also perhaps worthy of note that Manners and McCrae (1963) used the total hydrolysis method of analysis of Venu (1947) while Spray and Widdowson employed classical carcass analysis. It was therefore felt quite justified to apply the equations of Wood and Groves to the in vivo body water values determined throughout this study.

TABLE IV: RELATIONSHIPS BETWEEN BODY COMPARTMENTS: --- PREDICTION EQUATIONS

Body water interval (kg)	X = kg body water	Error, %
0.5 - 3.9	Body protein, kg = $0.1594X^{1.2598}$	+10.0 - 9.0
3.9 - 20.0	Body protein, kg = $0.1727X^{1.0867}$	+12.2 -11.0
0.5 - 2.9	Ash, g = $47.083X^{0.8109}$	+32.0 -24.0
2.9 - 20.0	Ash, g = $38.984X^{1.0377}$	+12.5 -11.0
0.5 - 20.0	FFDM, kg = $0.2312X^{1.0790}$	+ 7.1 - 6.5

(after Groves 1960)

TABLE V: COMPARISON OF BODY COMPOSITION PREDICTED BY REGRESSION EQUATIONS WITH THAT DETERMINED IN VITRO

A. Body weight (kg)	Body water, kg (S & W)[1]	Protein, kg (S & W)	Predicted protein, kg (W & G)[2]	Ash, g (S & W)	Predicted ash, g (W & G)
7.450	4.954	1.006	0.983	216.2	205.1
6.400	4.755	0.890	0.910	191.3	196.6
9.600	6.326	1.315	1.282	296.1	264.3
5.782	4.018	0.740	0.753	174.2	165.1
5.500	3.740	0.754	0.724	139.6	153.2
9.500	5.501	1.093	1.101	245.3	228.6

B. Body weight (kg)	Body water, kg (M & M)[3]	Protein, kg (M & M)	Predicted protein, kg (W & G)	Ash, g (M & M)	Predicted ash, g (W & G)
1.520	1.198	0.174	0.200	60.4	54.5
1.815	1.398	0.237	0.243	66.8	61.8
3.221	2.207	0.437	0.432	94.1	89.5
5.563	3.557	0.770	0.788	160.8	146.5
9.928	6.138	1.427	1.341	323.9	296.2

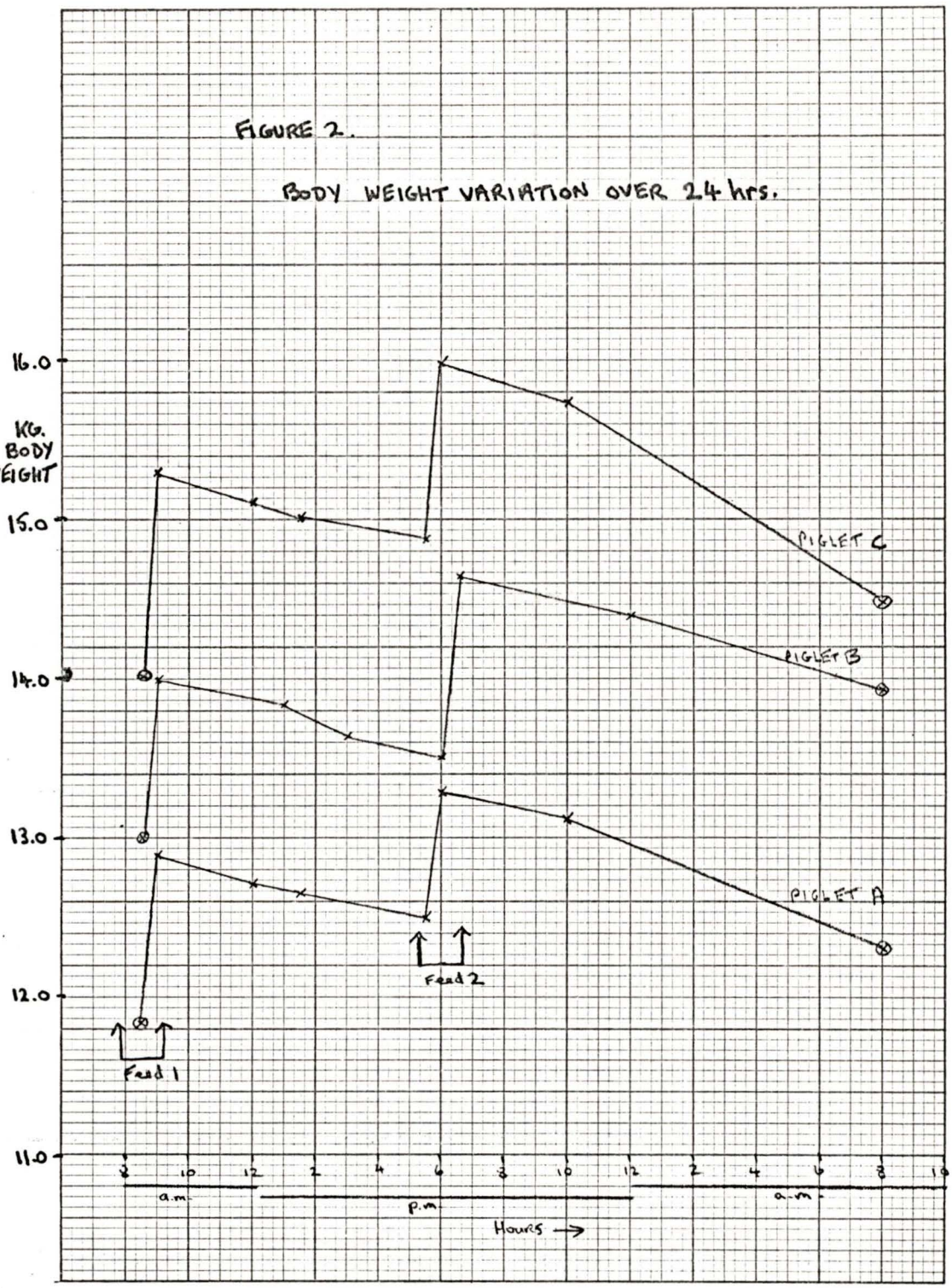
[1] S & W Spray and Widdowson (1950).

[2] W & G Wood and Groves (1965).

[3] M & M Manners and McCrae (1963).

FIGURE 2.

BODY WEIGHT VARIATION OVER 24 hrs.



Body fat

In the determination of body composition *in vivo*, it is difficult to determine accurately the component usually referred to as chemically determined fat. It is a highly variable component affected by the nutritional environment afforded an animal. Attempts to relate fat content to other body parameters generally lead to a high standard error of estimate (e.g. Reid *et al* 1968). *In vitro* determination of ether extractives includes various lipid components which are not strictly "energetic" contributors, that is, which are not readily available as energy sources e.g. phospholipids. Much of the body's lipids are not physically separable while those which are may contain from 30 to 90% of ether extractives (Reid *et al* 1968). In this study, lipids are determined by subtraction:

Kg Body lipids = Kg body weight - kg body water - kg FFDM.

Body weight is therefore an important factor in the estimation of body fat. There arises a problem of intestinal contents which are strictly "outside" of the chemically determined body yet are unavoidably included in the body weight and body water measurement. Figure 2 indicates how an animal fed twice daily grows during a single day in terms of body weight. Equilibration of isotope was usually timed to occur around 4 to 5 p.m. It was felt that the mean weight of the a.m. body weight on the day of assay and of the a.m. body weight on the following day both body weight obtained from a smooth curve (see later), would give a fairly accurate esti-

mate of the "true" body weight at the time of assay. Therefore in the determination of lipids, such a procedure was adopted.

RESULTS AND DISCUSSION

Growth curves

During the latter part of the nineteenth century, observations of the growth patterns of micro-organisms led to the formulation of population growth curves (Müller 1895). There then followed the application of mathematical concepts of microbial growth to animals (Slator 1916; Brody 1927). A review of these concepts is presented by Brody (1945). The shape of most age curves of growth whether of individuals or populations appears sigmoidal and of two principle segments, one of increasing slope or self-accelerating phase (increasing exponential curve) and a second of a decreasing slope or self-inhibiting phase (decreasing exponential curve); the two phases meet at the point of inflection of the curve. Proven exceptions to this shape are the double sigmoid human growth curve and that of the black-tailed deer (Odocoileus hemionus columbianus) which exhibits a cyclical pattern of growth and development growing rapidly in spring and summer, then exhibiting weight stasis or loss in autumn and winter (Wood et al 1962). A curve of the sigmoidal type is illustrated in figure 3. However, although the overall shape appears sigmoidal, there appear to be properties of the curve which are overlooked in the process of smoothing growth data either of the individual or, more often, by statistical smoothing of data from several individuals. There exist phases of growth beginning and ending in growth "breaks". Brody (1945) states:

> "in the rat ..... from conception age 32 days (10 days after birth) to 52 days, the instantaneous relative growth rate appears to be 4 per cent per day; from 52 days up to inflection (65 days after birth) 3 per cent per day. (We are not certain of the presence of later breaks) ..... The conclusion is, then,

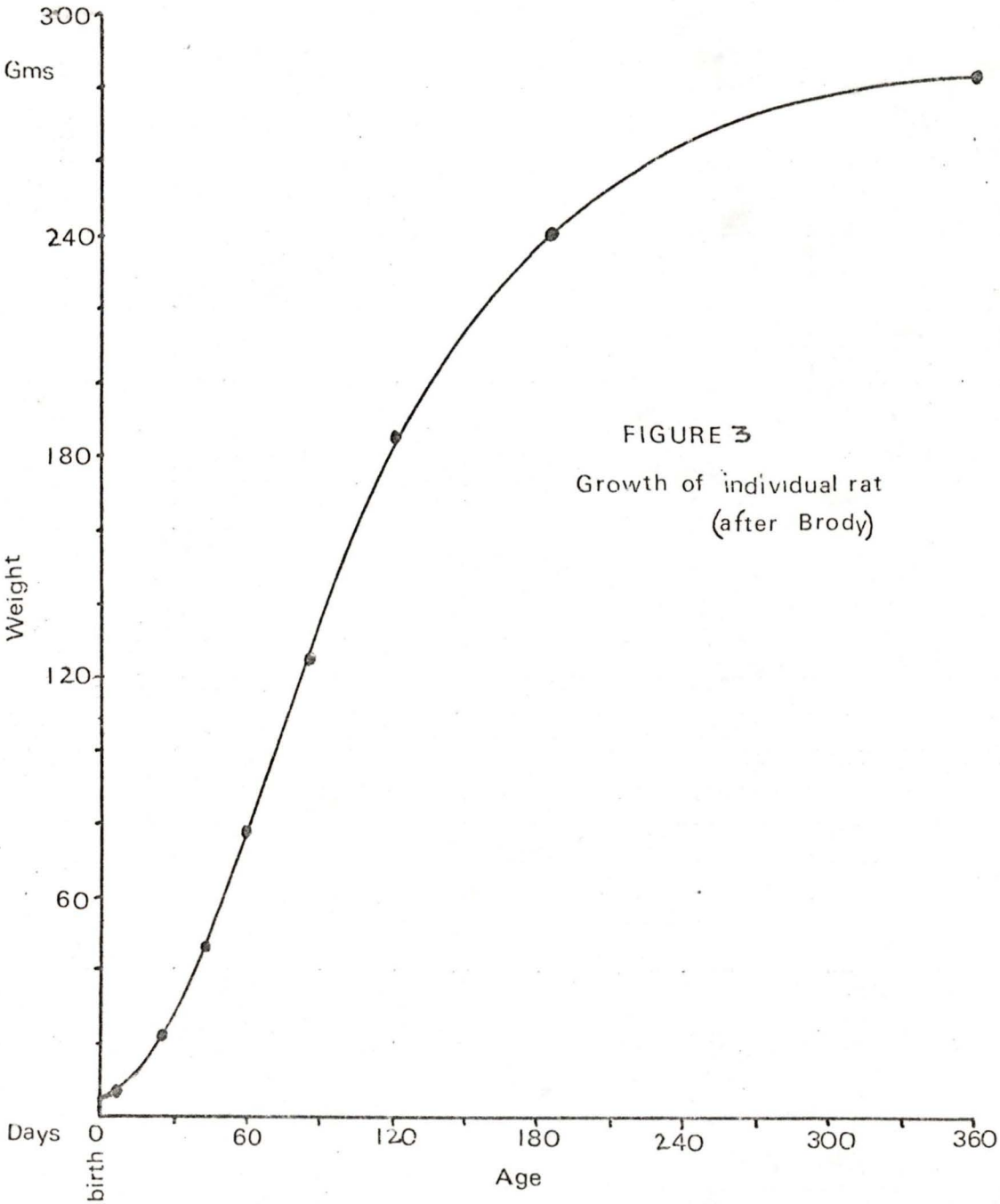


FIGURE 3

Growth of individual rat
(after Brody)

> that while the percentage growth rate declines with age, the decline ..... does not appear to be continuous. The percentage growth rate remains relatively constant between rather wide limits and then declines relatively abruptly to a new low level."

Such breaks have also been well recorded during mammalian foetal development (Widdowson 1950) and during the growth of chick embryos (Brody 1920; Romanoff 1929; Lerner 1939). Lerner (1939) warned of the danger of reaching invalid conclusions regarding embryonic development when such discontinuities in growth were disregarded. In "Bioenergetics and Growth" Brody (1945) writes:

> "It is illogical to object to the presence of relative discontinuities in the growth curve when their presence in the individual and in the race are generally known. When external conditions are equal, growth exhibits general statistical continuity in its path towards a certain equilibrium, but within this general continuity there appear to be detailed discontinuities."
>
> (Emphases by this author)

The establishment and quantification of postnatal growth phases is subject to difficulties imposed by a variable environment; whereas the foetus or embryo is subjected to near-optimal conditions, this is rarely the case in the neonate. Obviously, birth itself marks a growth break. Environmental conditions may be instrumental in locating a break on the basis of sidereal time. For example, when environmental conditions of chick embryos were altered by increasing or decreasing incubation temperature, the chronological time at which growth breaks occurred was displaced -- later when the temperature was decreased, earlier when the temperature was increased (Romanoff 1929).

At this point it is necessary to introduce some mathematical expressions derived by various authors to fit growth data. It is a subject of continuous debate as to how near the truth one may approach by the use of mathematical expressions in growth work. There often exists the danger of missing detail when "sweeping equations", somewhat analogous to generalised statements, are used. On the other hand, examination of raw data is so unmanageable in its vast quantities that often little information may be gleaned. A set of "laws" or statements is perhaps the easiest way to introduce new concepts and such an approach was employed by Brody (1927; 1945) in putting forward the theory and use of the instantaneous relative growth rate equation first suggested in relation to micro-organisms by Slator (1916) (although no credit is given to Slator by Brody).

Until 1927, Minot's equation (1891) for computing rate of growth was in use:

$$\text{Average relative growth rate, } R = \frac{W_2 - W_1}{W_1}$$

W_1 = weight of organism at the beginning of the time interval.

$W_2 - W_1$ = weight gain during a given time interval.

The limitations of Minot's equation occur when $W_2 - W_1$ is very large in relation to W_1. In place of finite weight gain, Brody (1927) used instantaneous weight gain dW/dt, dividing the instantaneous gain by the weight at the time of gain:

$$\text{Instantaneous relative growth rate} = \frac{dW/dt}{W} = k$$

$$\frac{dW}{dt} = kW$$

By integrating:

$$A\int^{W}\frac{dW}{W} = k\int_{o}^{t}dt$$

$$\therefore \ln W = \ln A + kt$$

$$\therefore W = A_e^{kt} \quad \text{or} \quad k = \frac{\ln W_2 - \ln W_1}{t_2 - t_1}$$

k x 100 = percentage growth rate.

Such a treatment utilises the analogy between early growth and a monomolecular chemical reaction, the speed of which is proportional to the number of available "units" entering into the process at any given time; or compound interest at a constant percentage. The implication of a constant percentage rate of growth is that the postnatal growth curve is exponential between breaks which occur abruptly, changing the percentage rate of growth to a lower value in the next phase. Since $\ln W = \ln A + kt$, a plot of W versus time on arith-log paper yields a straight line of slope K. Data may be fitted by the method of least squares only if the distribution on the arith-log grid is linear. Data will never be exactly linear if recorded frequently and can only be judged approximately so by eye and then treated statistically to make it linear. In terms of an indication of how quickly the animal is growing based on gross body weight, the instantaneous relative growth rate is useful. Neglected in all treatments of gross body weight data are changes in the composition of the body as weight accretion continues (as outlined in the introduction); these two parameters must be integrated, and therein lies a major criticism of the instantaneous relative growth equation. Animal growth is not "monomolecular"; cell multiplication in an exponential fashion does not account for gross weight increase

in animals as it does in a young microbial population, the interaction of body components involves hydration, cell multiplication, cell enlargement and intestinal fill and it is this interaction which determines the shape of the growth curve. Growth of muscle particularly influences the shape of the growth curve. McMeekan (1940) concluded that probably all postnatal growth of muscle occurs by cell enlargement in a wide variety of animals. Widdowson (1951) concluded the same for the human. The full expression of genetic potential for growth is rarely realised in experimental studies so that most of the available data is based on a false premise. It seems illogical by such reasoning to conclude that early growth is exactly exponential; limitations of the environment may occasionally make it exactly exponential but this is probably more fortuitous than real.

In this study, a major problem is the means of expression of liveweight growth data to which can be related the body compositional changes. From evidence in the literature (cited earlier) and from data on the growth of the pig (Waldron 1952; Groves 1960; Wood and Groves 1965; this study) and the deer (Wood et al 1962), a single exponential equation describing early postnatal growth and neglecting the occurrence of growth phases has been dismissed as inadequate. The instantaneous relative growth rate equation has been applied to the growth phases for comparative purposes but is considered inadequate for reasons cited above and for other reasons to be discussed later.

To each growth phase was applied a second or third order

TABLE VI: HIGH PLANE H3 - MATHEMATICAL PREDICTION OF BODY WEIGHT: A COMPARISON

a) Actual recorded weight (kg).
b) Predicted weight by phasic polynomials (kg).
c) Predicted weight by overall polynomial (kg).
d) Predicted weight by instantaneous relative growth constants (kg).

Age (days)	a	b	c	d
5	1.30	1.244	1.351	
6	1.33	1.409	1.470	1.421
7	1.52	1.564	1.592	1.554
8	1.74	1.715	1.727	1.699
9	1.95	1.870	1.871	1.858
10	2.04	2.038	2.025	2.042
11	2.20	2.223	2.188	2.233
12	2.45	2.436	2.360	2.441
13	2.60	2.681	2.542	2.669
14	3.02	2.968	2.733	2.918
15	3.30	3.302	2.934	3.190
16	3.27	SE=+0.023 kg	SE=+0.045 kg	SE=+0.075 kg
17	3.50	3.465	3.364	3.444
18	3.65	3.658	3.593	3.627
19	3.85	3.866	3.832	3.820
20	4.00	4.087	4.080	4.023
21	4.40	4.323	4.338	4.237
22	4.50	4.572	4.606	4.462
23	4.95	4.834	4.883	4.699
24	5.12	5.109	5.170	4.949
25	5.30	5.398	5.466	5.212
26	5.70	5.700	5.772	5.490
27	6.05	6.014	6.088	5.790
28	6.30	6.341	6.414	6.101
29	6.70	6.681	6.749	6.426
30	7.18	7.033	7.094	6.992
31	7.34	7.398	7.448	7.384
32	7.65	7.774	7.812	7.777
33	8.15	8.162	8.187	8.191
34	8.50	8.562	8.570	8.627
35	9.05	8.974	8.964	9.086
36	9.40	9.397	9.367	9.570
37	9.80	SE=+0.056 kg	SE=+0.071 kg	SE=+0.112 kg
38	10.30	10.159	10.204	10.149
39	10.65	10.704	10.637	10.510
40	11.00	11.220	11.079	10.954
41	11.85	11.713	11.532	11.344
42	12.10	12.187	11.995	11.748

TABLE VI: HIGH PLANE H3 - MATHEMATICAL PREDICTION OF BODY WEIGHT: A COMPARISON (cont'd)

Age (days)	a	b	c	d
43	12.60	12.649	12.467	12.166
44	13.10	13.102	12.950	12.945
45	13.60	13.554	13.442	13.406
46	14.20	14.008	13.944	13.883
47	14.65	14.471	14.456	14.377
48	14.50	14.948	14.979	14.908
49	15.50	15.444	15.511	15.439
50	16.35	15.964	16.053	15.989
51	16.50	16.514	16.606	16.558
52	16.83	17.100	17.168	17.147
53	17.43	17.725	17.740	17.757
54	18.70	18.397	18.323	18.389
55	19.10	SE=±0.093 kg	SE=±0.141 kg	SE=±0.174 kg
56	20.20		19.517	

polynomial regression as well as the Brodian instantaneous relative growth rate constant. The positioning of growth phases was chosen by visual assessment of both an arith-arith body weight versus time plot, and a semilogarithmic plot of the same data, the latter indicating more clearly the approximate chronological position of growth rate changes. An illustration of choice of growth phases is shown in Figure 4 and Figure 4A. Examination of the arithmetic plot (Figure 4) suggests growth breaks at approximately days 15 and 37. Figure 4A confirms a change in growth pattern shortly before and after these days. A polynomial was then fitted to each phase and was considered to most nearly approach the true growth of the animal throughout that phase. The use of polynomial expressions to fit growth data is by no means original: Pearl and Reed (1923) presented a logistic equation to fit the intricate human growth curve.

Table VI illustrates some justification for the use of the polynomial expression. Actual daily recorded weight of an animal is compared with its weight predicted a) by applying a polynomial equation to each phase (= "phasic" polynomial) b) by applying a single polynomial equation to the whole growth period studied, and c) by applying the Brody instantaneous relative growth rate constant calculated for each phase. The standard error of estimate obtained when these treatments are compared with the actual data are shown. Application of a polynomial to each phase yields a lower standard error than is obtained when the growth constants are applied. It is concluded that the phasic polynomial equations more accurately predict the true growth of the animal. The

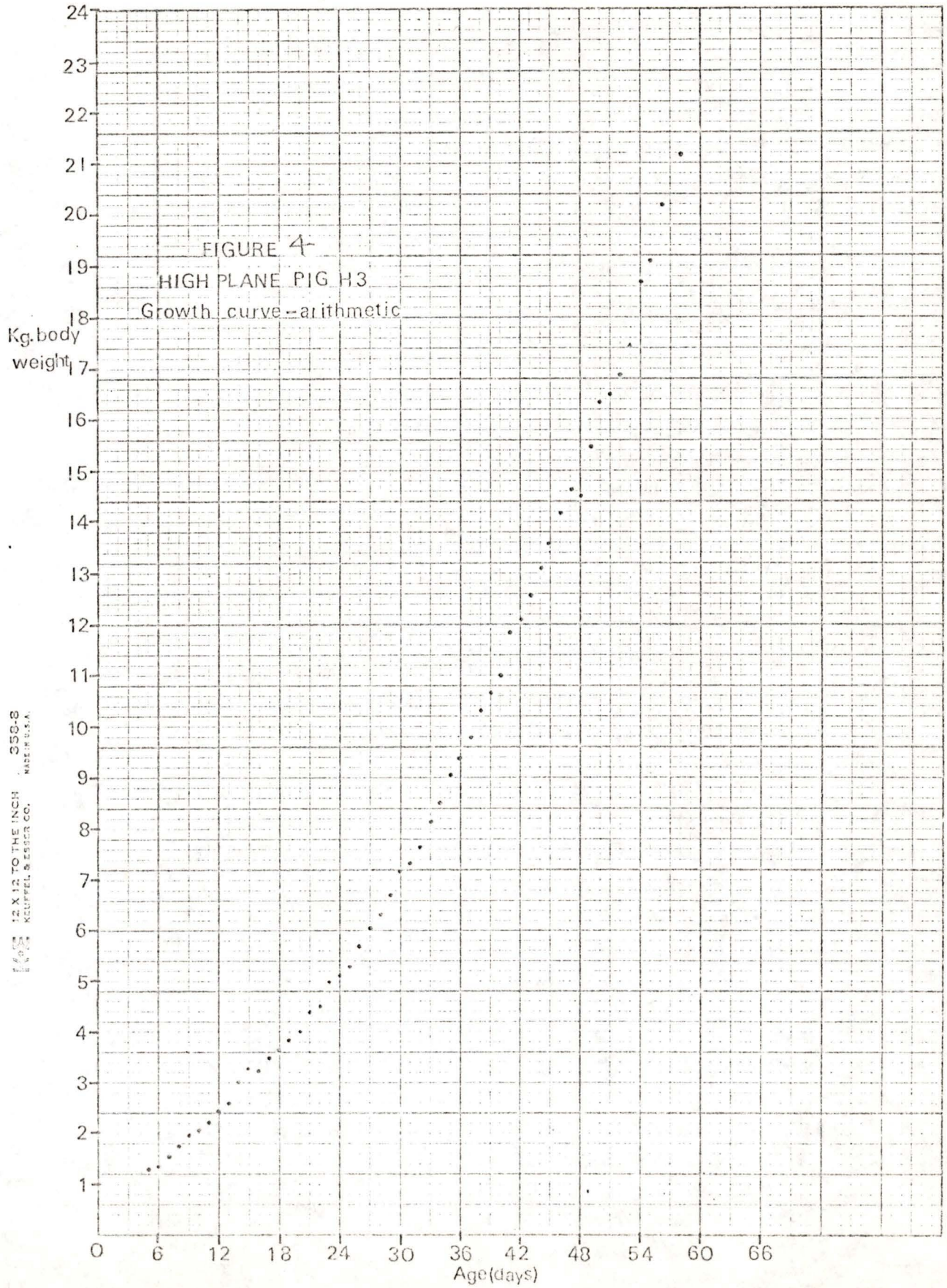


FIGURE 4
HIGH PLANE PIG H3
Growth curve--arithmetic
Kg. body weight
Age (days)
0
6
12
18
24
30
36
42
48
54
60
66
1
2
3
4
5
6
7
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KEUFFEL & ESSER CO.
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MADE IN U.S.A.

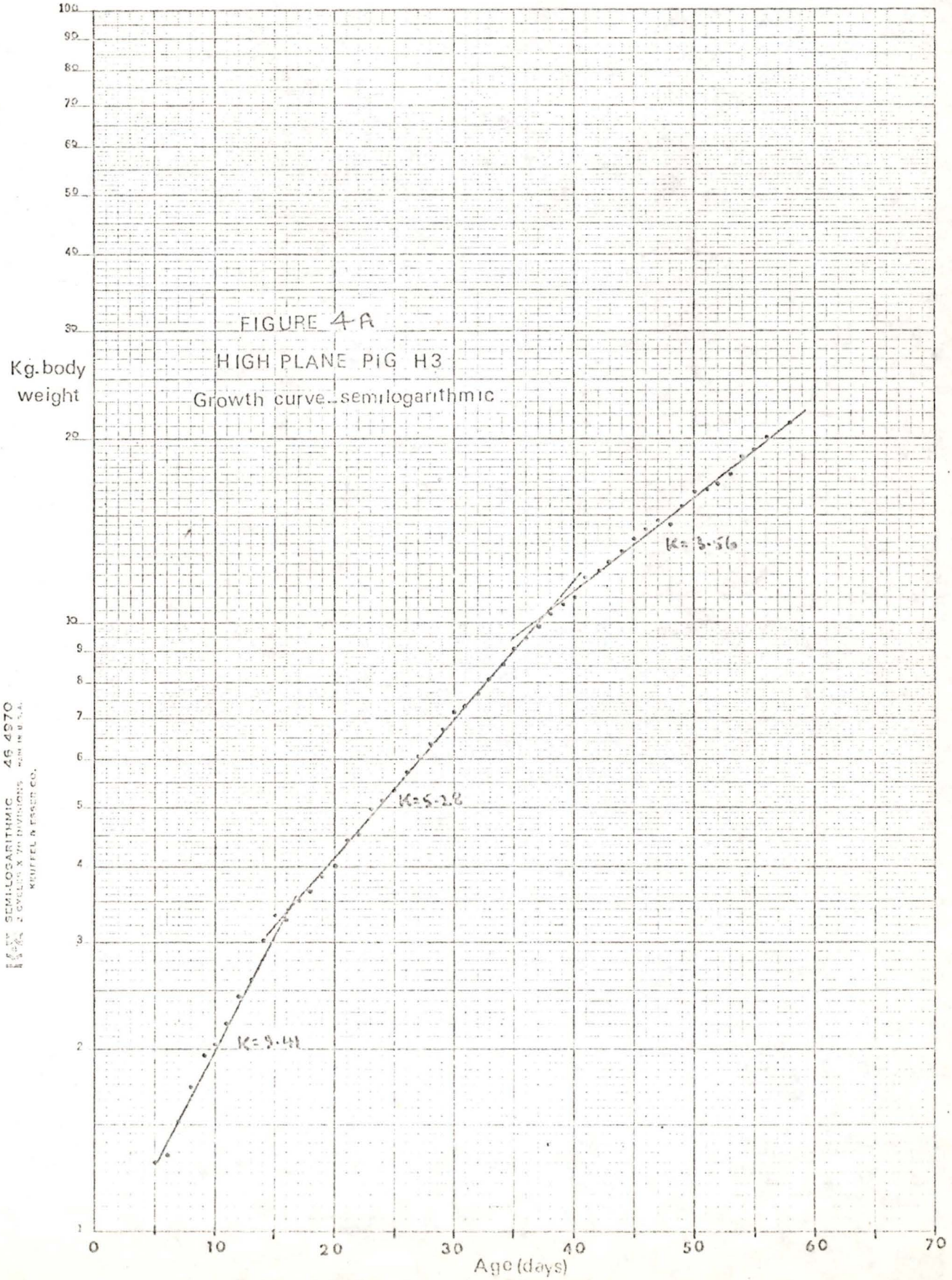


FIGURE 4A
HIGH PLANE PIG H3
Growth curve semilogarithmic
Kg. body weight
Age (days)
K=3·41
K=5·28
K=3·56
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
0
10
20
30
40
50
60
70

same approach was taken in considering the growth of each animal. Complete weight data of twelve piglets throughout the growth period studied are presented in Appendix Tables IV to XV along with body weights predicted by phasic polynomial equations and by growth rate constants calculated by the method of Brody (1945) for comparison. The phasic polynomial equations themselves are presented in Appendix Tables I and II, and the growth rate constants in Appendix Table III. Growth data is presented graphically in Figures 5 to 16A in arithmetic and semilogarithmic form. Growth following realimentation of low plane piglets is discussed in a later section.

The semilogarithmic plots, and in most cases, the arithmetic curves also, indicate definite phases of body weight gain. That the Brody instantaneous relative growth rate equations are not entirely a satisfactory expression of growth is indicated by the often non-linear fit of growth data on a semilogarithmic plot when measured daily. If body weight had been measured once or twice a week, it is very likely that a straight line fit would have resulted (e.g. Brody 1945 p. 497; Waldern 1952). In Appendix Tables IV to XV, the closeness of fit of the values calculated by the growth constants to the actual body weight data is inferior to the fit obtained when calculated by polynomial equations. The standard error terms for the growth constant equation and polynomial equation applicable to each growth phase are indicated in the weight data tables. The phasic polynomial expression would appear to be a refinement over the instantaneous relative growth rate values.

The positions of growth breaks have been determined from semilogarithmic curves and are tabulated in Table VIIA along with the body weight at that time. One pattern which emerges common to all animals, low and high plane, is an apparent change of rate of growth on or around 37 days of age. Body weight at this age differs considerably between the two nutritional planes; in the high plane piglets body weight varied from 8 to 11 kilograms whilst on the low plane regimen, body weights of 4 to 6 kilograms were recorded. Whereas a consistent pattern of breaks around 37 days was evident, this usually represented the second of two breaks, although the pattern of the first breaks showed less consistency and in three cases did not show at all. This early break occurred between 14 and 25 days of age at body weights between 3 and 6.5 kilograms on a high plane and 2 to 2.6 kilograms on the low plane of nutrition. The narrow body weight range encountered in the low plane would suggest a body weight-dependent metabolic change at this point. It is possible that the second break in the growth curve of the low plane animals corresponds to the first break noted in the high plane piglets since the weight range is approximately the same, and the close similarity of chronological time (37 days) may be a coincidence imposed by the nutritional plane. If this is so, then the early break (about 2.3 kg) was missed in the high plane animals and the second break shown by the low plane corresponds to the first break shown by the high plane animals. Clearly, it is unwise to compare the body weights of high and low plane piglets in relation to the occurrence of growth breaks since the fat contents of any two animals at the same weight but on different nutritional planes might

TABLE VII A AND B: OCCURRENCE OF "BREAKS" IN BODY WEIGHT-AGE AND PROTEIN-AGE CURVES

Animal Number	A. Growth curve	age (days)	body weight (kg)	B. Protein curve age (days)	body weight (kg)
H1	1st Break	27	6.5	26	6.1
	2nd Break	39	11.5	40	12.0
H2	1st Break	39	8.0	30	5.1
	2nd Break	-	-	43	9.5
H3	1st Break	16	3.3	23	4.8
	2nd Break	37	9.5	43	12.0
H4	1st Break	23	4.0	-	-
	2nd Break	39	10.0	37	9.6
H5	1st Break	16	3.2	23	5.0
	2nd Break	35	9.5	37	10.0
H6	1st Break	17	3.0	17	3.0
	2nd Break	37	9.0	40	10.0
L1	1st Break	30	8.0	22	5.0
	2nd Break	-	-	35	9.5
L2	1st Break	20	2.1	-	-
	2nd Break	29	4.0	32	4.3
L3	1st Break	31	5.5	23	4.0
	2nd Break	-	-	42	8.8
L4	1st Break	15	2.3	-	-
	2nd Break	40	6.0	37	5.5
L5	1st Break	14	2.6	16	2.6
	2nd Break	36	5.5	37	5.7
L6	1st Break	20	2.4	-	-
	2nd Break	36	4.3	35	4.2

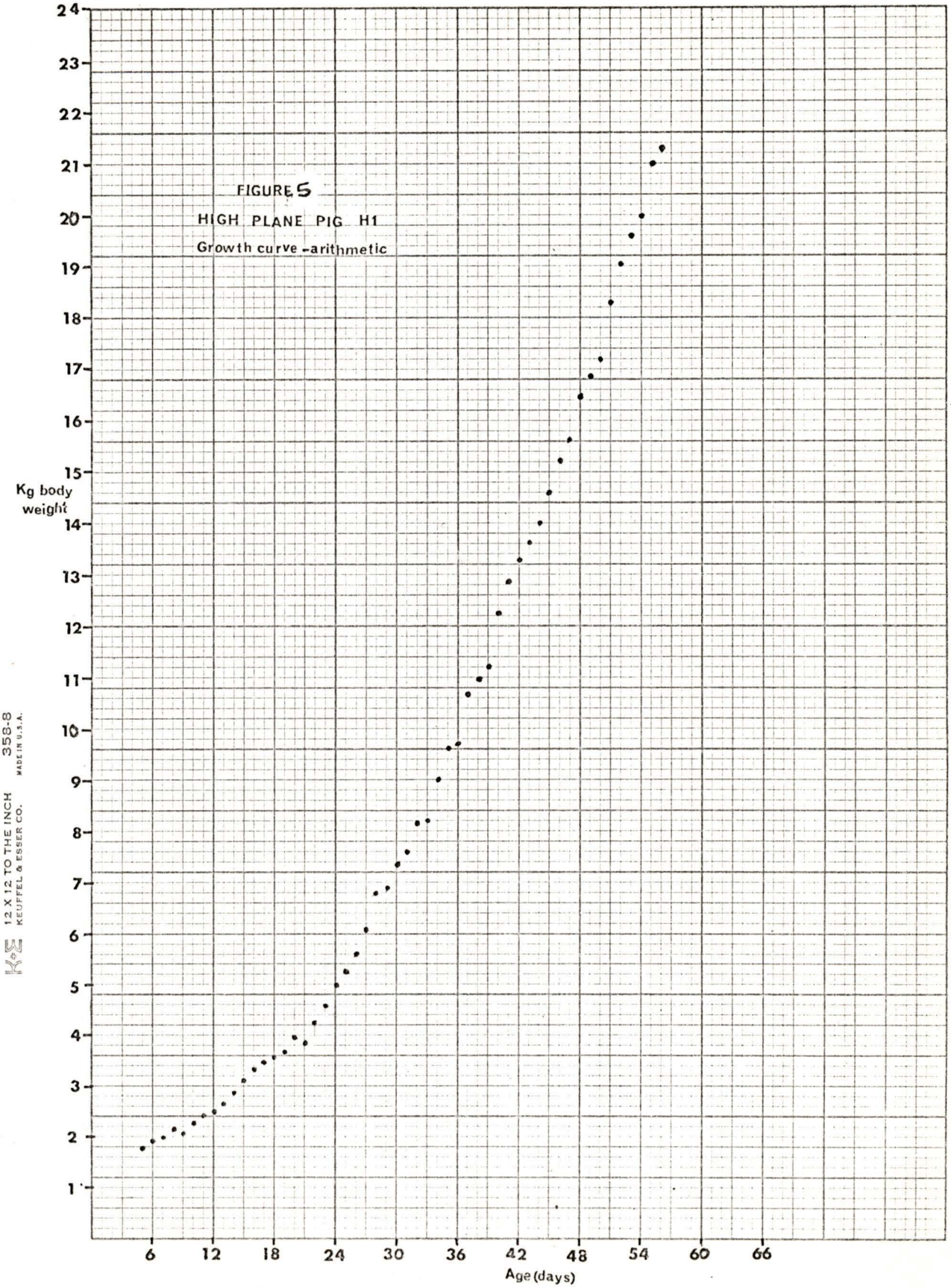
be expected to differ. Body weight changes should not be considered in isolation from body composition and therefore further discussion of the growth breaks is continued in relation to growth of body compartments.

EXPERIMENT I

FIGURE 5

HIGH PLANE PIG H1

Growth curve - arithmetic



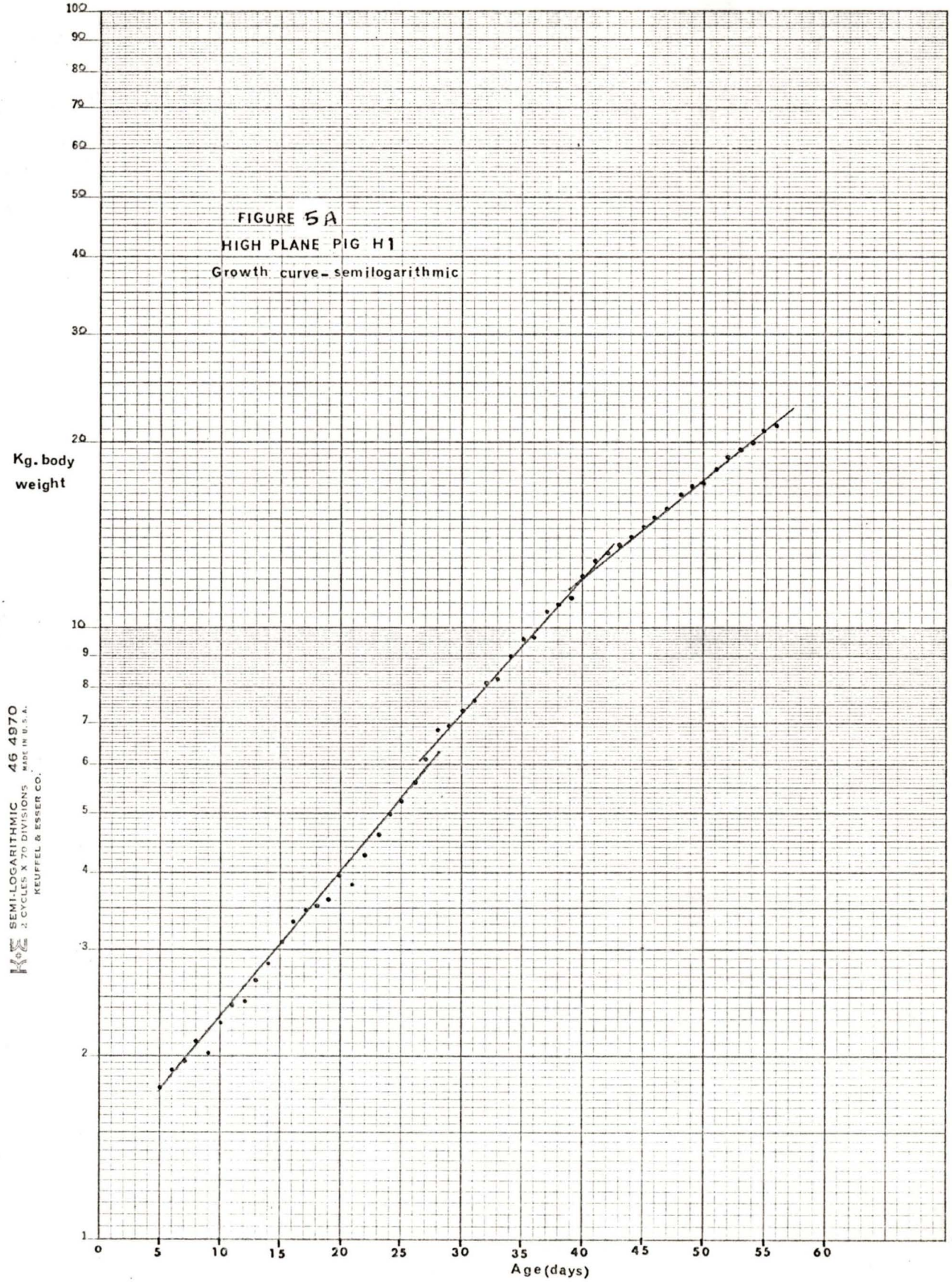


FIGURE 5A
HIGH PLANE PIG H1
Growth curve - semilogarithmic
Kg. body weight
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
0
5
10
15
20
25
30
35
40
45
50
55
60
Age (days)
SEMI-LOGARITHMIC 46 4970
2 CYCLES X 70 DIVISIONS MADE IN U.S.A.
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FIGURE 6

HIGH PLANE PIG H2

Growth curve - arithmetic.

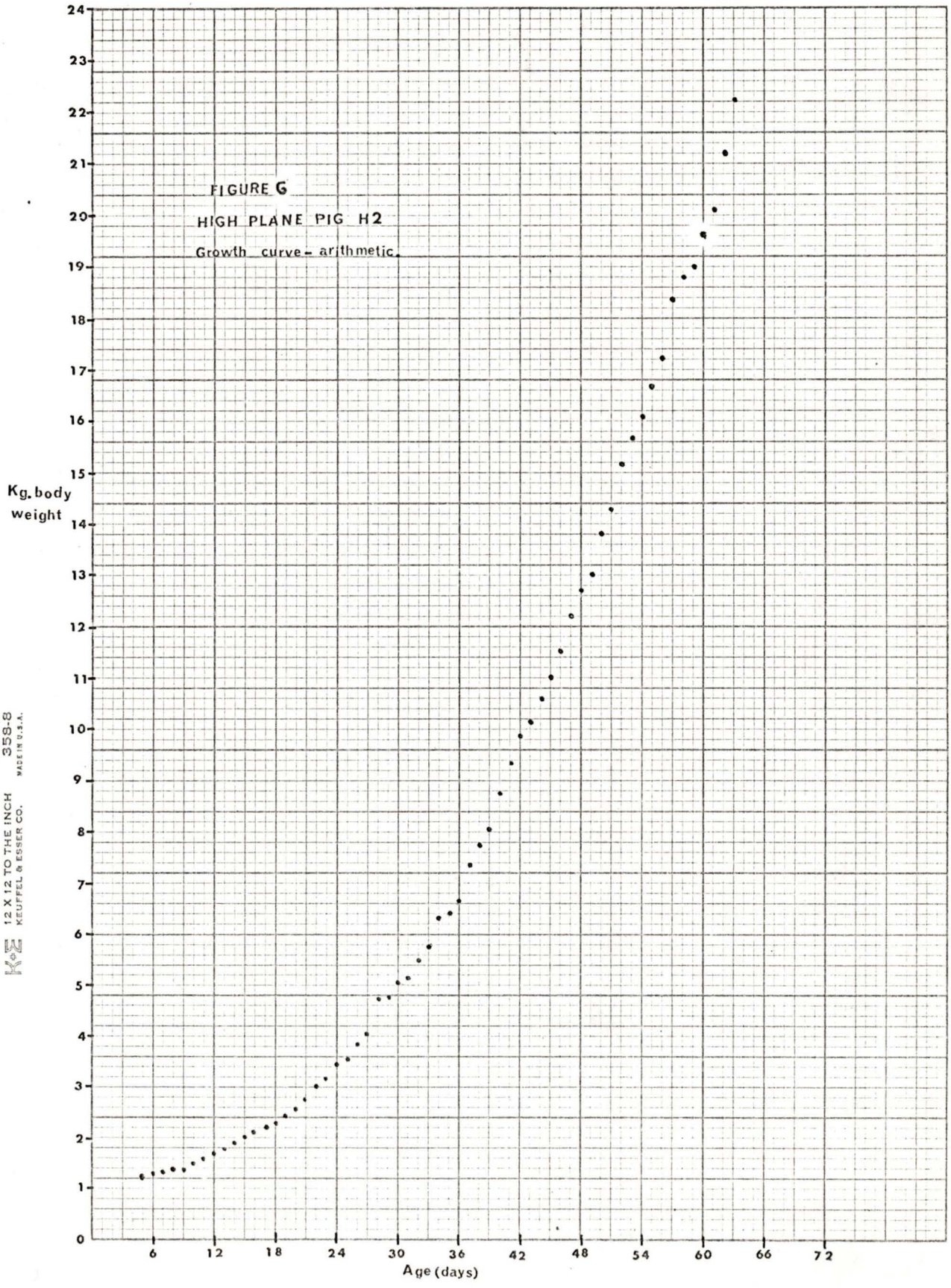
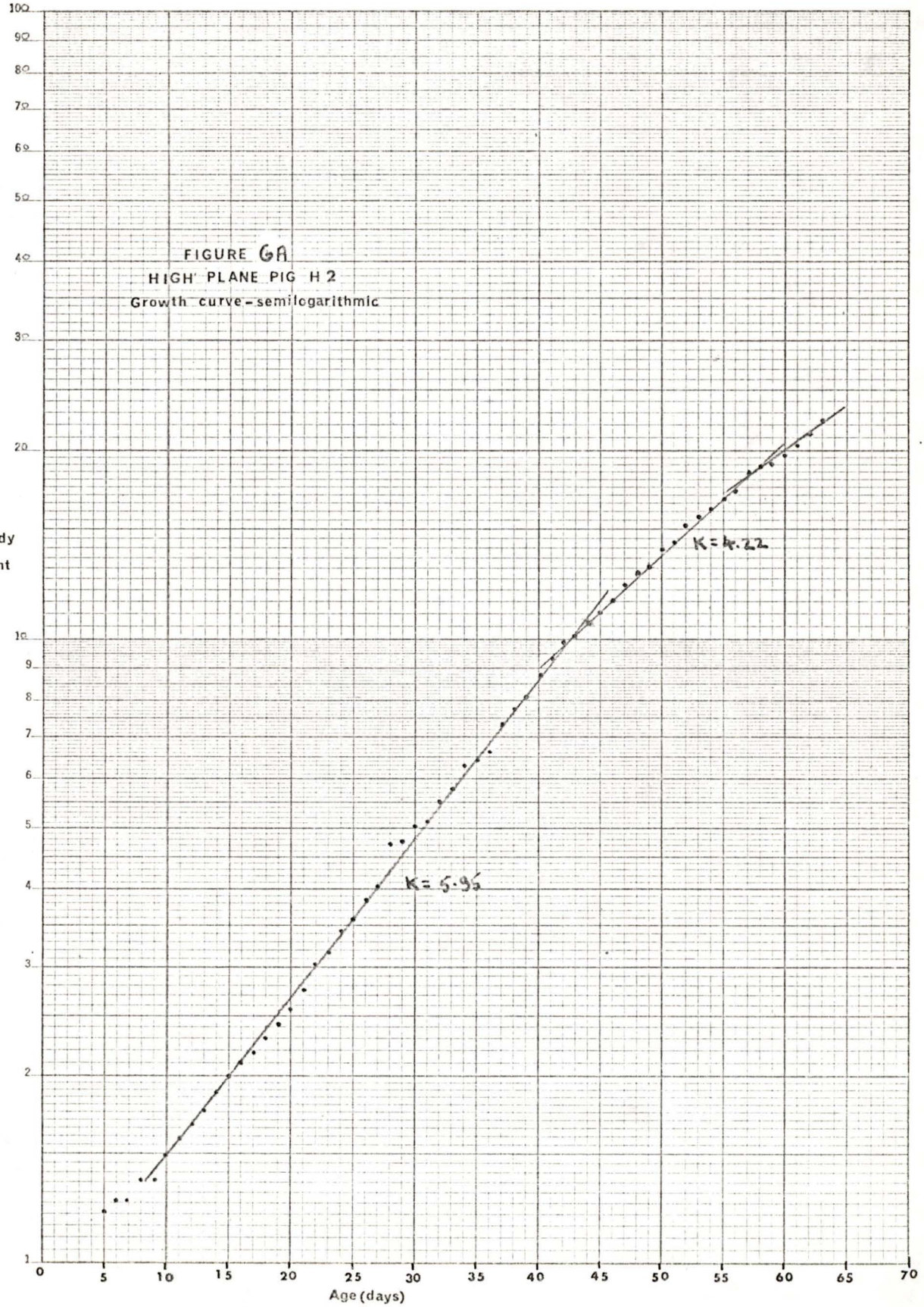


FIGURE 6A

HIGH PLANE PIG H 2

Growth curve - semilogarithmic



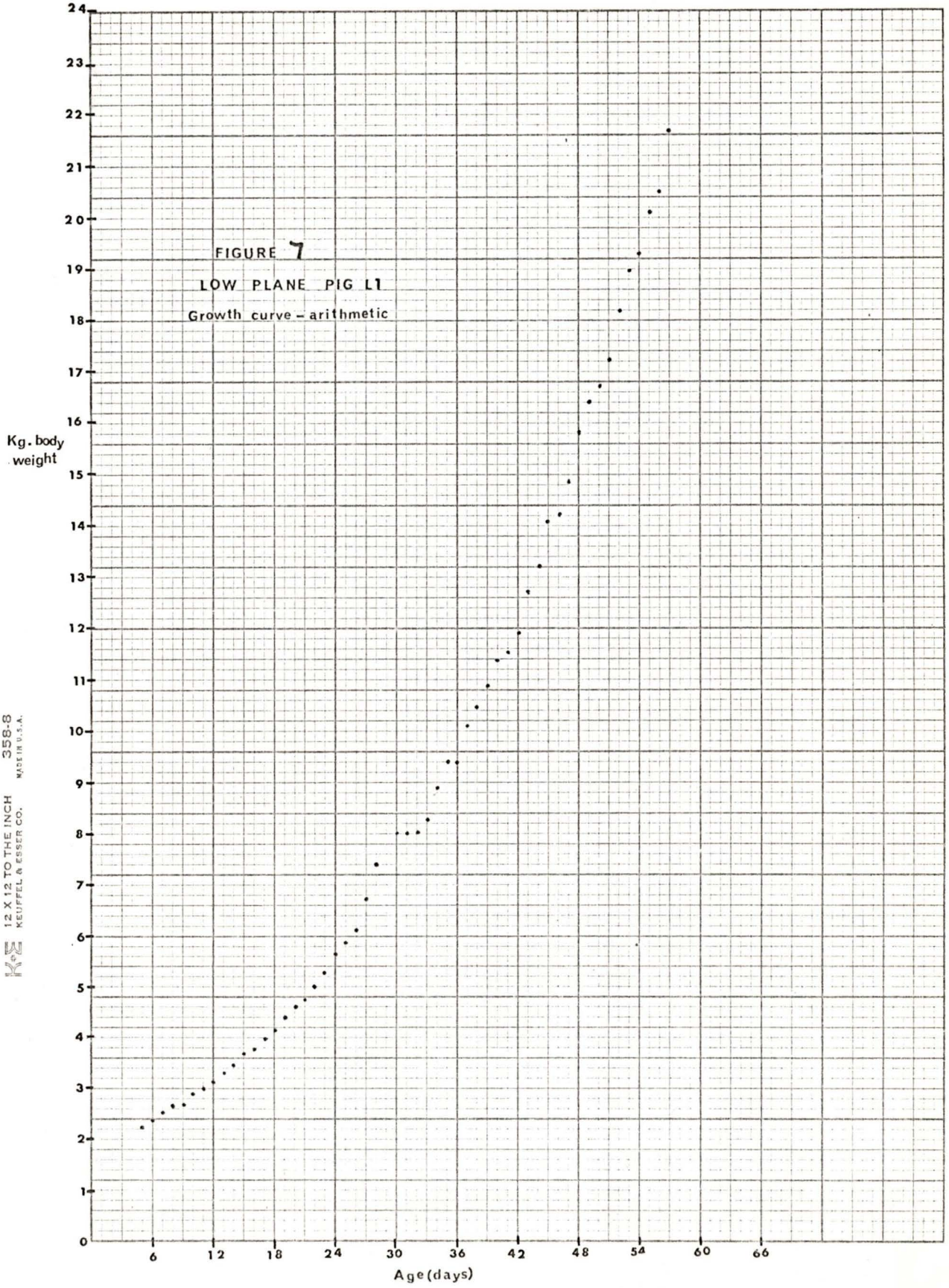


FIGURE 7
LOW PLANE PIG L1
Growth curve – arithmetic
Kg. body weight
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
6
12
18
24
30
36
42
48
54
60
66
Age (days)
12 X 12 TO THE INCH
KEUFFEL & ESSER CO.
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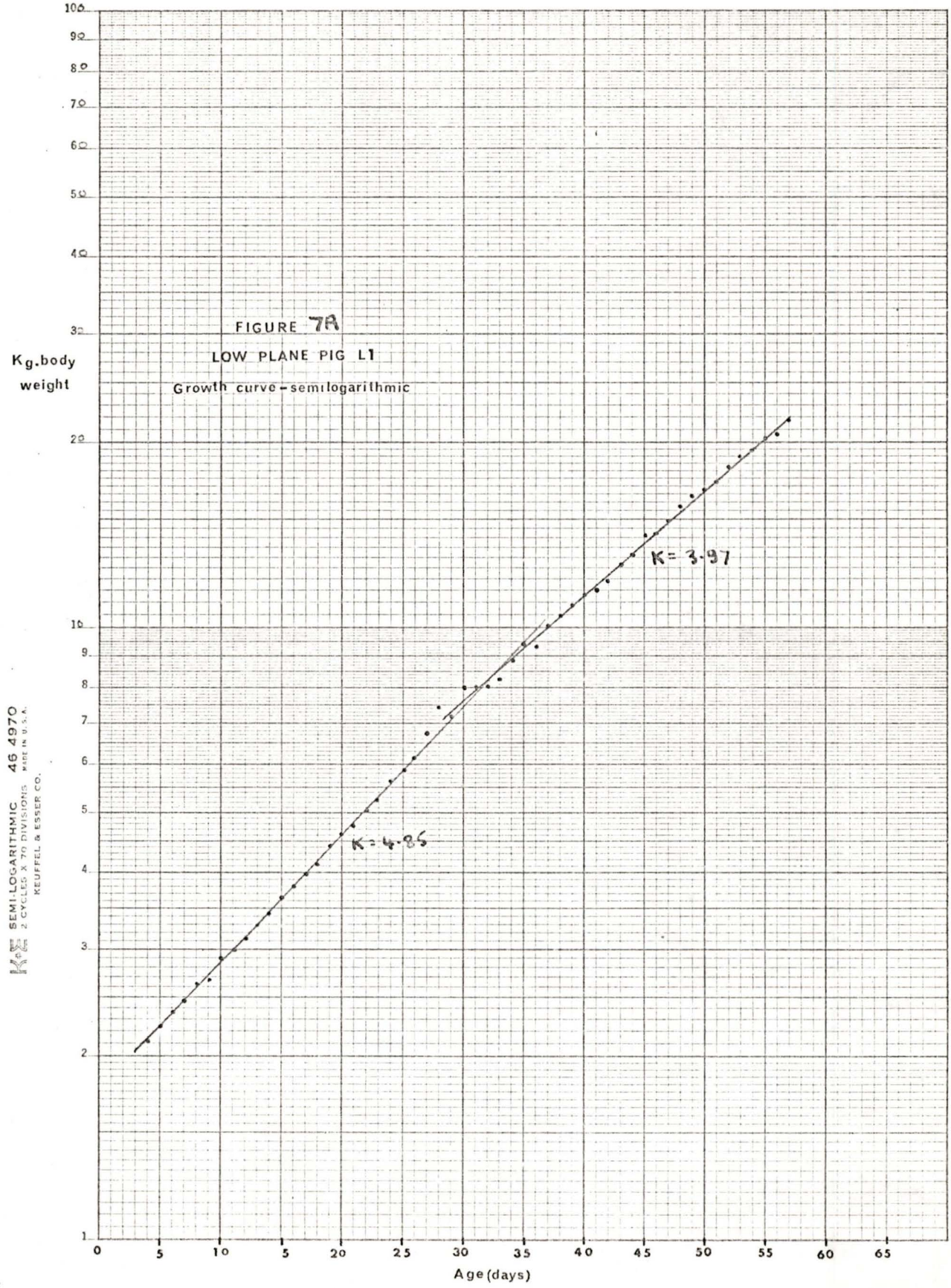
FIGURE 7A
LOW PLANE PIG L1
Growth curve - semilogarithmic
Kg. body weight
Age (days)
K = 4.85
K = 3.97
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
0
5
10
15
20
25
30
35
40
45
50
55
60
65
SEMI-LOGARITHMIC 46 4970
2 CYCLES X 70 DIVISIONS MADE IN U.S.A.
KEUFFEL & ESSER CO.

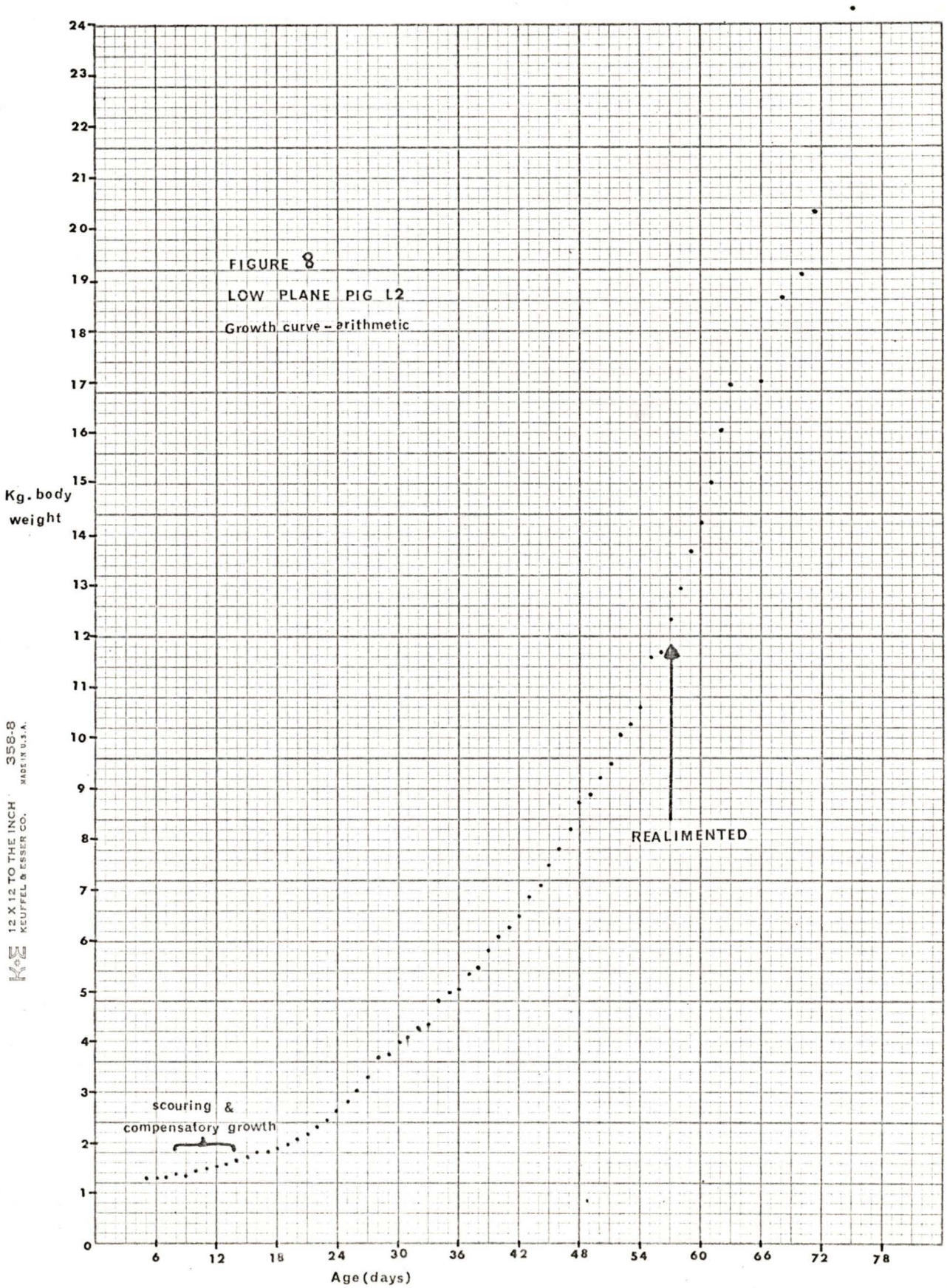
FIGURE 8
LOW PLANE PIG L2
Growth curve – arithmetic
Kg. body weight
Age (days)
REALIMENTED
scouring &
compensatory growth
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
6
12
18
24
30
36
42
48
54
60
66
72
78
12 X 12 TO THE INCH
KEUFFEL & ESSER CO.
358-8
MADE IN U.S.A.

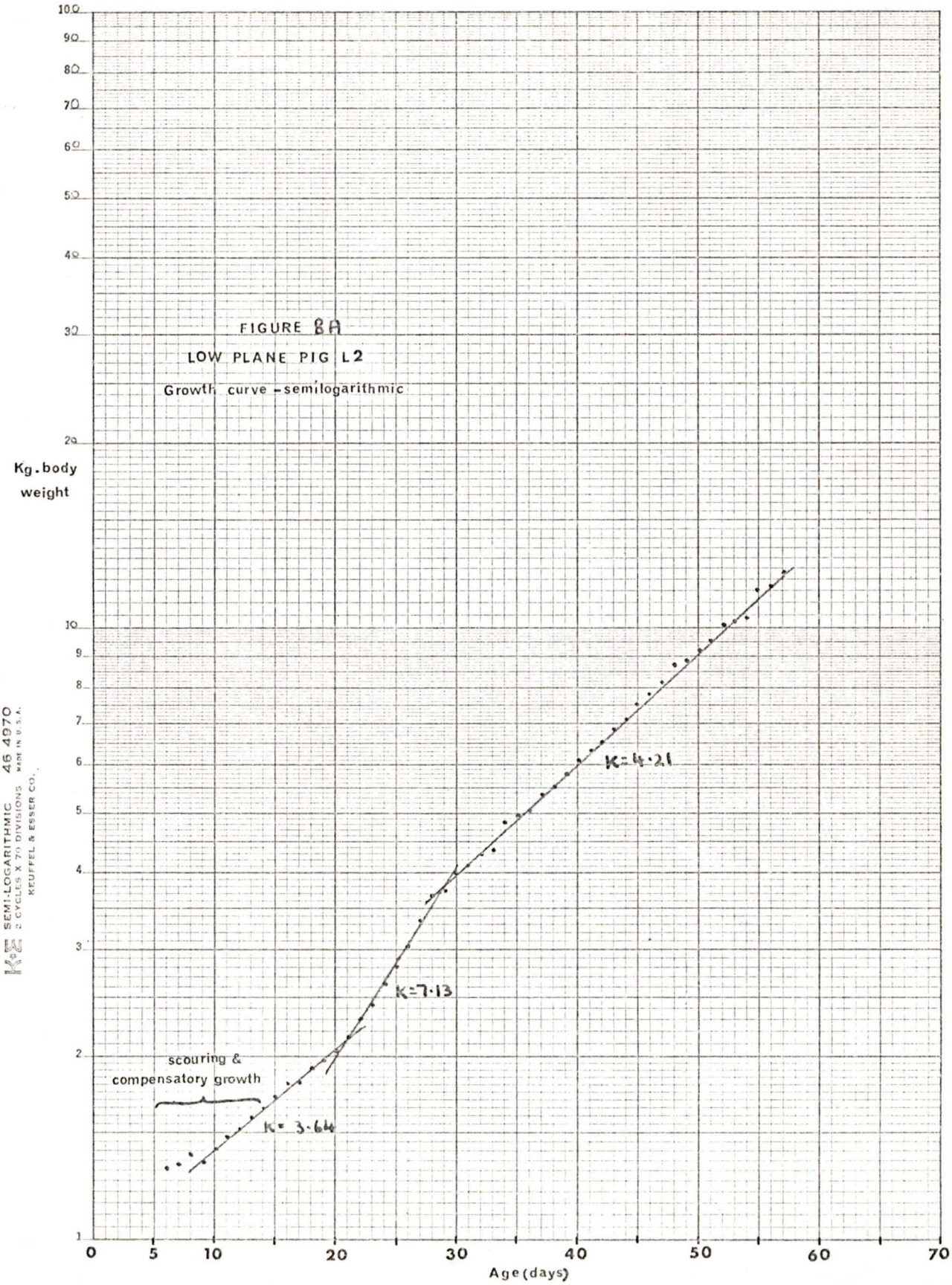
FIGURE 8A
LOW PLANE PIG L2
Growth curve - semilogarithmic
Kg. body weight
Age (days)
K=4·21
K=7·13
K= 3·64
scouring & compensatory growth
SEMI-LOGARITHMIC 46 4970
2 CYCLES X 70 DIVISIONS
KEUFFEL & ESSER CO.

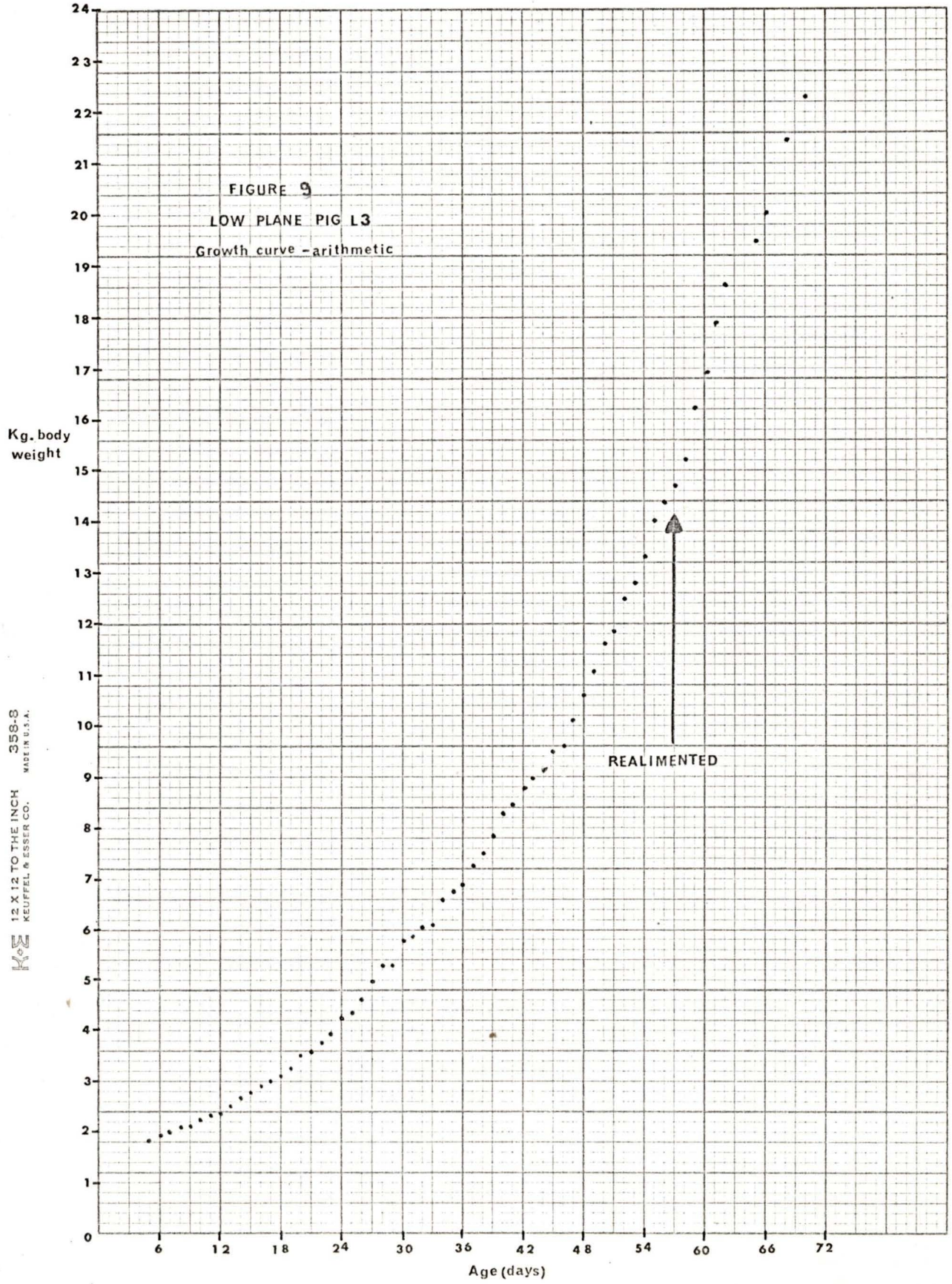
FIGURE 9
LOW PLANE PIG L3
Growth curve - arithmetic
Kg. body weight
Age (days)
REALIMENTED
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
6
12
18
24
30
36
42
48
54
60
66
72
12 X 12 TO THE INCH
KEUFFEL & ESSER CO.
MADE IN U.S.A.
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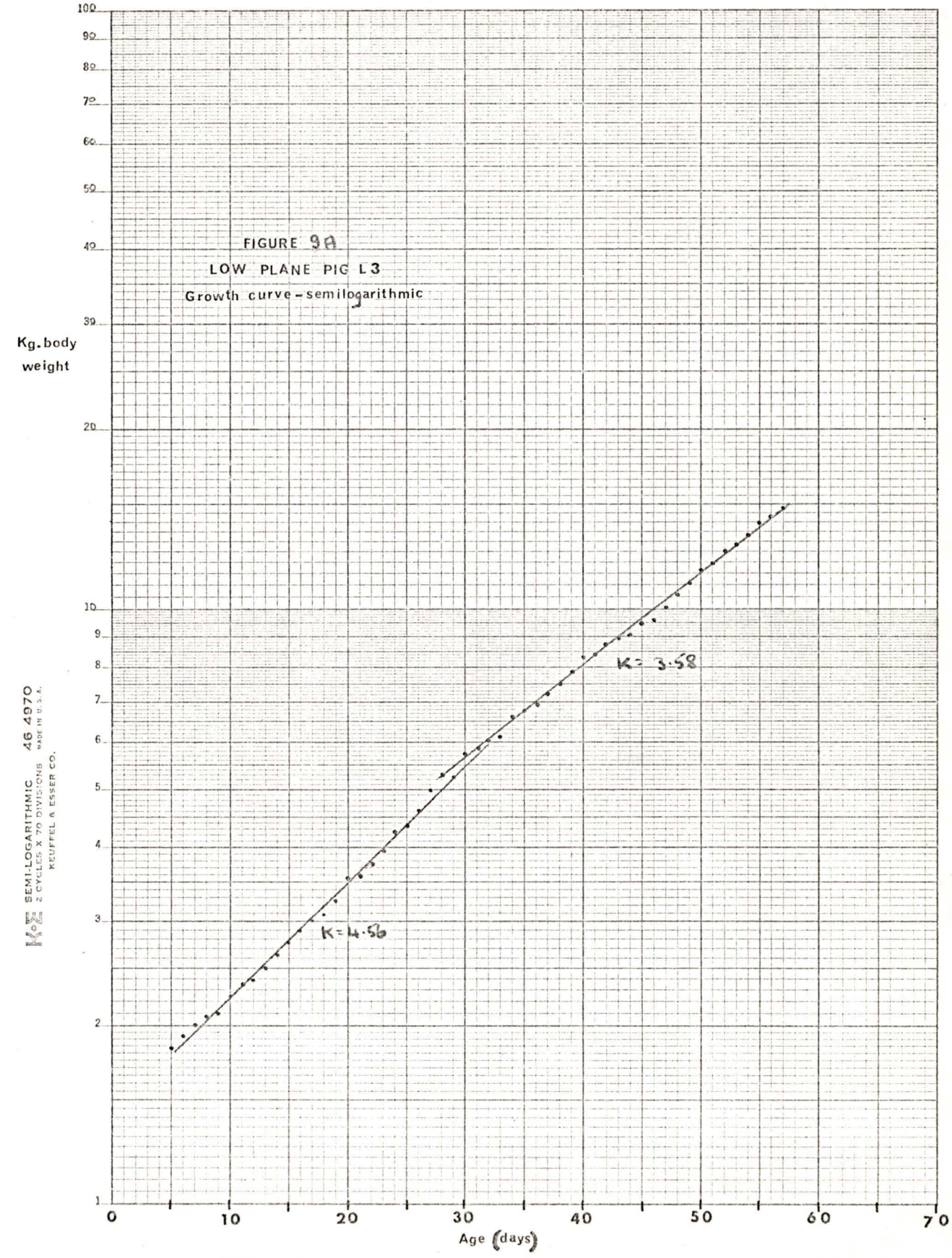
FIGURE 9a
LOW PLANE PIG L3
Growth curve - semilogarithmic
Kg. body weight
Age (days)
K=4.56
K=3.58
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
0
10
20
30
40
50
60
70
SEMI-LOGARITHMIC 46 4970
2 CYCLES X 70 DIVISIONS MADE IN U.S.A.
KEUFFEL & ESSER CO.

EXPERIMENT II

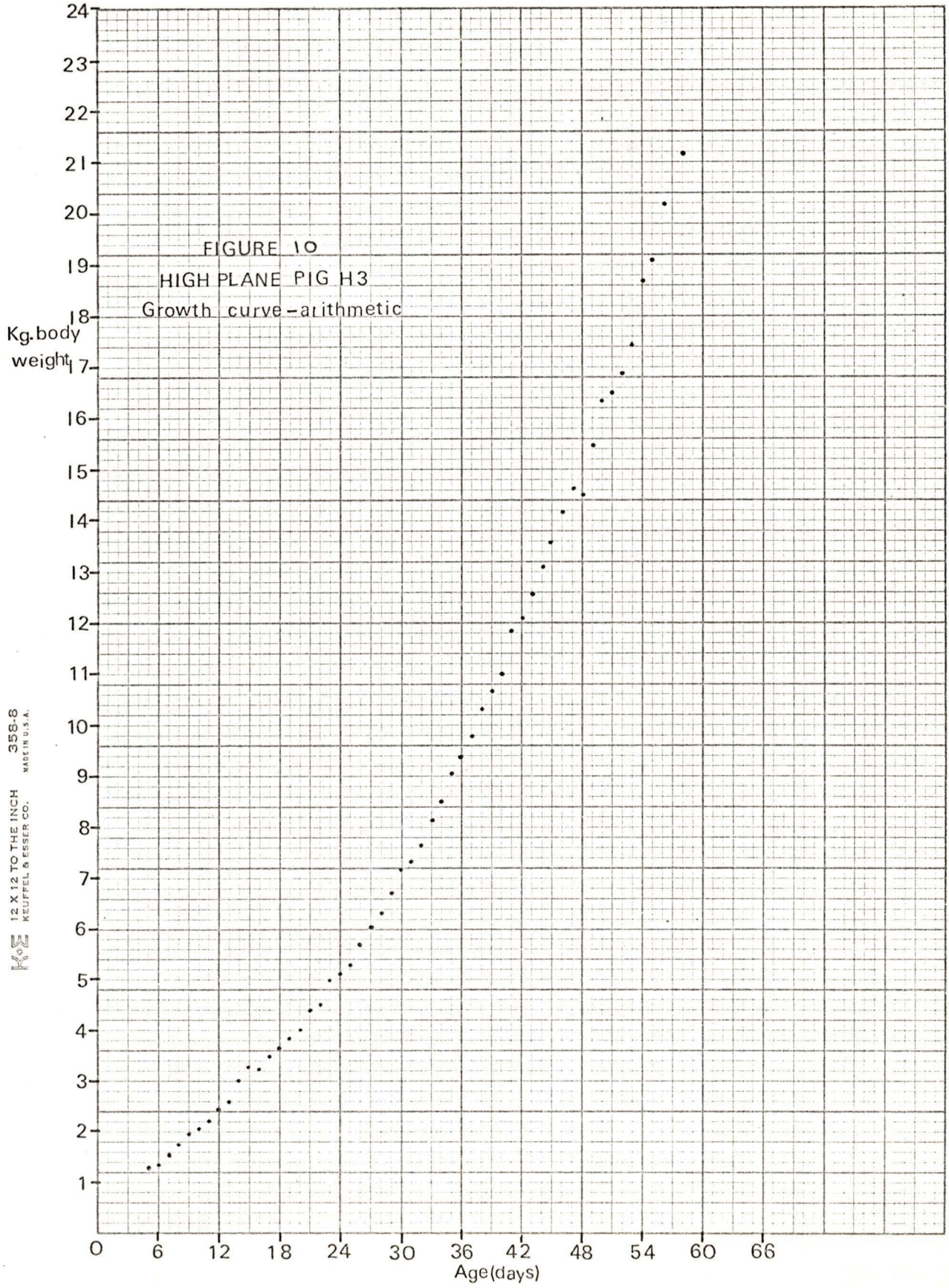
FIGURE 10
HIGH PLANE PIG H3
Growth curve - arithmetic
Kg. body weight
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
6
12
18
24
30
36
42
48
54
60
66
Age (days)
12 X 12 TO THE INCH
KEUFFEL & ESSER CO.
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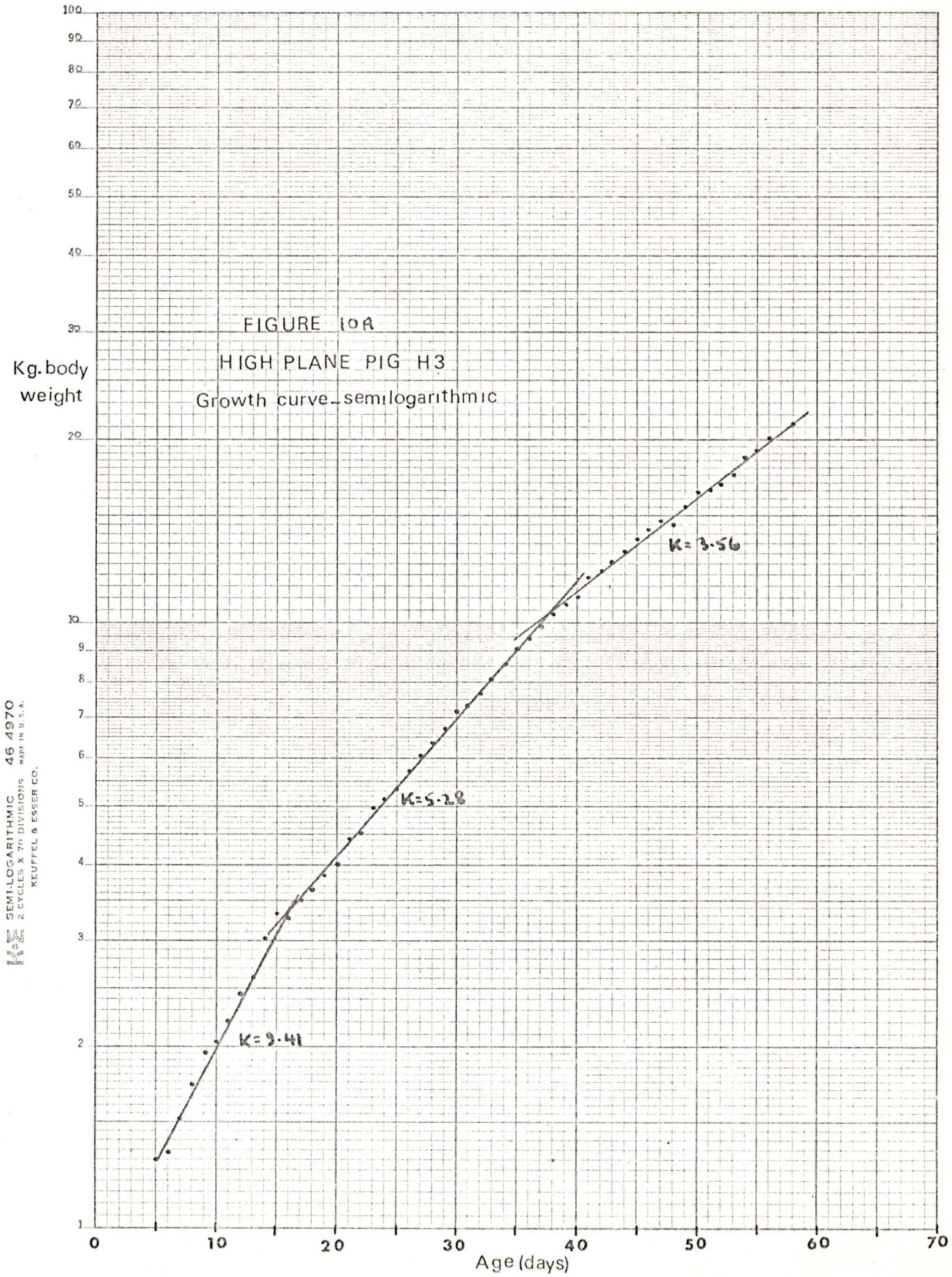
FIGURE 10A
HIGH PLANE PIG H3
Growth curve - semilogarithmic
Kg. body weight
Age (days)
K=9.41
K=5.28
K=3.56
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
0
10
20
30
40
50
60
70
SEMI-LOGARITHMIC 46 4970
2 CYCLES X 70 DIVISIONS MADE IN U.S.A.
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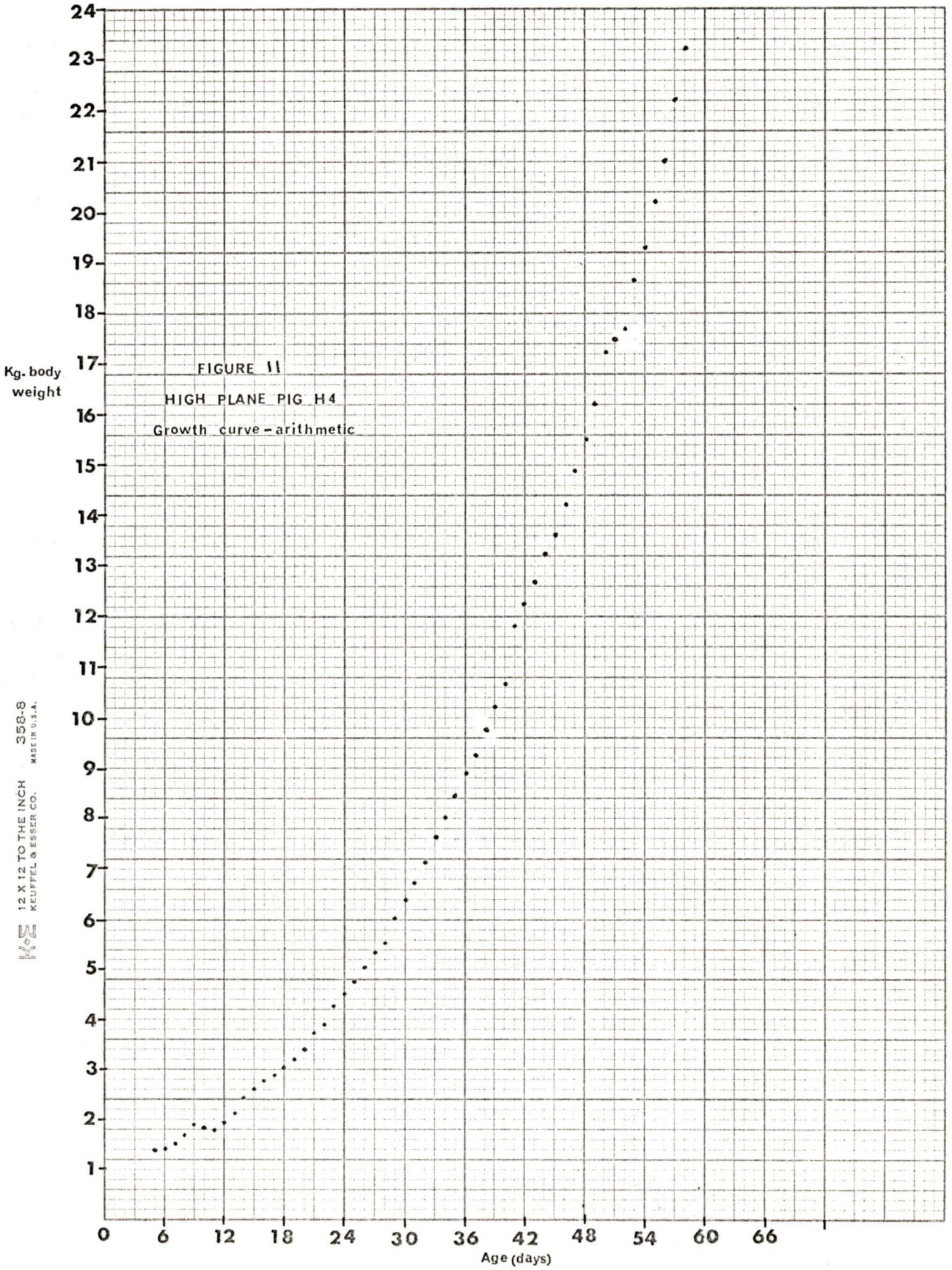
Kg. body weight
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
6
12
18
24
30
36
42
48
54
60
66
Age (days)
FIGURE 11
HIGH PLANE PIG H4
Growth curve - arithmetic
12 X 12 TO THE INCH
KEUFFEL & ESSER CO.
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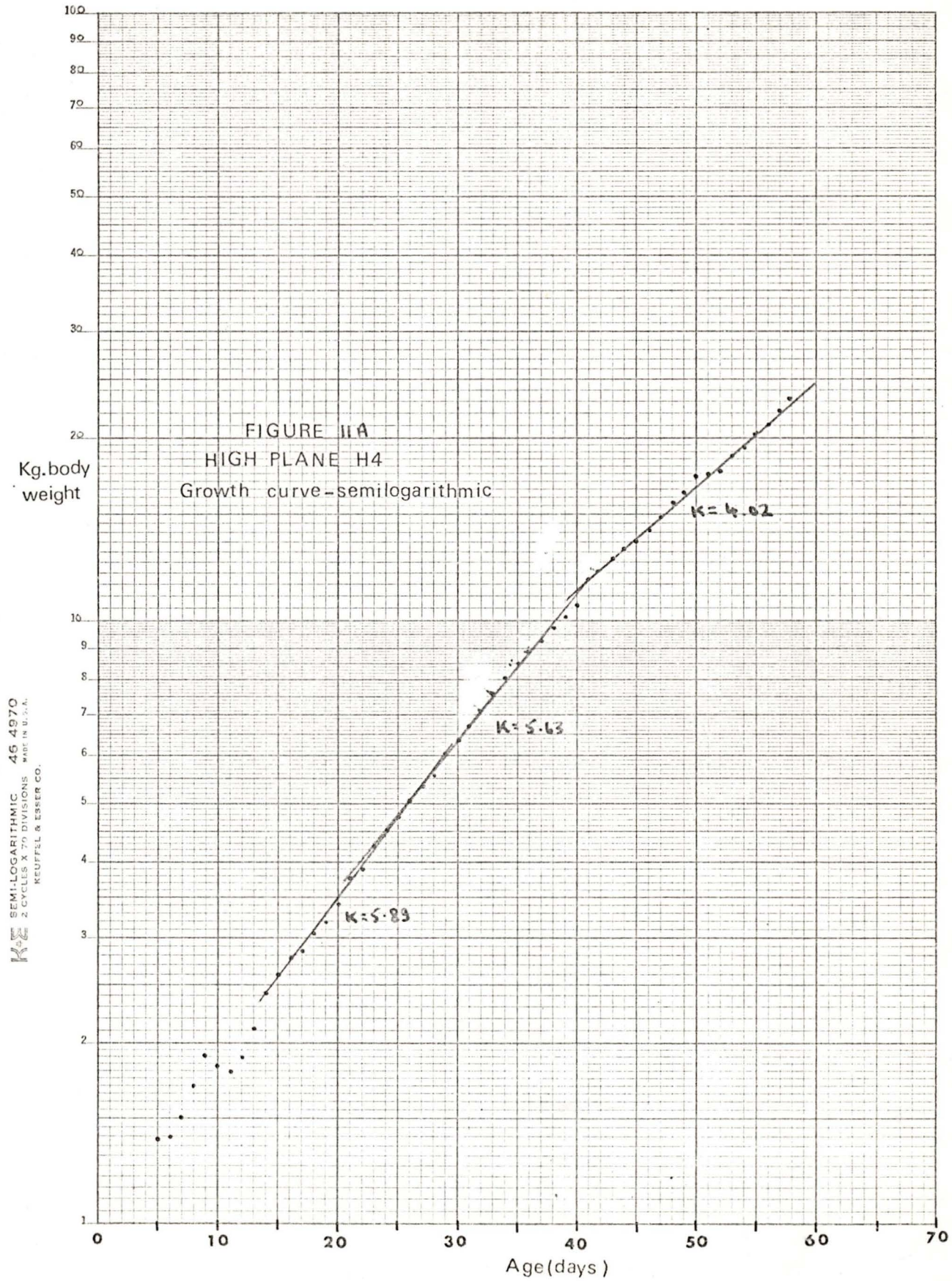
FIGURE IIA
HIGH PLANE H4
Growth curve-semilogarithmic
Kg.body weight
Age(days)
K=5·89
K=5·63
K=4·82
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
0
10
20
30
40
50
60
70
SEMI-LOGARITHMIC 46 4970
2 CYCLES X 70 DIVISIONS MADE IN U.S.A.
KEUFFEL & ESSER CO.

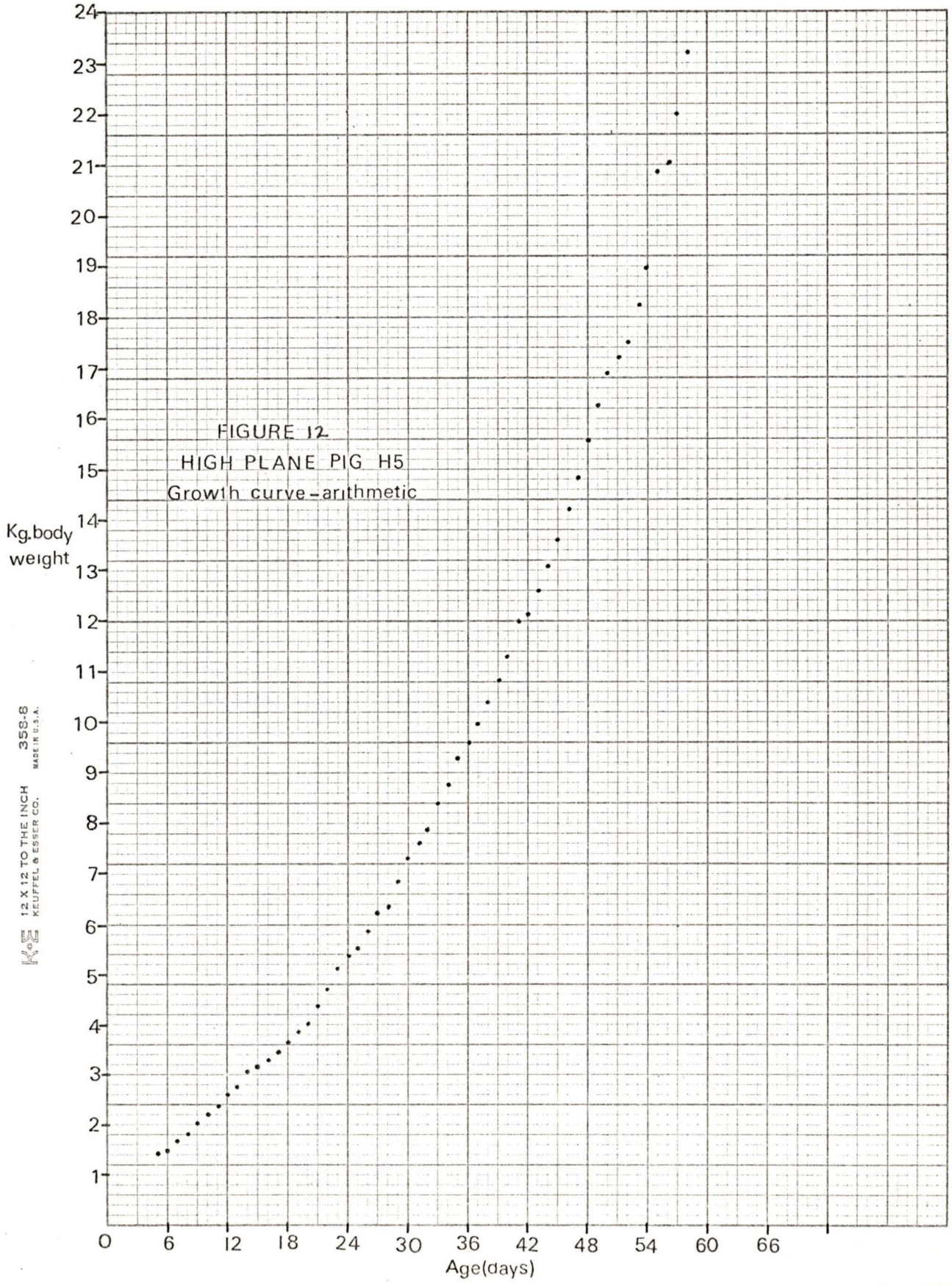
FIGURE 12.
HIGH PLANE PIG H5
Growth curve - arithmetic
Kg. body weight
Age (days)
0
6
12
18
24
30
36
42
48
54
60
66
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
12 X 12 TO THE INCH
KEUFFEL & ESSER CO.
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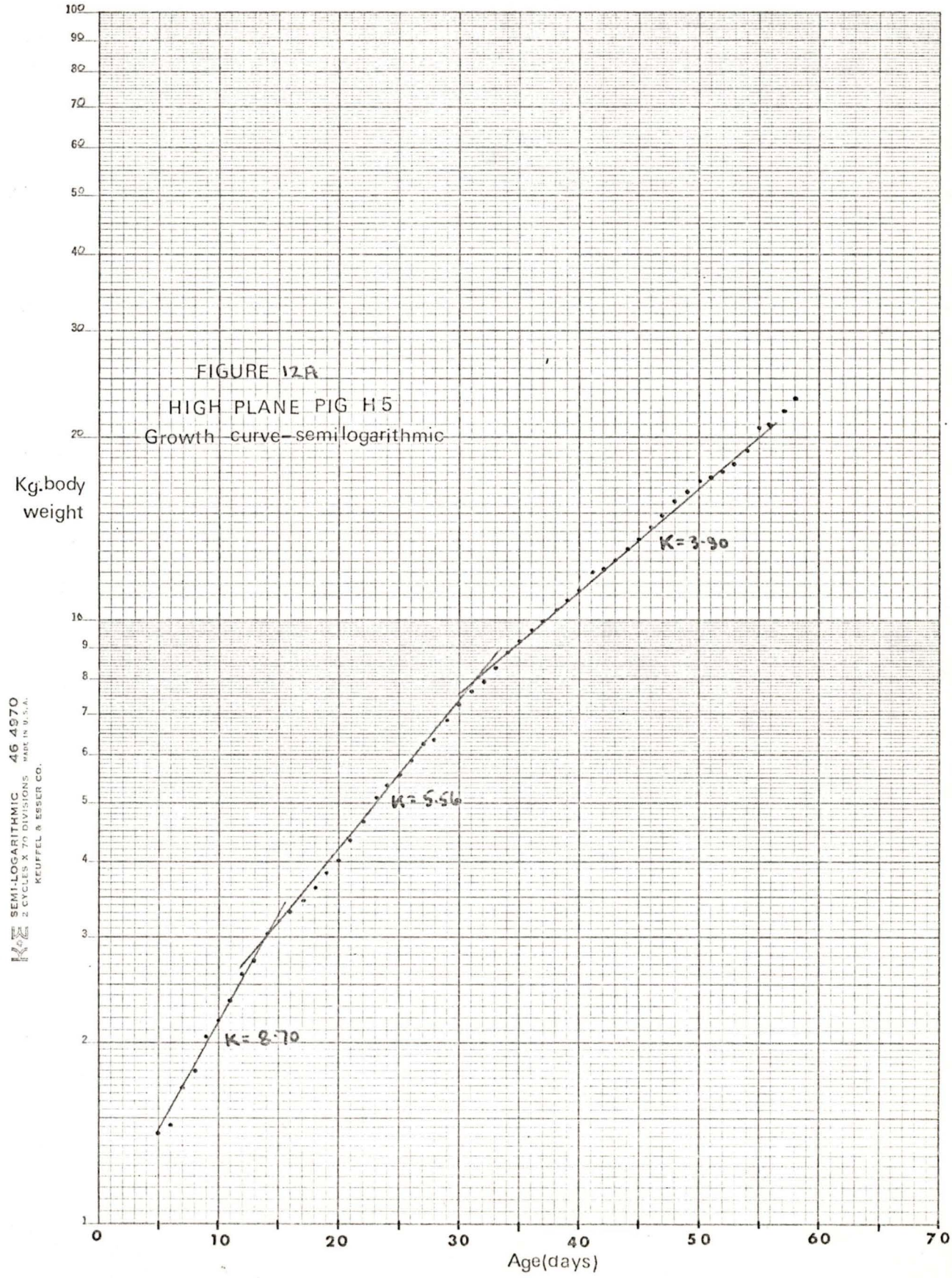
FIGURE 12A
HIGH PLANE PIG H5
Growth curve–semi logarithmic
Kg. body weight
Age(days)
K=8·70
K=5·56
K=3·90
100
99
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
0
10
20
30
40
50
60
70
SEMI-LOGARITHMIC 46 4970
2 CYCLES X 70 DIVISIONS MADE IN U.S.A.
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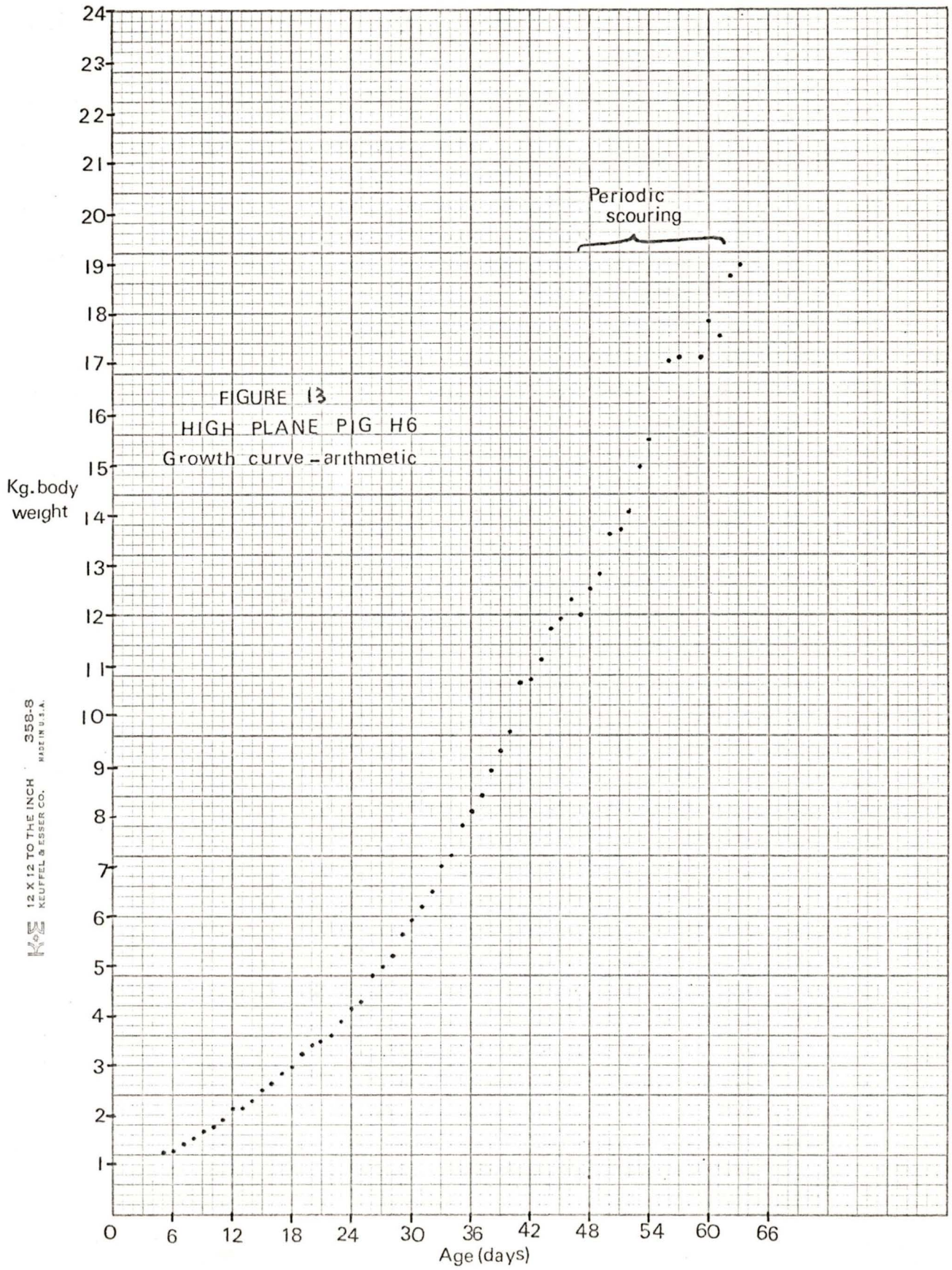

FIGURE 13
HIGH PLANE PIG H6
Growth curve - arithmetic

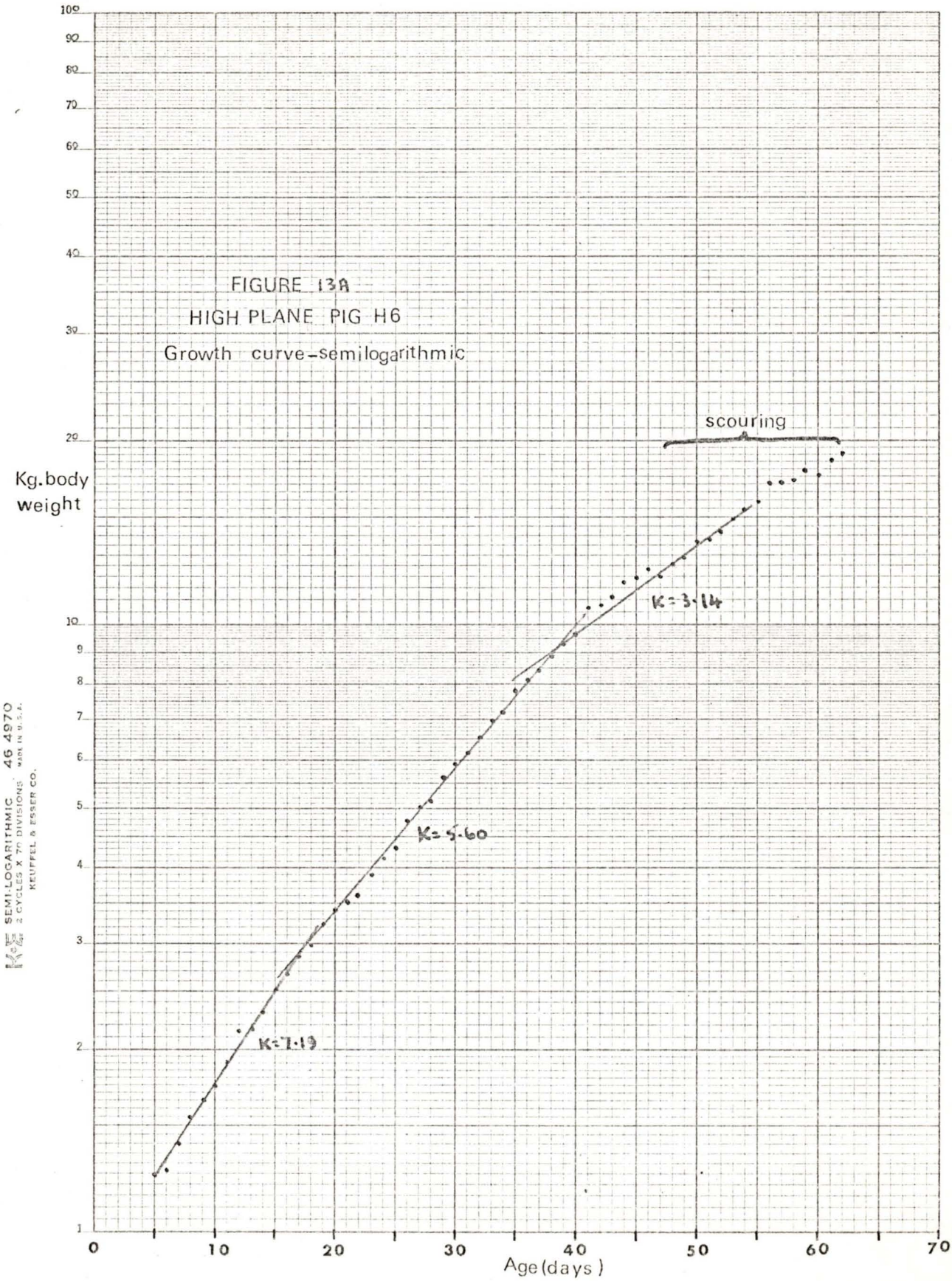
FIGURE 13A
HIGH PLANE PIG H6
Growth curve-semilogarithmic
scouring
K=7·19
K=5·60
K=3·14
Kg. body weight
Age (days)
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
0
10
20
30
40
50
60
70
SEMI-LOGARITHMIC 46 4970
2 CYCLES X 70 DIVISIONS MADE IN U.S.A.
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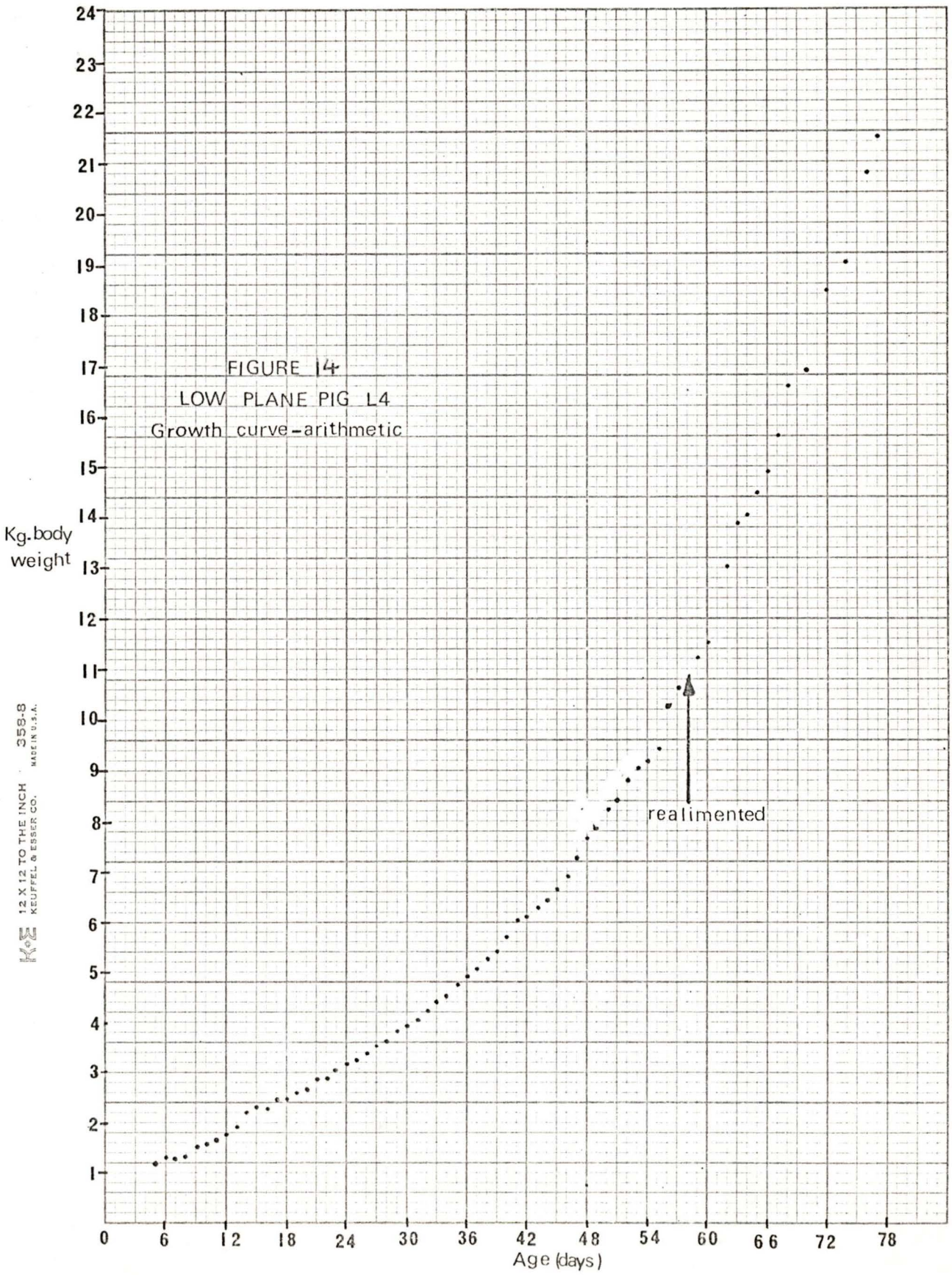
FIGURE 14
LOW PLANE PIG L4
Growth curve-arithmetic
Kg. body weight
realimented
Age (days)
0
6
12
18
24
30
36
42
48
54
60
66
72
78
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
12 X 12 TO THE INCH 358-8
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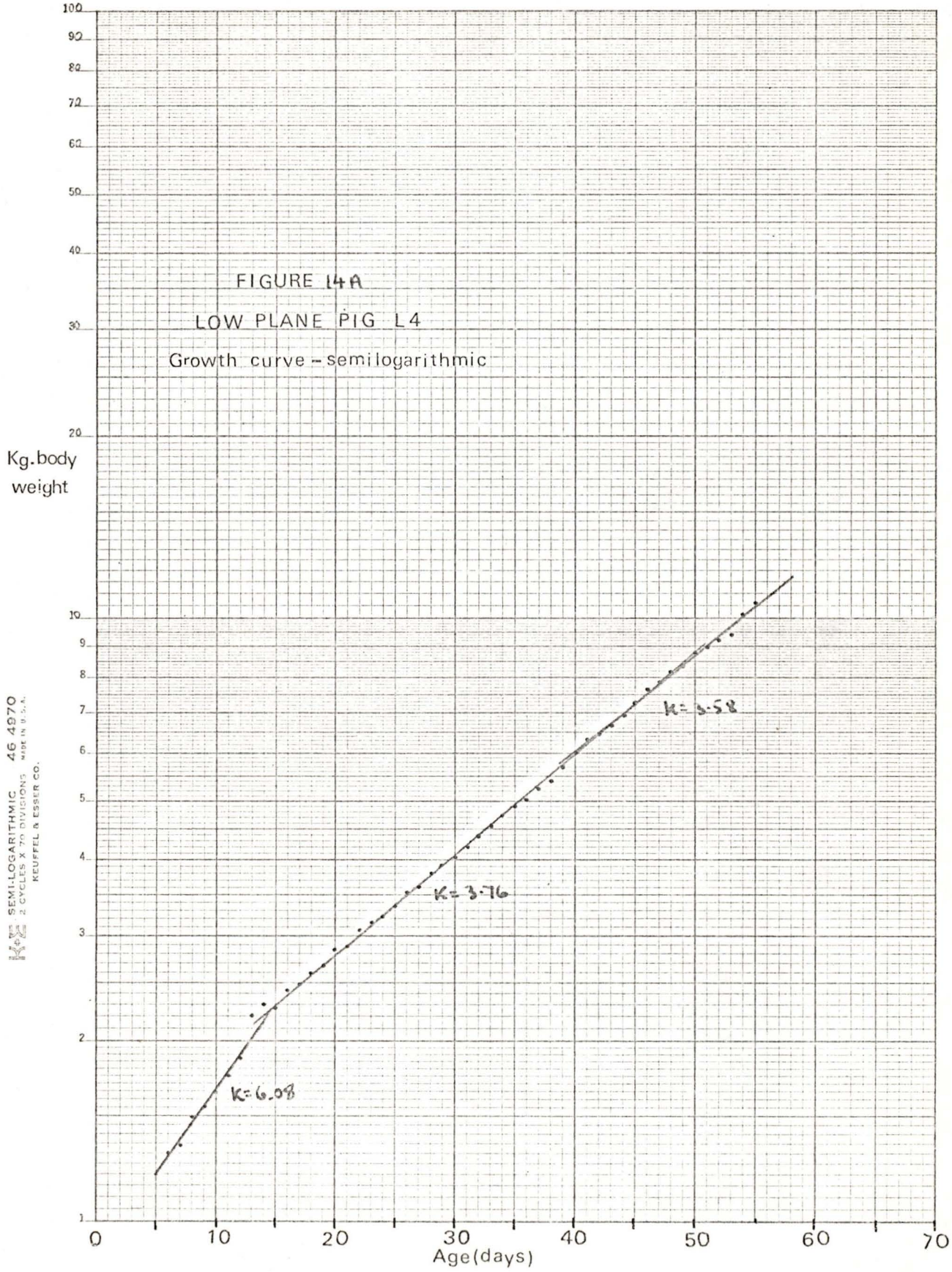
FIGURE 14A

LOW PLANE PIG L4

Growth curve – semilogarithmic



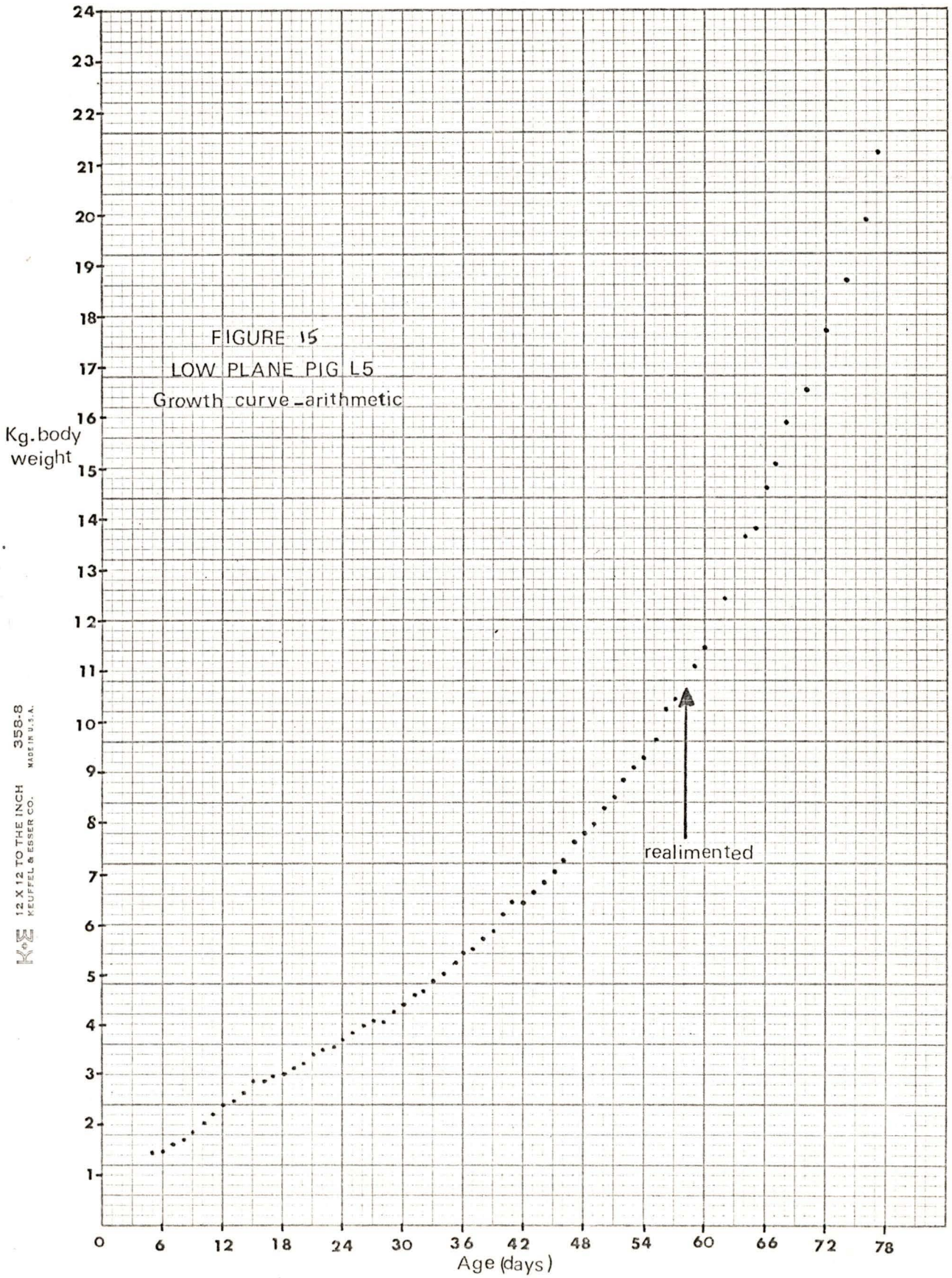


FIGURE 15
LOW PLANE PIG L5
Growth curve - arithmetic
Kg. body weight
realimented
Age (days)
0
6
12
18
24
30
36
42
48
54
60
66
72
78
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
12 X 12 TO THE INCH
KEUFFEL & ESSER CO.
358-8
MADE IN U.S.A.

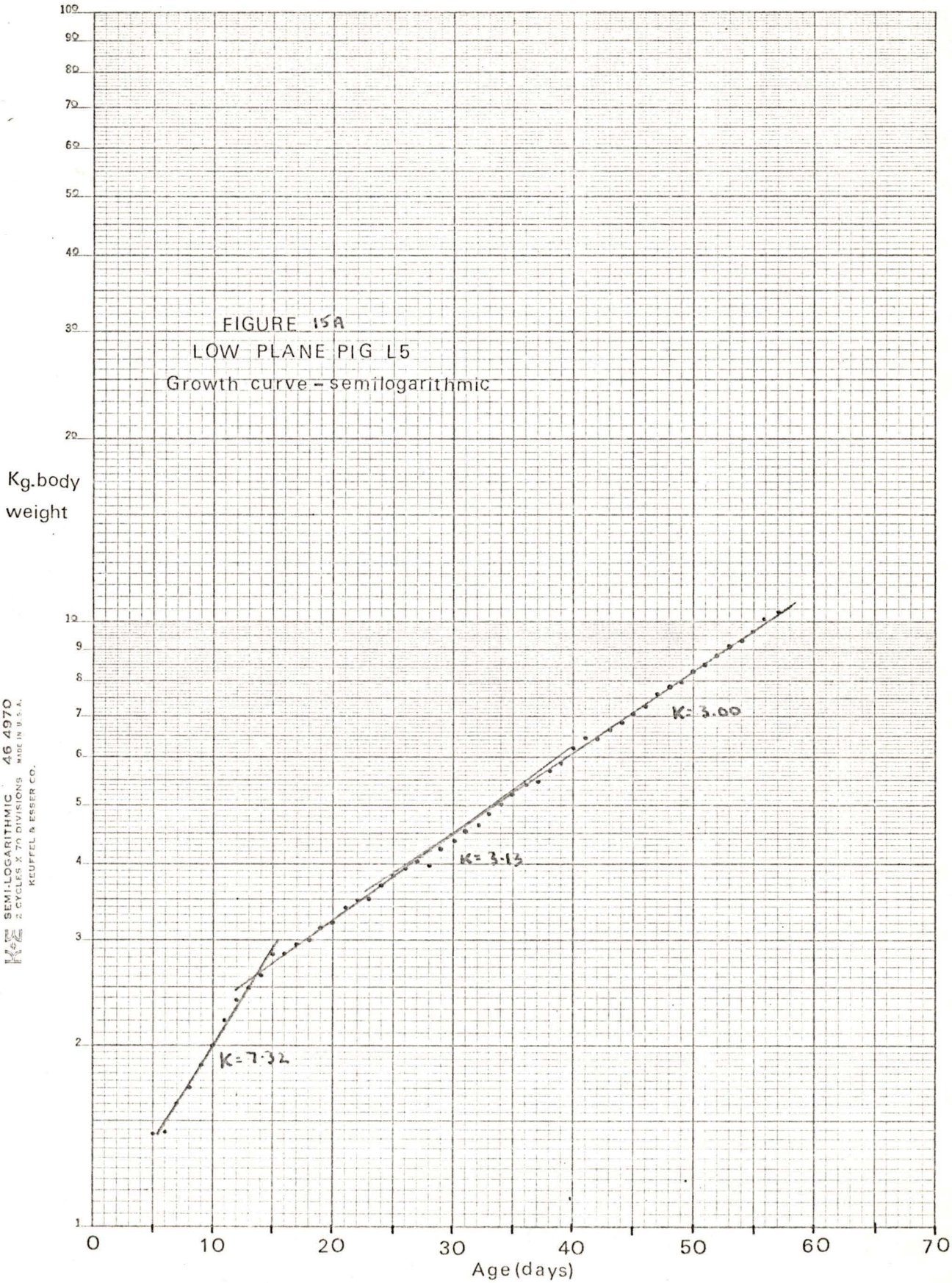


FIGURE 15A
LOW PLANE PIG L5
Growth curve – semilogarithmic
Kg. body weight
Age (days)
K= 7.32
K= 3.13
K= 3.00
SEMI-LOGARITHMIC 46 4970
2 CYCLES X 70 DIVISIONS MADE IN U.S.A.
KEUFFEL & ESSER CO.

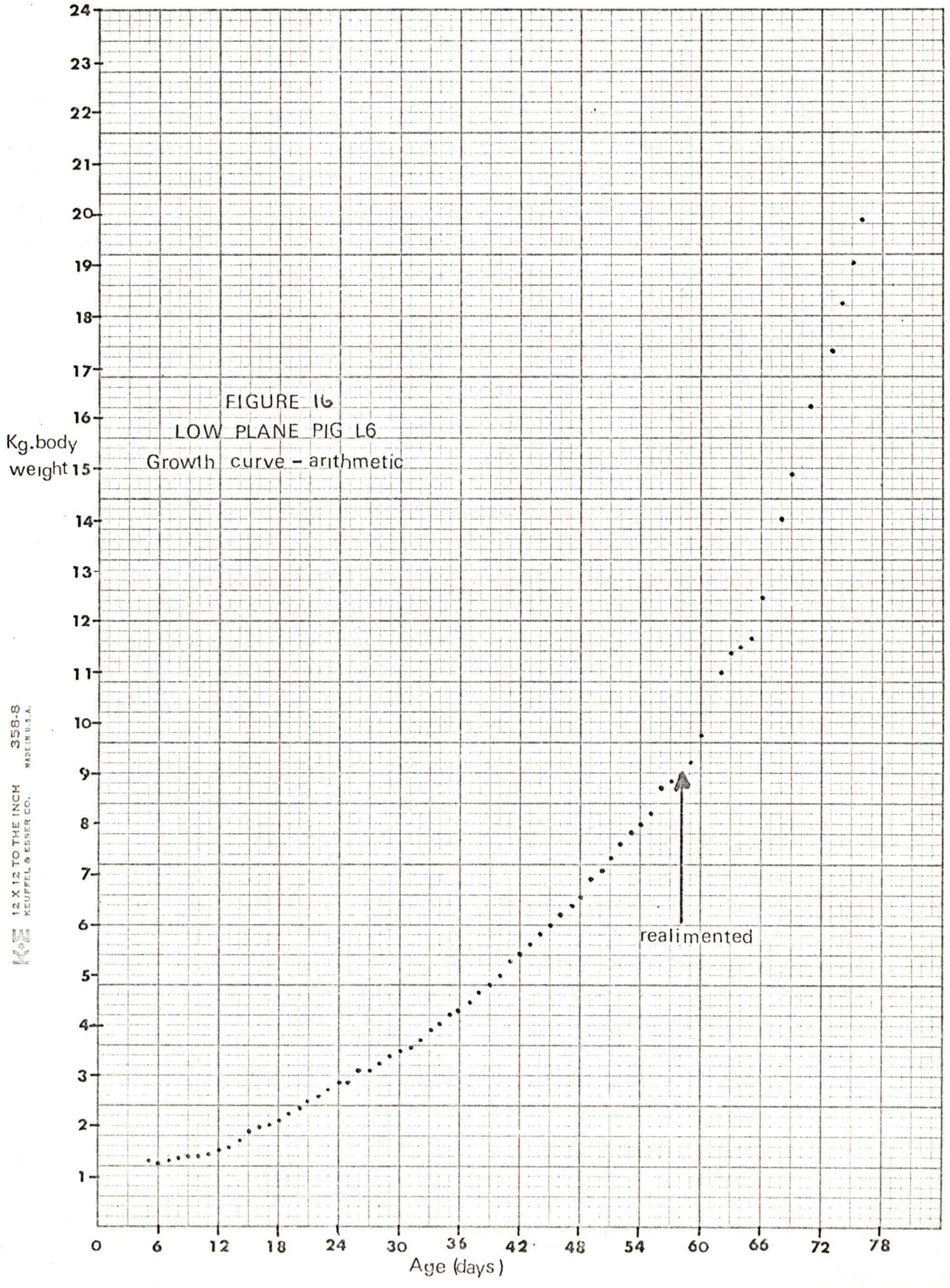


FIGURE 16
LOW PLANE PIG L6
Growth curve - arithmetic
Kg. body weight
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
A
realimented
0
6
12
18
24
30
36
42
48
54
60
66
72
78
Age (days)
12 X 12 TO THE INCH
KEUFFEL & ESSER CO.
358-8
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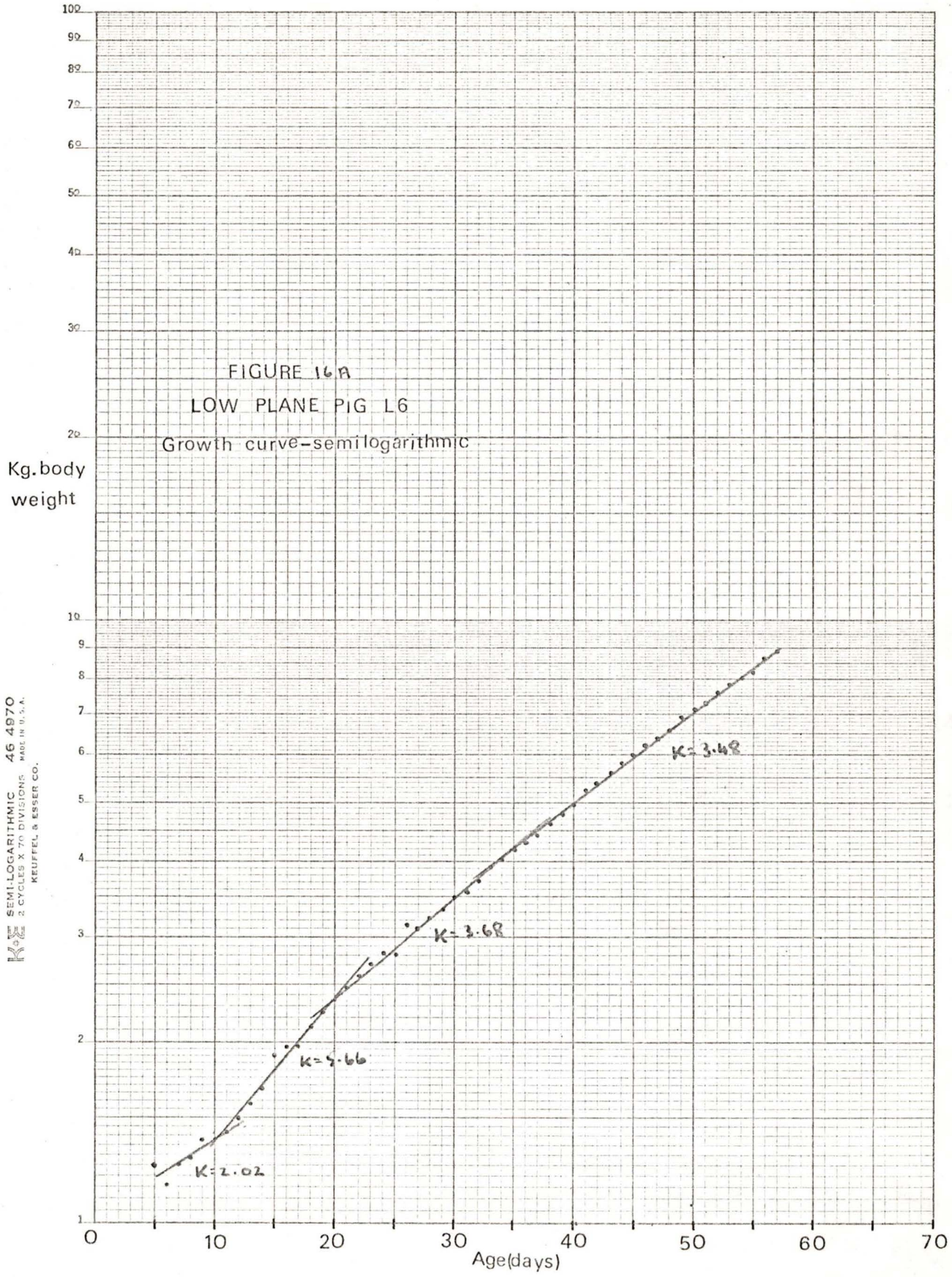
FIGURE 16A
LOW PLANE PIG L6
Growth curve-semilogarithmic
Kg. body weight
Age(days)
K=2.02
K=4.66
K=3.68
K=3.48
SEMI-LOGARITHMIC 46 4970
2 CYCLES X 70 DIVISIONS MADE IN U.S.A.
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Efficiency of live weight gain (feed efficiency)

$$\text{Feed efficiency} = \frac{\text{body weight day}_n - \text{body weight day}_{n-1}}{\text{dry matter milk intake day}_{n-1}}$$

The expression used to calculate feed efficiency in this study follows the recommendation of Brody (1945) where feed intake is the independent variable and therefore the denominator. Traditionally feed efficiency is the amount of food to produce one unit of gain, being in this form more closely related to the economics of feedstuff buying. The expression used here can of course be converted to the traditional form by taking its reciprocal.

Daily feed efficiencies are presented in Appendix Tables XVI to XXVII a) when calculated using body weight predicted by phasic polynomial equations and b) when calculated using body weight predicted by the growth rate constants. Daily dry matter milk intake was calculated at each predicted body weight from the milk intake regression equations of Table III.

Feed efficiency using growth rate constants

A consistent increase in daily feed efficiency throughout each growth phase was noted when body weight was calculated by growth rate constants. Efficiency appears to increase in a regular manner throughout each phase after which it drops abruptly to a new less efficient level at the beginning of the next phase and begins increasing again. In physiological terms, a consistent increase in feed efficiency is unlikely: the energy costs of maintaining physiological systems within the body, the maintenance costs, increase with increasing age

or body weight. Therefore of the energy fed to the animal, a larger and larger proportion of it is used to meet maintenance requirements so that less is available for increase in size, weight, etc. The efficiency of liveweight growth must then decrease with age or body weight. Daily efficiencies calculated using the growth constants increases over considerable periods in a regular fashion; although the efficiency at the end of the total experimental period is less than at the beginning in keeping with the thermodynamic considerations outlined above, it is felt that the phasic efficiency increase is an artefact of the instantaneous relative growth concept.

The only occasion when efficiency of overall growth will increase is during a period of compensatory growth. This effect is normally noted over a relatively short time interval.

Feed efficiency using the phasic polynomial equations

When body weight is calculated from the phasic polynomial equations efficiency of liveweight gain appears to cycle within each phase of growth so that over short periods, efficiency increases followed by a decrease and vice versa.

The values of feed efficiency calculated using the phasic polynomial equations show a wider range of values throughout any one phase than do those calculated using the instantaneous relative growth rate equations. Since the magnitude of the differences in body weights predicted by these two expressions is usually relatively small, the differences in feed efficiencies appear at first to be inconsistent with the body weight data. However, feed efficiency is a ratio, the denominator of which (dry matter intake) is determined by the predicted

body weight. Small variations in the denominator greatly influence the value of feed efficiency and such variations in the denominator are the result of small variations in the predicted body weight. In other words, the small differences in predicted body weight are amplified in the feed efficiency calculation.

Why determine feed efficiency? Traditionally the feed conversion efficiency is used as an indication of the economics of practical animal husbandry. In its simplest form, the quantity of food is directly related to cost, and liveweight gain is related to profit. Therefore, the greater the gain per unit of feed, the greater the profit margin as a result of faster gain and lowered overheads. In body composition studies, feed efficiency may be interpreted as an indication of the composition of gain. Energy absorbed from the intestinal tract becomes part of the energy pool of the body. If there is a net gain of energy then its addition to body deposits must be in the form of either protein or fat (and to a small degree, carbohydrate). One gram of body protein has approximately 5 g of water associated with it, while fat contains on average only 10% water (Reid et al 1963) so that the deposition of one gram of wet protein has associated with it only about one quarter the dry matter associated with one gram of fat. If only protein were laid down during growth, the feed efficiency would be very high. The value of feed efficiency may therefore be used as an indication of the composition of gain since the liveweight gain is "wet" and the feed intake is expressed as dry matter.

Efficiencies of liveweight gain were of a similar magnitude

to those reported by several authors for artificially raised piglets exhibiting rapid growth. Braude et al (1970) reported a slightly better rate of growth from birth to 28 days of age when piglets were fed reconstituted milk (20% solids) on a high plane of nutrition. Feed conversion efficiencies were measured throughout the total growth period of 28 days and were comparable to, though slightly better than, those of the high plane piglets in this study. Table VIII shows the average efficiency of liveweight gain from birth to 56 days. It is apparent that the higher rate of growth shown on the higher level of feeding occurred at the expense of efficiency of liveweight gain. Many workers (e.g. Lucas and Lodge 1961; Braude et al 1970) have noted the same effect.

Table IX represents an attempt to summarise the lengthy data of Appendix Tables XVI to XXVII. The efficiencies of liveweight gain at different body weights are presented, as calculated from body weights predicted by the phasic polynomial equations. It must be pointed out that while presentation of data at fixed body weights is useful, it does not allow for the interference of growth "breaks" when the efficiency may change rather abruptly. For more detailed data on efficiency changes with age and weight see Appendix Tables XVI to XXVII.

TABLE VIII: AVERAGE EFFICIENCIES OF LIVEWEIGHT GAIN FROM 7 DAYS TO 56 DAYS OF AGE*

Piglet No.	Efficiency	Piglet No.	Efficiency
H1	0.82	L1	0.97
H2	0.81	L2	1.02
H3	0.89	L3	0.94
H4	0.91	L4	0.92
H5	0.86	L5	0.82
H6	0.86	L6	0.90
Mean	0.86		0.93

*Calculated from actual data. Efficiency of liveweight gain = Weight gained (kg) between days 7 and 56/Milk intake (kg dry matter) over the same period.

TABLE IX: EFFICIENCY OF LIVEWEIGHT GAIN (FEED EFFICIENCY) AT DIFFERENT BODY WEIGHTS*

Body weight, kg	Expt. I H1	H2	Expt. II H3	H4	H5	H6	Expt. I L1	L2	L3	Expt. II L4	L5	L6
3	0.70	0.88	1.58	1.02	1.24	-	0.98	0.97	0.99	0.82	0.75	0.79
6	-	0.83	0.97	1.17	0.97	1.10	1.40	0.99	1.06	0.80	-	0.82
9	0.99	-	0.93	1.01	0.89	-	0.96	1.01	0.81	0.78	0.73	-
12	-	0.70	0.87	0.97	0.82	0.53	1.05	1.00	0.95	-	-	-
15	0.78	0.63	0.73	0.83	0.81	0.01	0.99					
18	0.80	-	0.84	0.71	0.68	-	0.94					
21	0.74	-	-	0.62	-	-	0.85					

*(Feed efficiency = g liveweight gain per g of milk dry matter)

BODY COMPOSITION

EXPERIMENT I

Figure 17: Body composition – H1

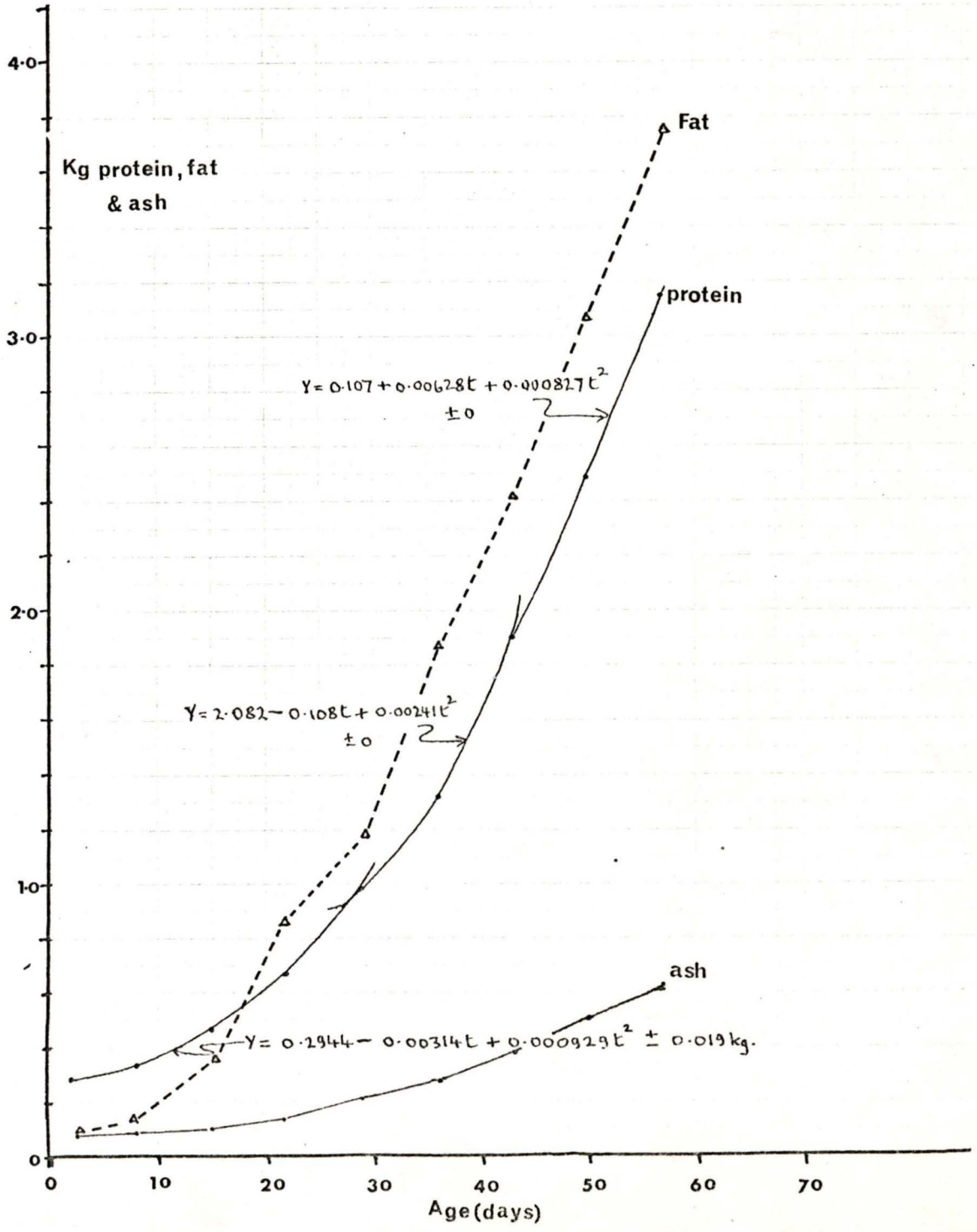


Figure 18: Body composition – H2

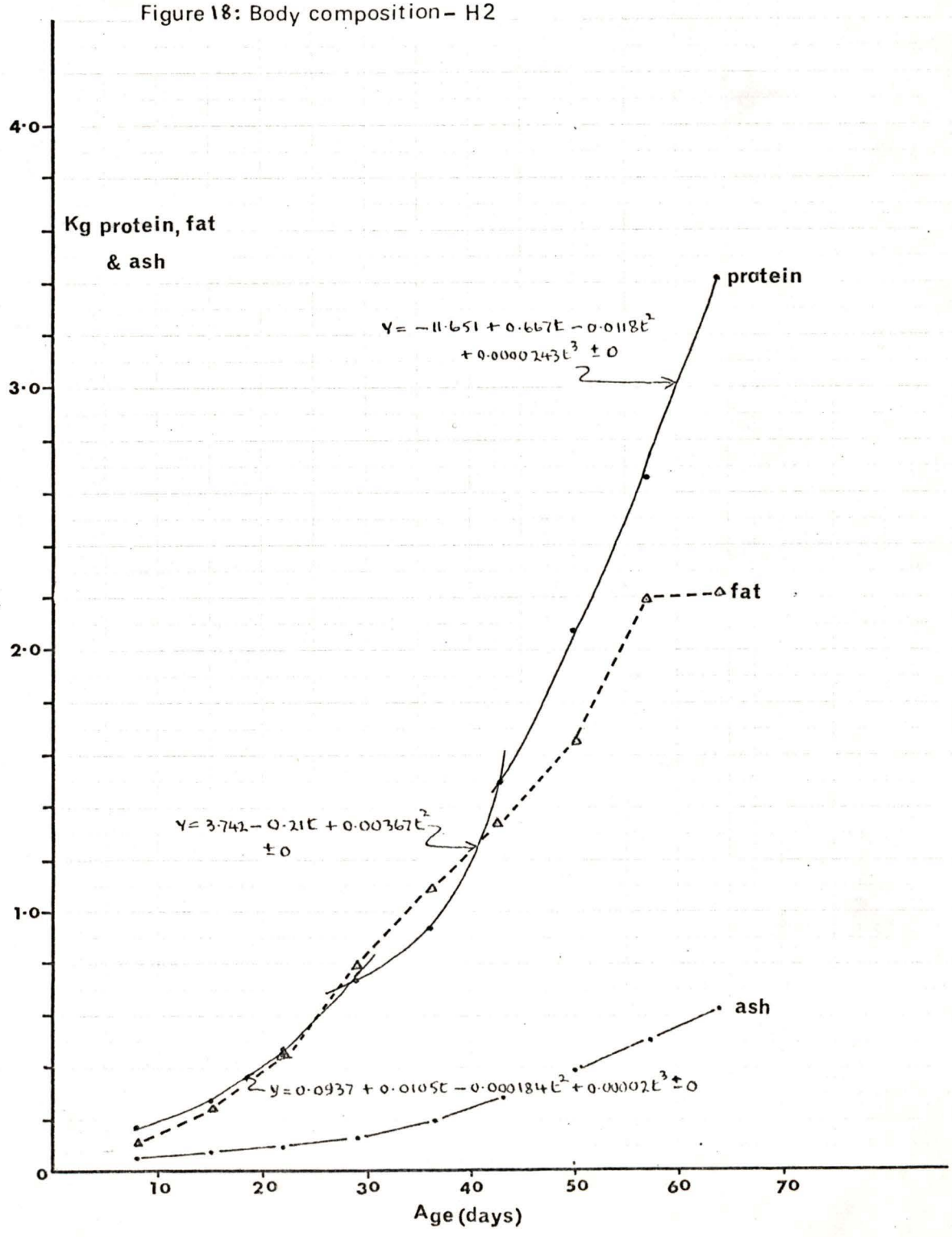


Figure 19: Body composition – L1

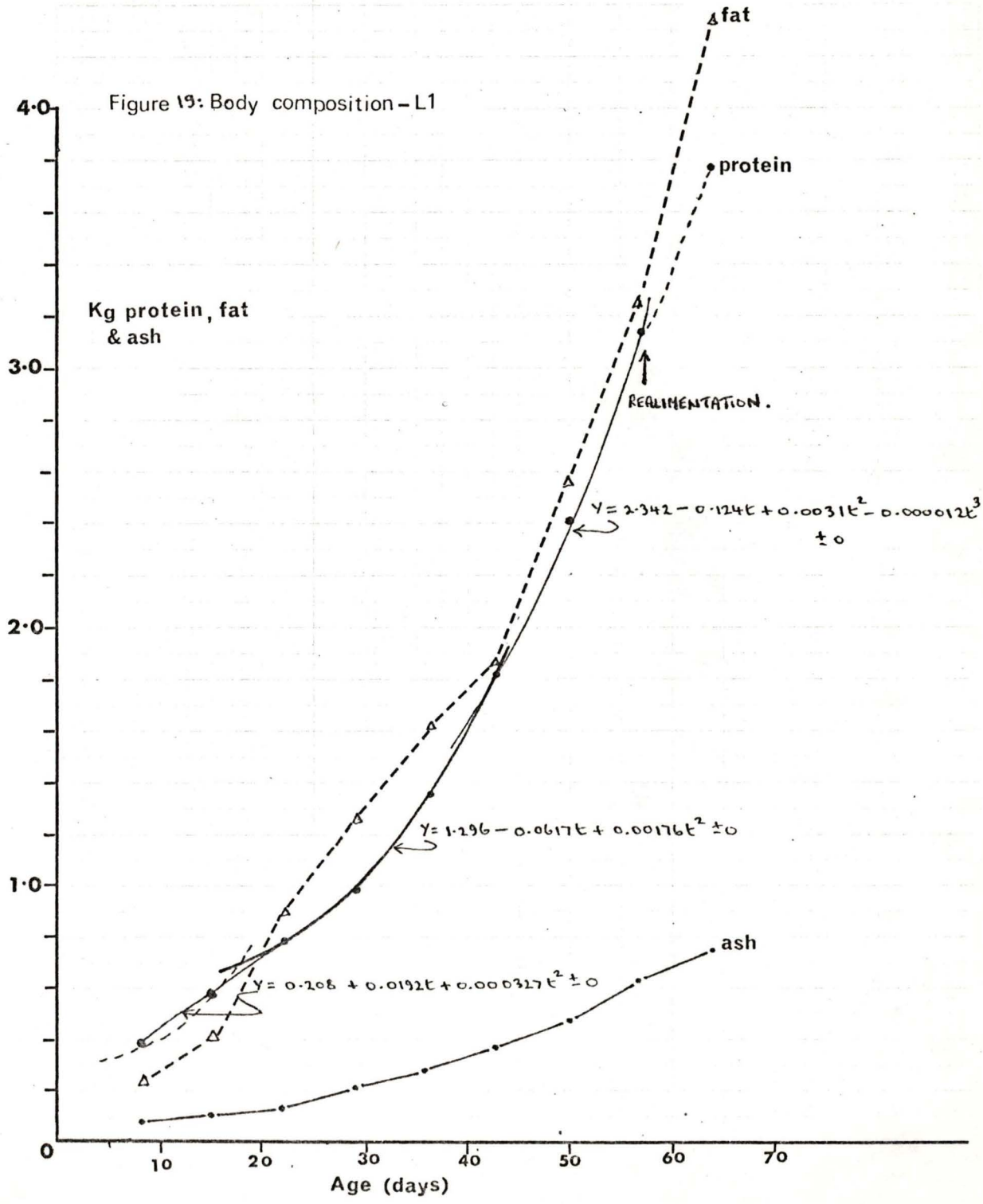


Figure 20: Body composition – L2

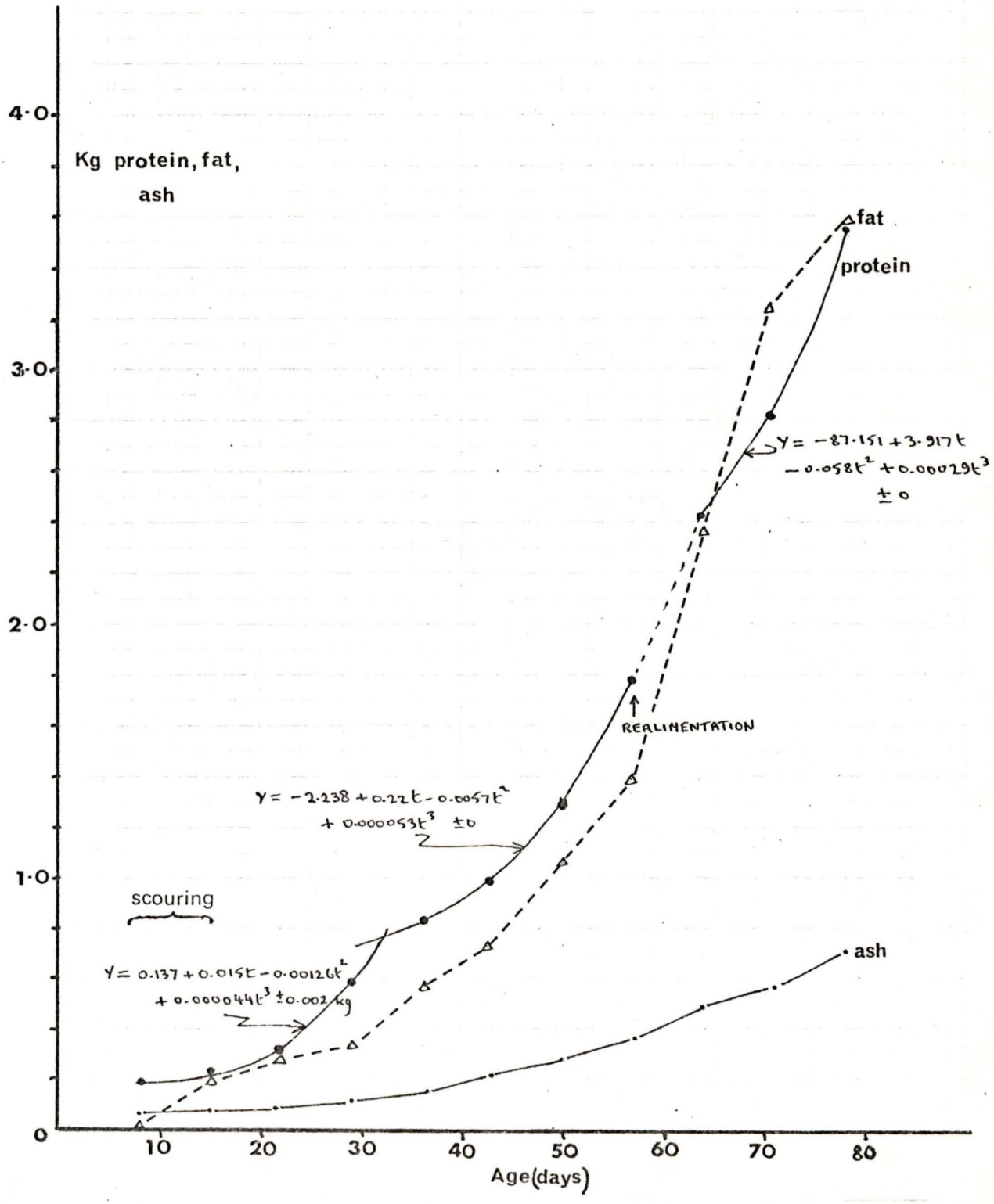
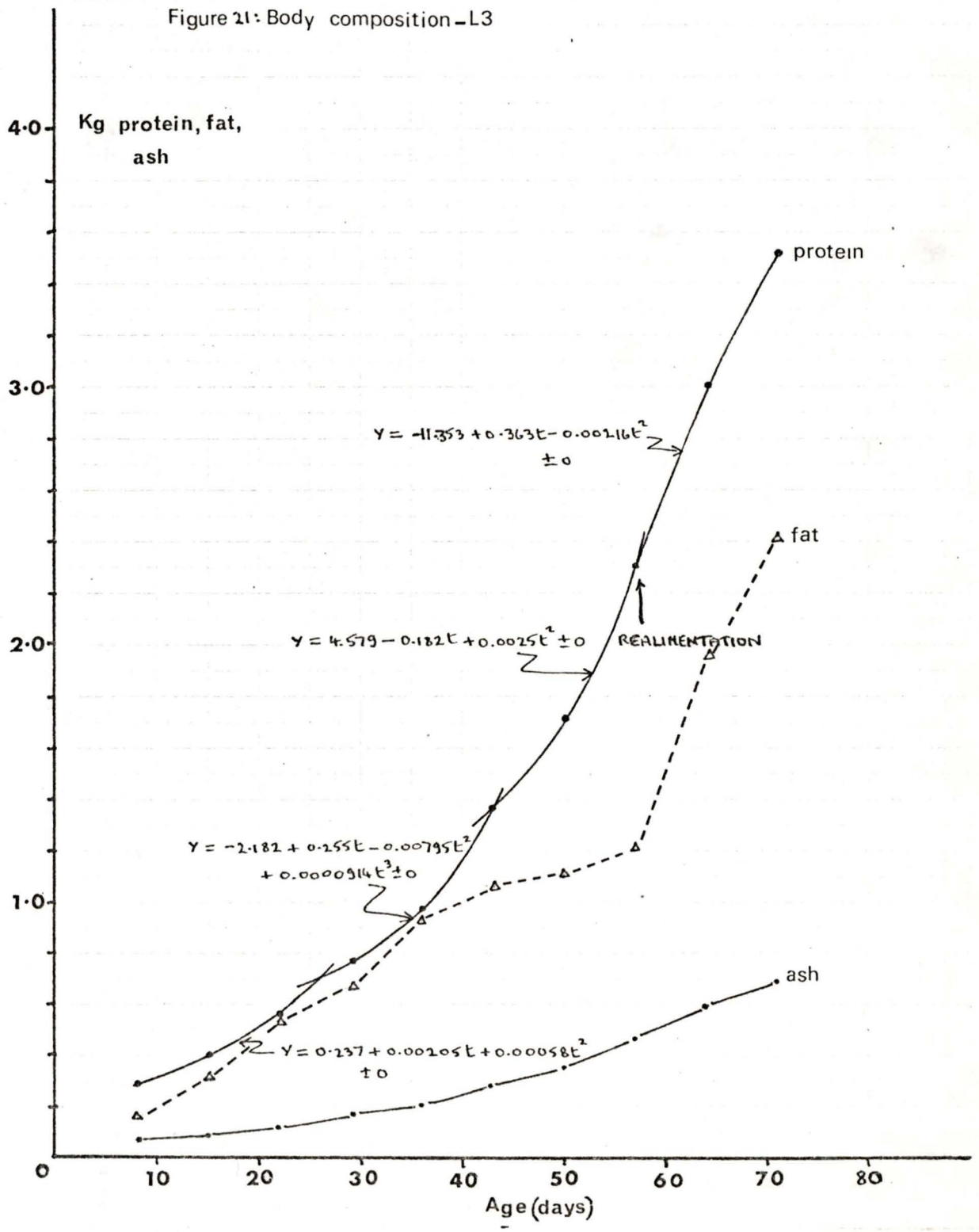


Figure 21: Body composition - L3



BODY COMPOSITION

EXPERIMENT II

Figure 22: Body composition - H3

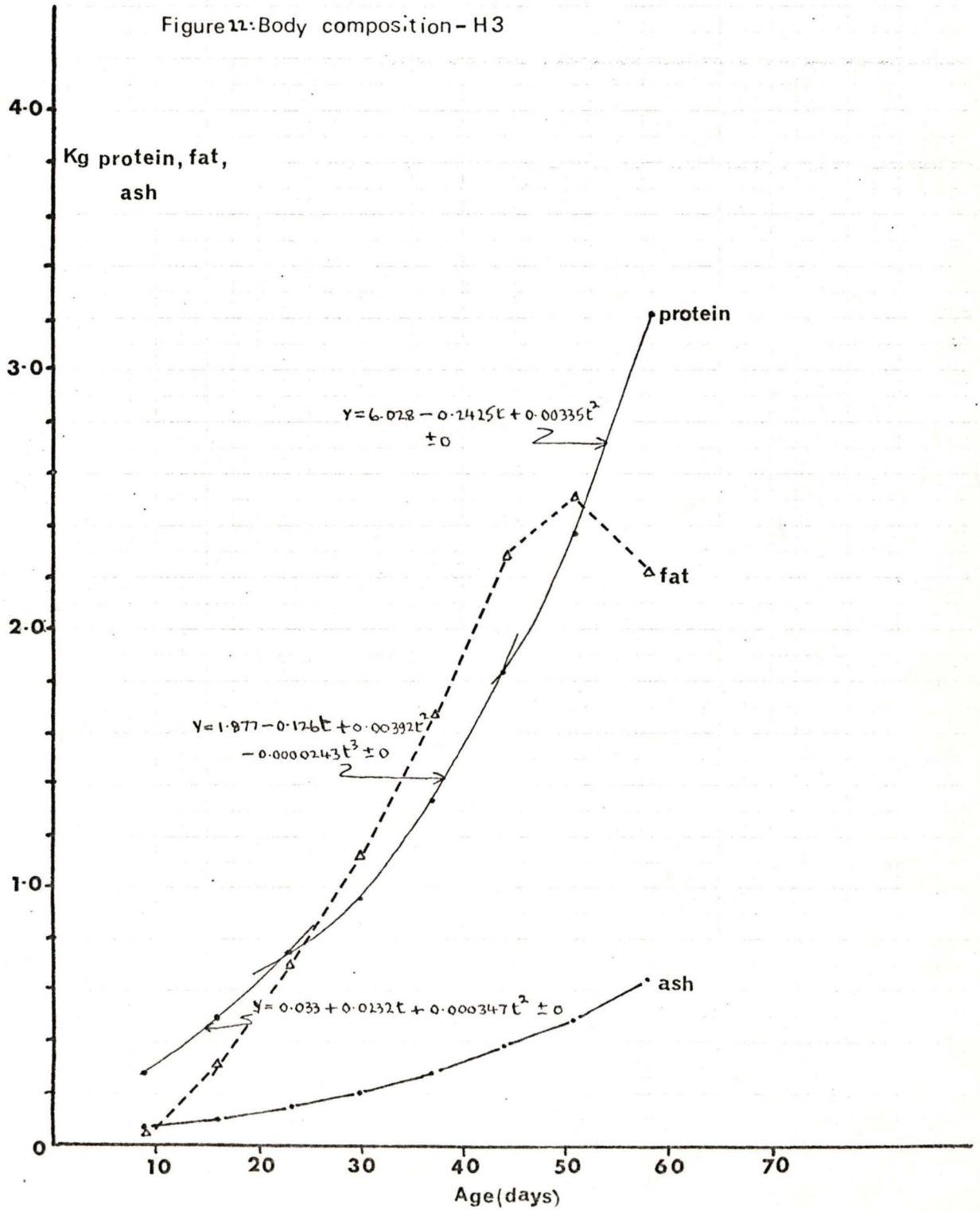


Figure 23: Body composition – H4

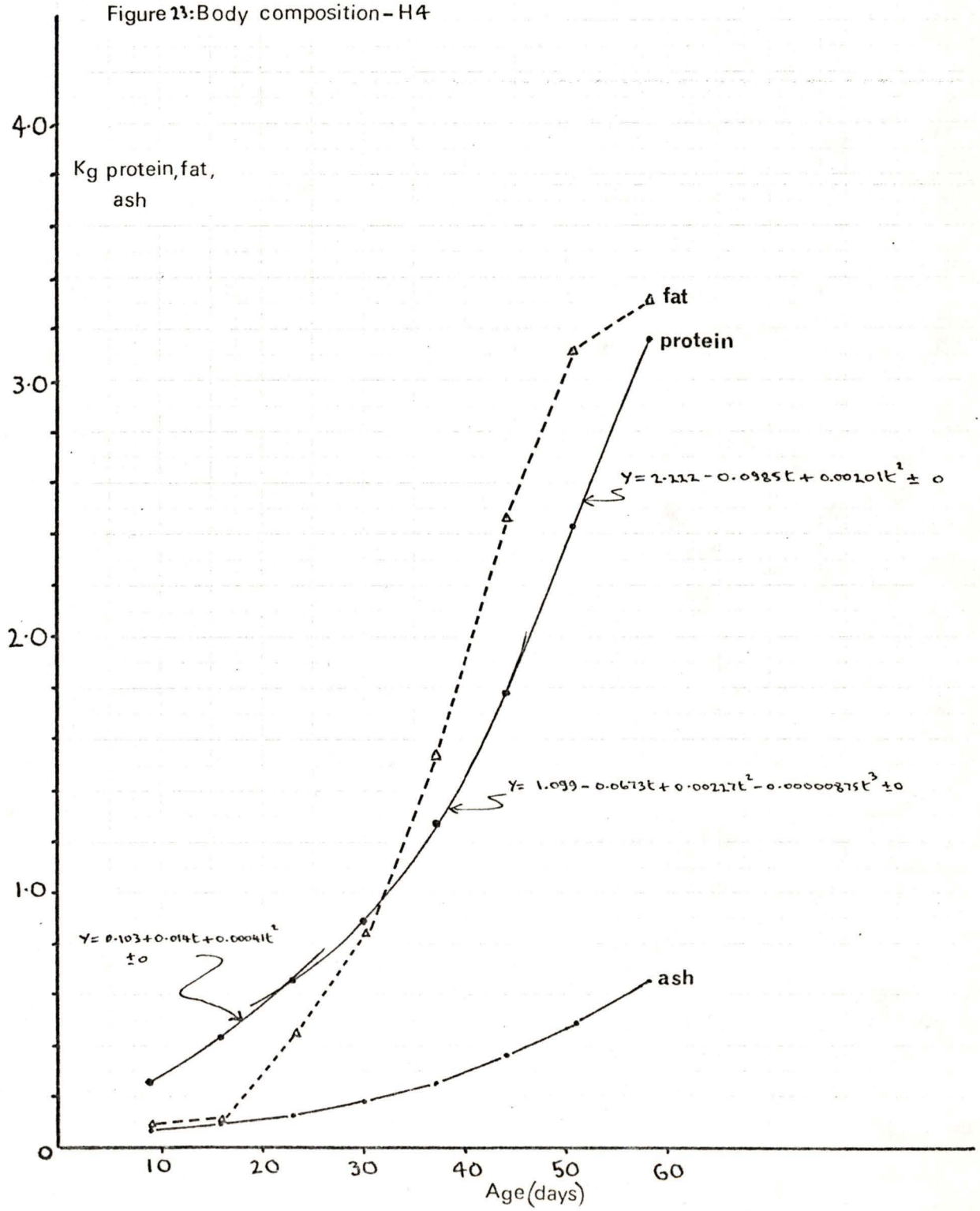


Figure 24: Body composition - H5

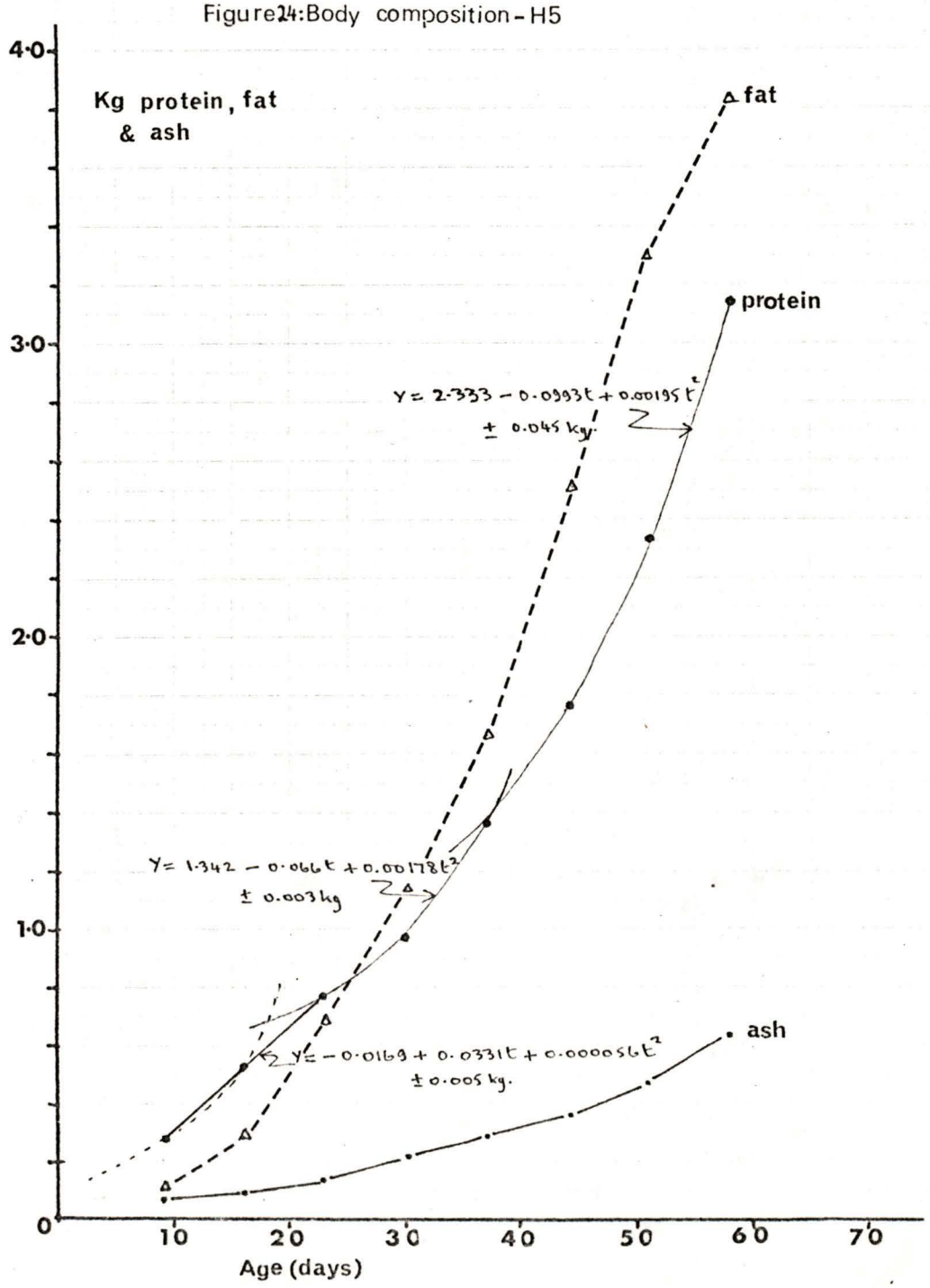


Figure 25: Body composition – H 6

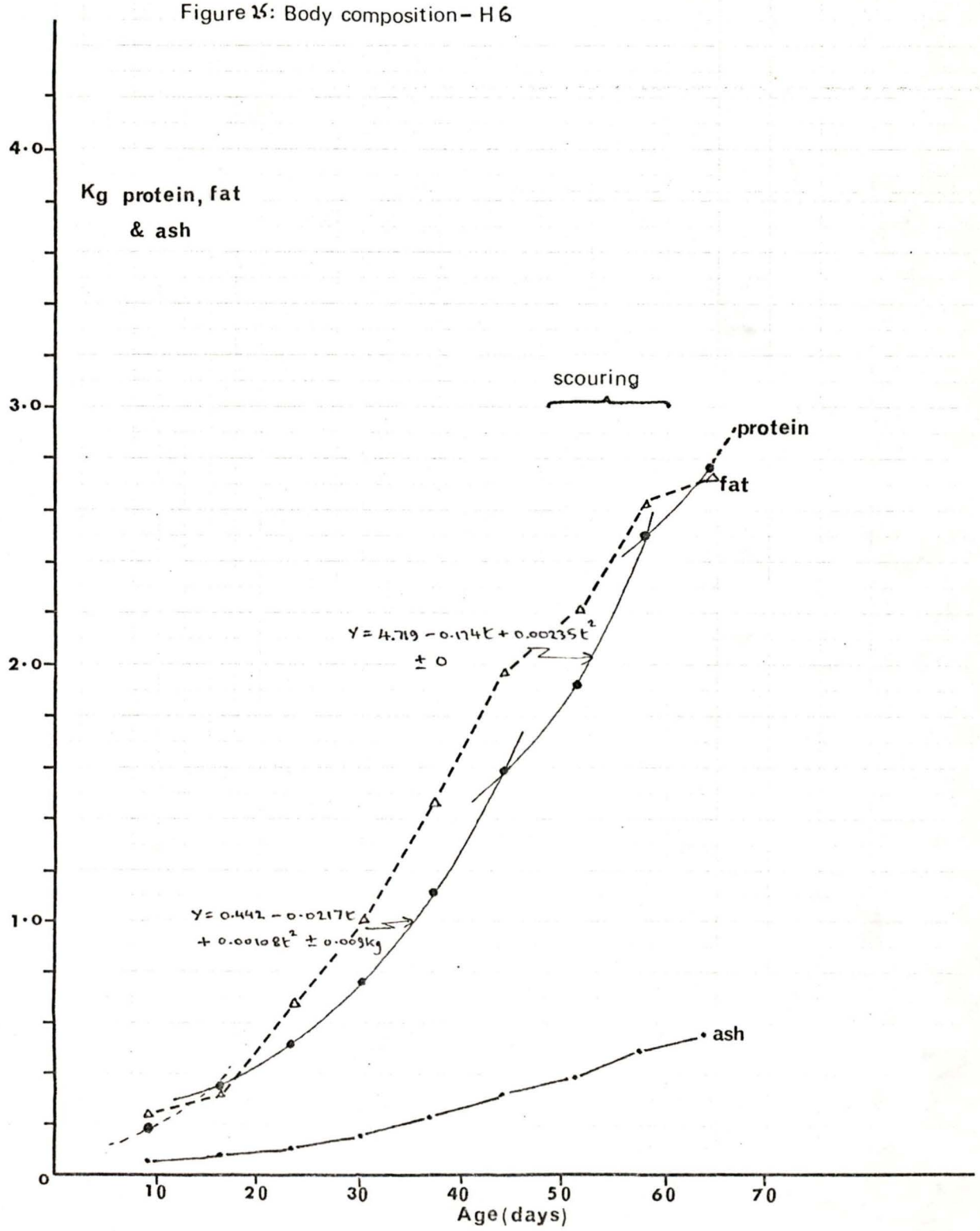


Figure 26: Body composition - L4

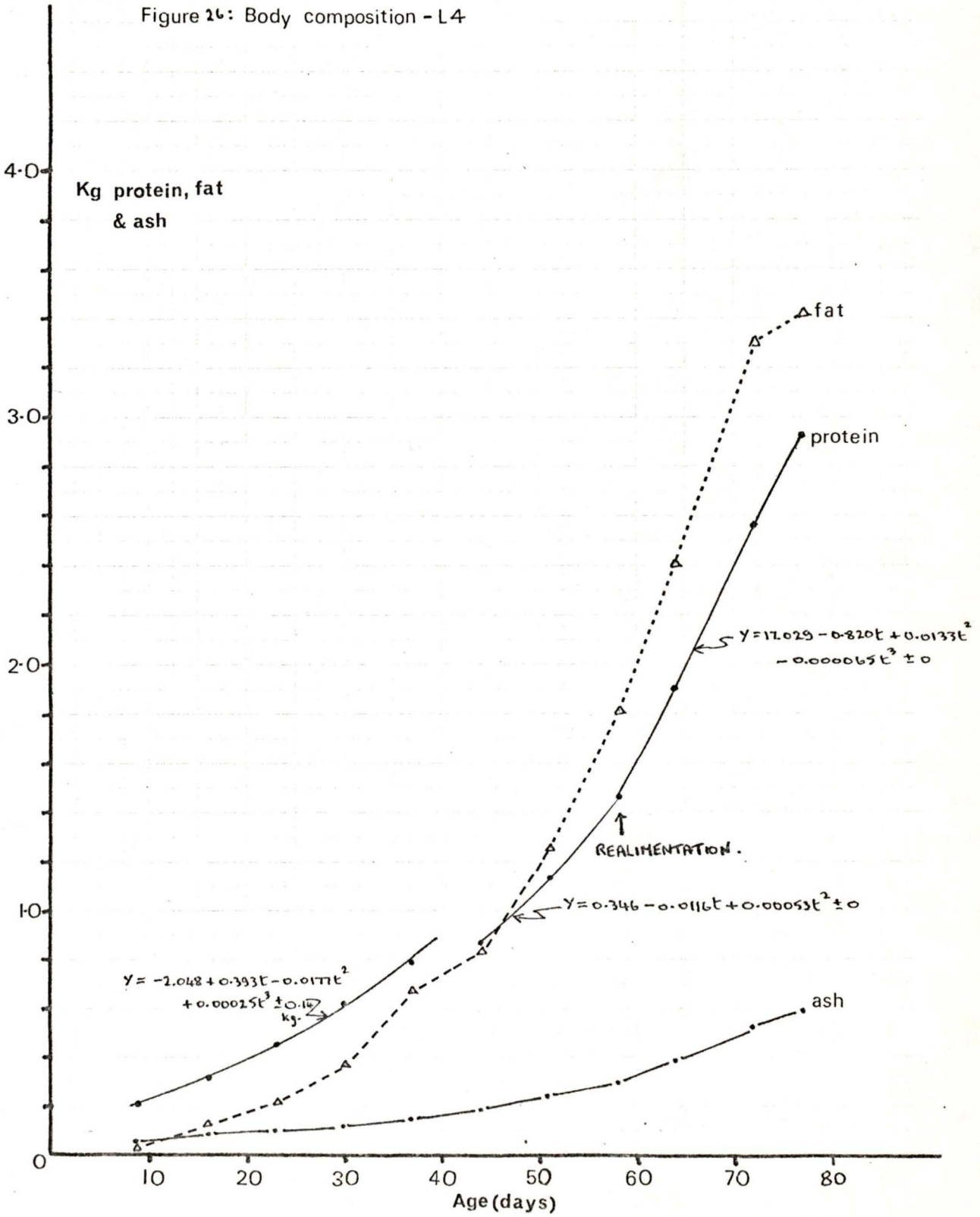


Figure 17: Body composition–L5

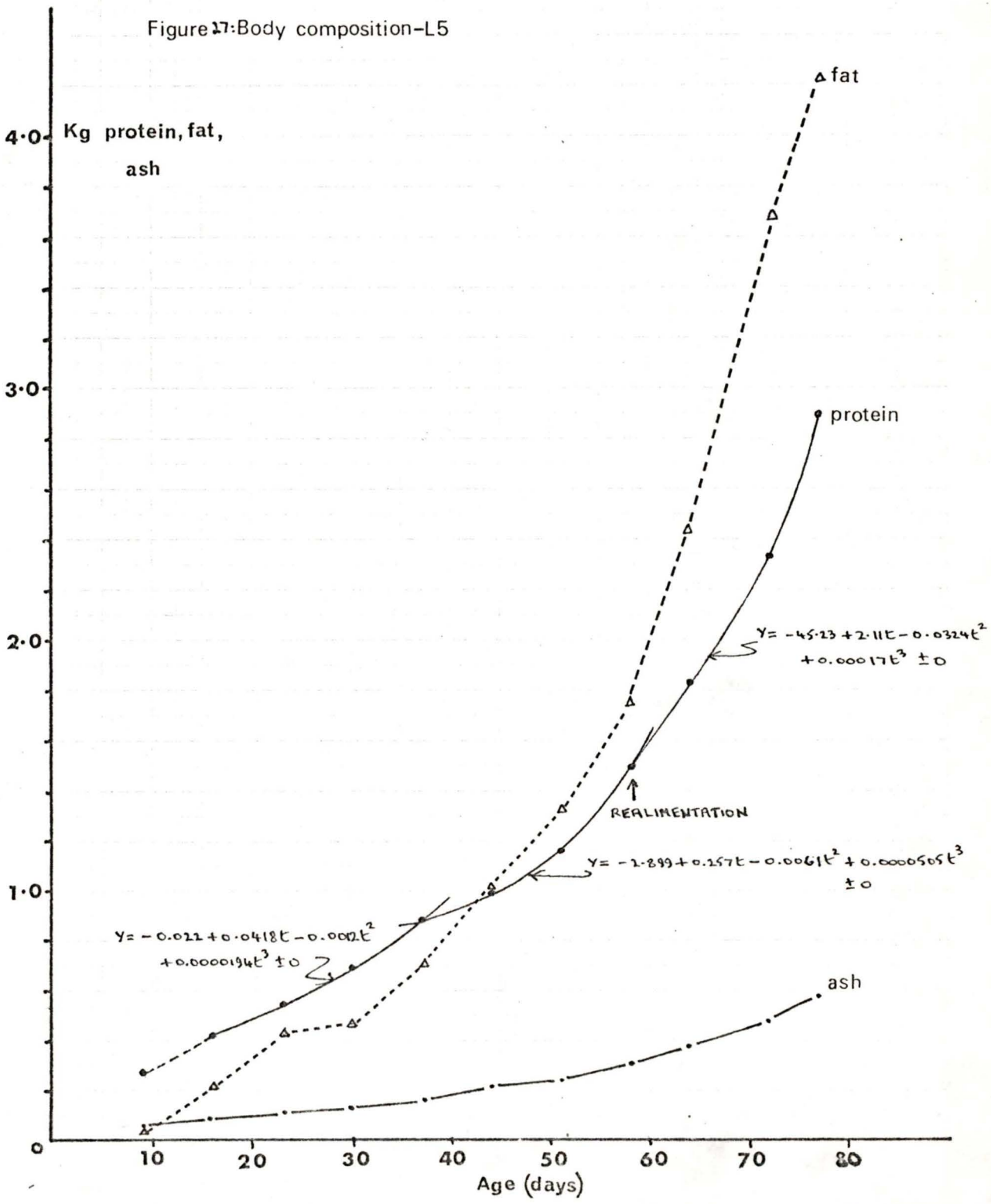
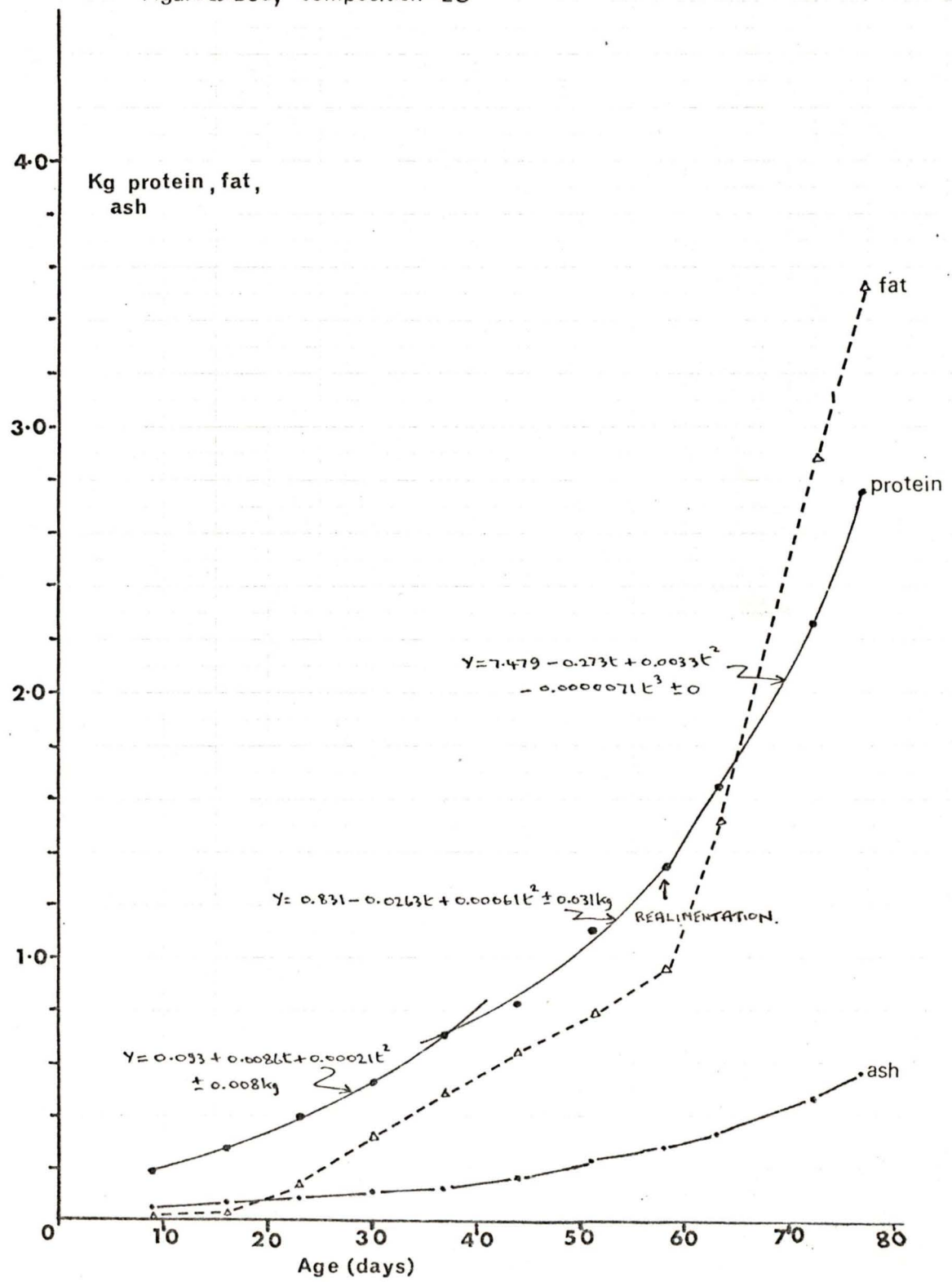


Figure 18: Body composition – LG



BODY COMPOSITION

The growth of protein, lipid and ash compartments of the body as determined *in vivo* for each animal are presented in Appendix Tables XXVIII to XXXIX and graphically in Figures 17 to 28. A similar approach was used in quantifying changes in protein growth as was applied to liveweight changes in that a polynomial was fitted to the data for each growth phase. Although the sparsity of points (one per week) is a weakness in applying such an equation to three or four points, nevertheless such a method enabled protein accretion on a daily basis to be calculated.

Body Protein

The protein growth data generally supports a phasic body weight-age curve by showing distinct phases throughout which the rate of protein synthesis changes, and which end in discrete "breaks" when there is a relatively sharp decline in the rate of synthesis. Furthermore, the occurrence of protein breaks closely coincides with breaks observed in the growth curve. Table VII A and B allows a comparison to be made between the protein and body weight breaks. It is hardly surprising that protein and body weight phases coincide since protein and its associated water constitute a major proportion of body weight. However, the determination of body protein from body water is independent of body weight and therefore their agreement supports the sensitivity of the analytical *in vivo* technique.

There is great similarity among the high plane piglets regarding both the time and body weight at which the rate of protein synthesis

changed, -- an early break at approximately 20 days (3.5 kg) followed by a second at about 38 days (10 kg). Three of the low plane piglets showed a single break which coincided with the second break shown by the other three low plane animals at about 35 days (5 kg). However, since the relationships between sidereal and physiological time are subject to nutritional manipulation, it is more useful to compare the physiological ages at which both body weight and protein breaks occurred. As outlined earlier, various indices of physiological age have been proposed related to the "chemical maturity" of the animal (Moulton 1923; Carrel 1931; Lansing 1951; Brozek 1952; Bailey *et al* 1960), the most promising of which appears to be the protein:water ratio of Bailey *et al* (1960). Groves (1960) noted breaks in the protein growth of suckling piglets at body weights of 5.5 kg and between 9 and 15 kg. These breaks determined *in vivo* coincided with breaks in the nitrogen: water ratio (=protein:water÷6.25) very closely when nitrogen and water had been determined *in vitro* on piglets from the same litters as were studied *in vivo*. Calculation of *in vivo* protein:water ratios of Groves's (1960) data reveal an actual *decrease* in the protein:water ratio after a body water content of 3.9 kg had been reached. This body water content corresponds to about one kilogram fat free dry matter, i.e. about 5 kg body weight. A semilogarithmic plot of protein:water ratio versus body weight for the piglets in this study on each nutritional plane is presented in Figures 29 and 30. It is evident that there is an actual decrease in protein:water ratio at approximately the same body weight as that reported by Groves (1960). Since the same equations were used

to predict body protein from body water in both studies, one must examine the basis of these equations to try to explain an effect which is difficult to interpret physiologically. The protein prediction equations arose from a log-log regression of body nitrogen determined *in vitro* against body water determined *in vitro*. This plot (Groves 1960) is reproduced in Figure 31. There is an apparent decrease in body nitrogen when body water reaches 3.9 kg and therefore a decrease in protein:water ratio at this point. Two regression equations were therefore calculated (Groves 1960, Figure 31) and applied as the prediction equations of body protein *in vivo* from body water. Since these equations predict the protein content of the body and there appears to be a distinct break (*in vivo*) in protein growth coincident with the changing nitrogen level, the validity of this break may be questioned if the nitrogen versus water plot harbours an artefact. The following evidence suggests that this is not so, and that two regression equations of the type discussed above are a more accurate representation of early mammalian nitrogen accretion than a single equation:

a) Miller and Bender (1953) described the relationship between nitrogen and body water in the rat as exponential and plotted it on a semilogarithmic grid according to the straight line equation: $Y = ax + b$. The residual standard deviations were high.

b) A better method of expressing the relationship between body nitrogen and body water was used by Robertson (1960) and Groves (1960) in which log nitrogen was plotted against log water to yield a straight line.

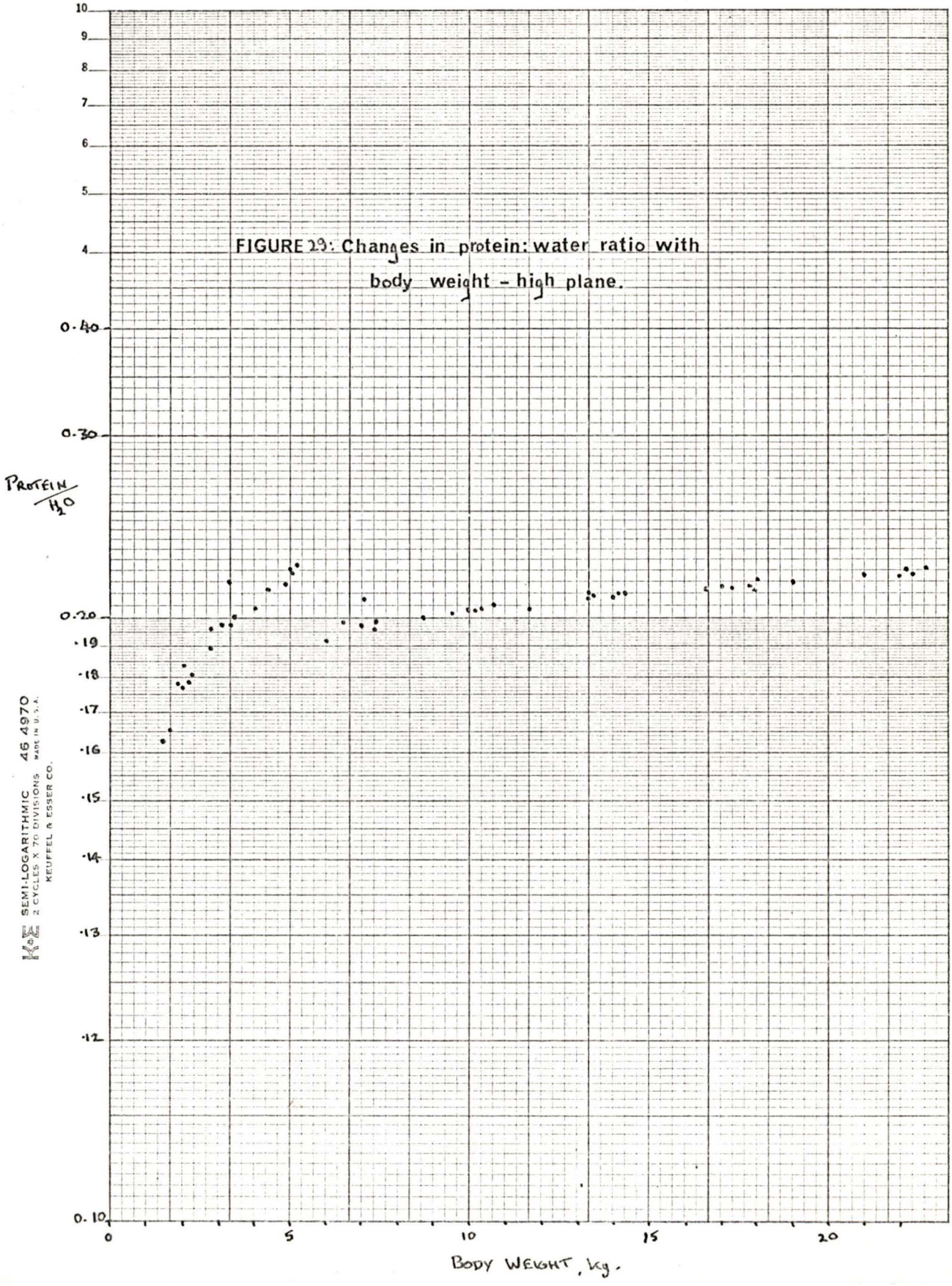


FIGURE 29: Changes in protein: water ratio with body weight - high plane.

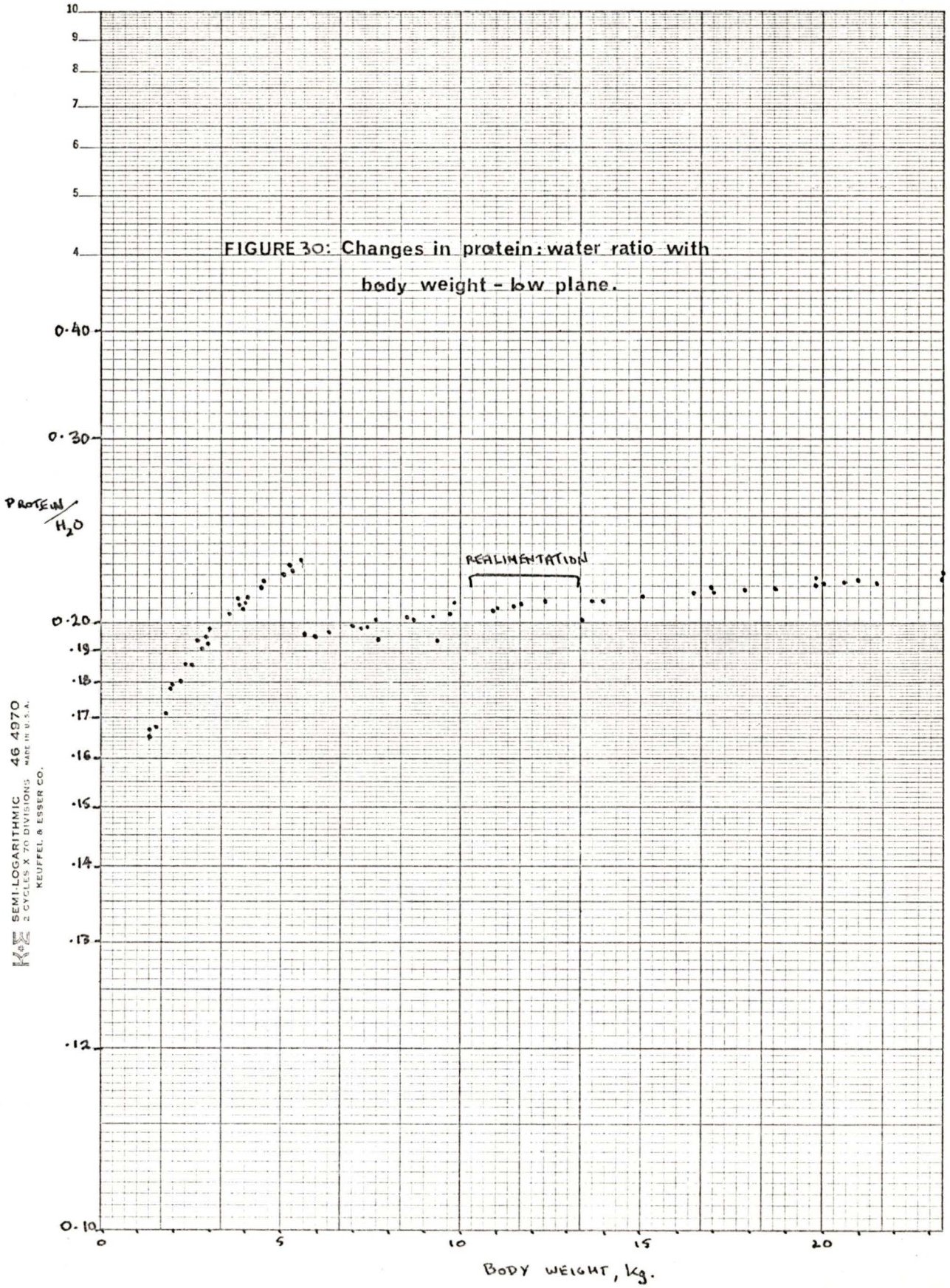


FIGURE 30: Changes in protein: water ratio with body weight - low plane.

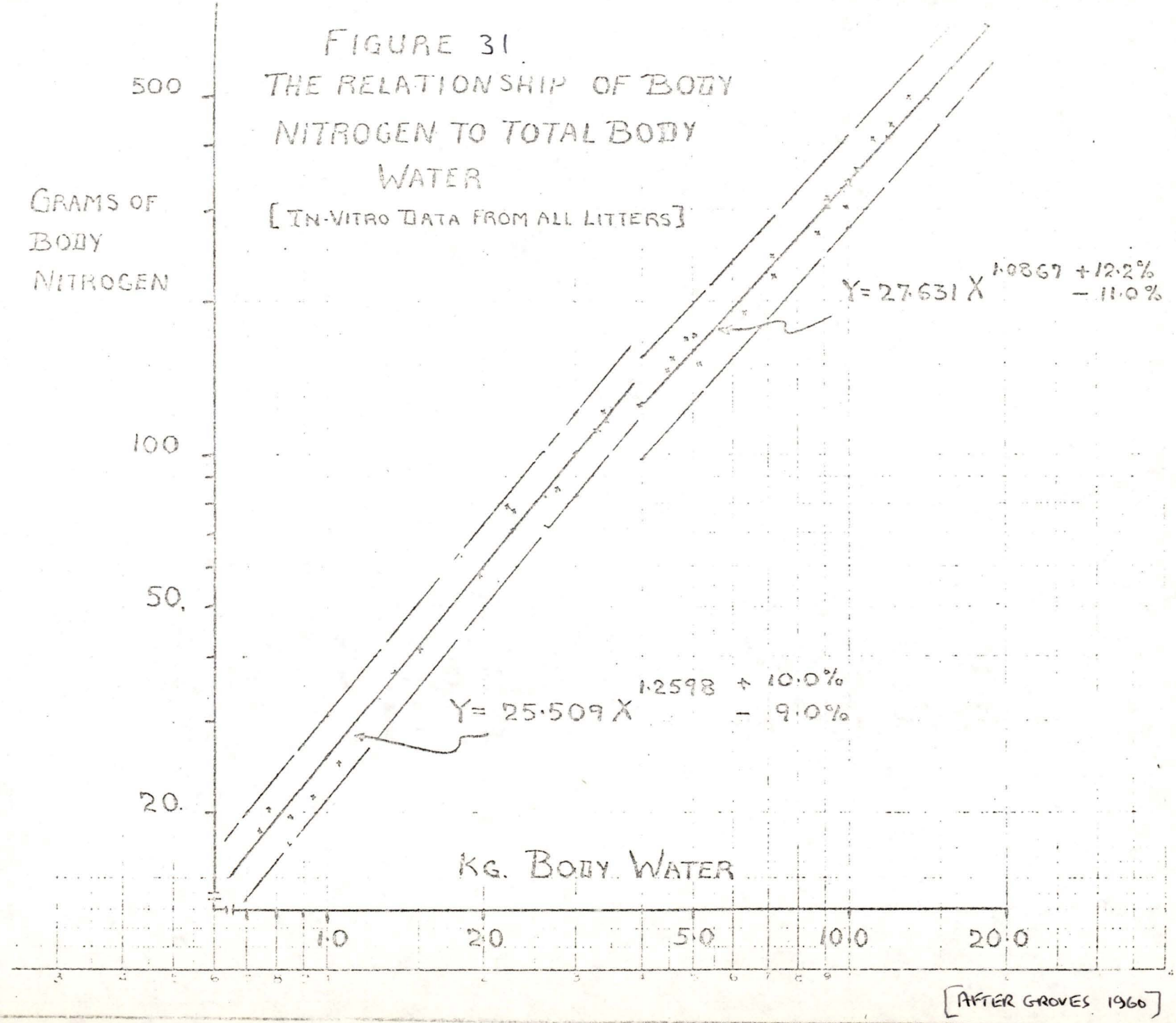
c) Log-log regressions of body nitrogen against body water determined by *in vitro* analyses of the mouse (Bailey *et al* 1960), two strains of rat (Robertson (1960) and the pig (Groves 1960) reveal a distinct break during early growth at which the nitrogen:water ratio declines.

d) The standard errors of estimate when two regression equations are used to describe the relationship between log nitrogen and log body water are lower than the standard error of estimate when a single regression equation over the whole period is applied (Robertson 1960).

Considering the above, it is felt that the application of two prediction equations for *in vivo* body protein is justified and therefore the protein-age curves and protein:water ratios are plotted according to these equations.

Reasons for the sudden decline in protein:water ratio are not obvious. The change represents a fairly sudden relative hydration or alternatively a reduction in rate of protein synthesis relative to rate of body water accretion. One suggested theory (Wood 1971) is that just before the apparent sudden decline, there occurs in the piglet a rapid rate of protein synthesis (and body weight gain) so that the animal is offered more to eat in proportion to its body weight. It is suggested that the increase in milk intake may result in a mild diarrhoea thereby withdrawing water into the alimentary tract so that when total body water is determined *in vitro* its value appears smaller and the protein:water ratio appears larger. Once this period is over, the body water as determined *in vitro* returns to normal and the protein:water ratio appears to decline. Alternatively, the blood system may be involved

FIGURE 31
THE RELATIONSHIP OF BODY NITROGEN TO TOTAL BODY WATER
[IN-VITRO DATA FROM ALL LITTERS]



[AFTER GROVES 1960]

although sudden changes to this system are unlikely. Resolution of the problem awaits further research.

In addition to the decrease in protein:water ratio shown by piglets on both a high and a low plane of nutrition, there is a point at which the protein:water ratio shows a slowing of its rate of increase. Both these points correspond to changes or breaks in the protein-age curve. In the low plane animals, the change occurs at 2.5 to 3.0 kg. There is also a change shortly after realimentation although not immediately afterwards. In those animals fed a high nutritional regimen, the "break" in the protein:water -- body weight plot at 2.5 kg is probably missed because of the rapid growth of these animals. (The few protein:water ratios calculated around this weight appear to be on a different slope to those calculated at slightly higher body weights, evidence which supports the data accumulated from the analyses of the animals on a low plane of nutrition). A slowing in the rate of increase of the protein:water ratio of the high plane piglets occurs around 12 kg and corresponds to the second break in the protein-age curve. This body weight was only attained by the low plane piglets just before or just after realimentation and was therefore obscured by the compensatory mechanisms operating.

An interesting point of note in Figure 30 is the delay following realimentation before a change in the protein:water ratio occurred. This effect was also noted in the protein growth curves, Figures 17 to 28, and is discussed in a later section headed "Realimentation".

EFFICIENCY OF PROTEIN SYNTHESIS

Several explanations of the cause of phasic protein growth will be offered; two are nutritionally based. This section deals with one: if dietary amino acids were insufficient to meet the requirements for body protein synthesis then a slowing of rate of protein synthesis would be obligatory.

To pursue this possibility, the efficiency of converting milk protein to body protein was investigated on a daily basis throughout each growth phase. The results are presented in Appendix Tables XL to LI. Milk intake and therefore protein intake was calculated by applying the milk intake regression equations (Table III) to the phasic polynomial-predicted body weight on each day. Daily protein gain was calculated from the polynomial expression of each phase of protein growth. The efficiency of utilisation of dietary protein for growth based on the net protein gained per day was calculated as:

$$\frac{\text{kg body protein on day}_n - \text{kg body protein on day}_{n-1}}{\text{protein intake on day}_{n-1}}$$

High utilisation of dietary protein for growth was recorded during the first two weeks of postnatal development with a decrease toward the end of the first phase of protein growth. However, between the end of the first phase and beginning of the second, there was usually a fairly abrupt decline in efficiency of protein gain followed by a steady slow increase (occasionally a cycling) to the end of that phase. When a third phase of protein growth occurred, the efficiency remained fairly steady or declined slowly. During the first few days, both levels of feeding resulted in similar efficiencies of protein gain

but that of animals on a high plane of nutrition declined more rapidly than those of their low plane littermates.

A summary of protein efficiency at fixed body weights is presented in Table XI. A major point arising from this data is the apparent increase in efficiency of protein utilisation during some phases of growth. The patterns of protein utilisation deduced from nitrogen balance studies (e.g. Braude et al 1970) show a decline in efficiency as the animal grows and the maintenance component increases. Two possible explanations are offered for the increases found in this study.

a) Consider first the fate of consumed protein. Absorbed amino acids may be utilised to replace endogenous losses, to synthesise new body protein, or deaminated in the liver and the carbon skeleton then becomes available as an energy substrate. The latter occasion arises when energy intake of the animal is limiting. Of the three pathways of protein metabolism (i) the efficiency figures reflect synthesis of new protein (ii) the maintenance component is unlikely to decrease so that (iii) the third variable, deamination, is probably a controlling factor. Control of the deamination process was thought in general terms to be nutritionally dependent and there is much evidence at the enzyme level that a fine control is exercised by induction and repression of key enzymes (Munro and Allison 1967). However, there is little direct evidence of overall control, probably at the endocrine level, and fine control mechanisms do not adequately explain the sharp decline in rate of protein synthesis at the termination of each protein growth phase

noted in this study and in that of Groves (1960). Major enzyme and/or endocrine shifts may account for the changes.

b) An increased efficiency of protein utilisation is often associated with a period of restricted nutrition. It is possible that at the beginning of a growth phase the plane of nutrition was high declining relatively throughout that phase. Such an occasion may have arisen by the practice of feeding according to the relationship: intake = a (Body weight)^{b} over the whole growth period rather than applying a separate equation to each growth phase. If a "decreasing" plane of nutrition was in effect as the animal grew through each growth period, then it is possible that the maintenance component decreased resulting in increasing efficiency of protein gain throughout the phase.

TABLE XI: EFFICIENCY OF PROTEIN SYNTHESIS AT DIFFERENT BODY WEIGHTS

(Efficiency = g dry protein gained per g of dry milk protein)

Body weight, kg	Expt. I			Expt. II			Expt. I				Expt. II	
	H1	H2	H3	H4	H5	H6	L1	L2	L3	L4	L5	L6
3	0.71		0.77	0.64	-	-	0.72	0.82	0.72	0.68	0.56	0.61
6	-		0.39	0.58	0.38	0.64	0.39	0.41	0.45	-	-	0.51
9	0.48		0.55	0.62	0.56	0.68	0.60	0.42	0.86	0.58	0.64	-
12	-		0.56	0.61	0.47	0.35	0.67	0.43	0.65	-	-	-
15	0.49		0.49	0.58	0.53	0.56	0.56					
18	0.47		0.63	0.59	0.58	-	0.56					

Braude et al (1970) fitted linear regression equations at various feeding levels to arith-arith plots of % nitrogen retention versus age of piglets during the growth period, birth to twenty eight days. Retentions of 90% were reported for piglets on the lowest level of feeding. On the other regimens, efficiencies around 90% were recorded during the first week, 70-80% during the second week, 60-70% throughout the third week, and 50 to 65% throughout the fourth week. In the study, nitrogen retention was determined over a six day balance period.

There are no other in vivo studies of daily compositional changes with which to compare this study. Decreasing efficiency of protein growth is to be expected as the proportion of protein required for maintenance increases with body weight. If the protein level absorbed each day were equivalent to the maintenance requirement, the efficiency of protein gain would be zero.

The average efficiencies of protein utilisation throughout each protein growth phase are presented in Table XII.

The data is in reasonable agreement with the average figures at different ages and body weights quoted by several authors (Miller and Bender 1953; Lucas and Lodge 1961; Braude et al 1970).

TABLE XII: AVERAGE EFFICIENCY OF PROTEIN SYNTHESIS CALCULATED THROUGHOUT EACH PROTEIN GROWTH PHASE

$$\text{Efficiency} = \frac{\text{Total gain in dry body protein throughout a given phase}}{\text{Total actual dry protein consumed throughout that phase}}$$

Piglet No.	Growth period (days)	Efficiency	Experiment
H1	7-26	0.692	I
	30-48	0.502	I
	45-56	0.475	I
H2			
H3	9-22	0.788	II
	25-43	0.500	II
	45-54	0.540	II
H4	9-22	0.727	II
	34-43	0.598	II
	45-54	0.586	II
H5	25-36	0.461	II
	38-55	0.521	II
H6	19-44	0.611	II
	46-54	0.471	II
L1	7-18	0.697	I
	20-43	0.511	I
	45-56	0.542	I
L2	20-27	0.781	I
	30-56	0.401	I
L3	7-26	0.734	I
	28-43	0.585	I
	45-56	0.607	I
L4	10-36	0.696	II
	45-54	0.593	II
L5	17-37	0.503	II
	43-56	0.513	II
L6	14-36	0.624	II
	40-54	0.518	II

RATE OF PROTEIN SYNTHESIS

The efficiency figures of Appendix Tablex XL to LI indicate that the rate of new protein synthesis changes throughout each protein phase and declines overall with time. Tables XIII and XIV show the rates of synthesis calculated at the beginning and end of the protein growth phases.

Rate of synthesis of new protein = g new protein synthesised per unit (g) of protein in the body per day

$$= \frac{dP_n/dt}{P_b}$$

It must be noted that this figure does not take into account the turnover of existing protein i.e. the maintenance cost. However some estimate of the partition of dietary protein into that required for maintenance, that required for growth and that required for other purposes such as to meet energy requirements can be made.

Synthesis of new protein was fairly rapid during the first two weeks but declined slowly throughout the first phase. There was often a sharp decline in rate from the end of the first phase to the beginning of the second. Throughout the second and third phase, the rate tended to cycle over a limited range of values usually increasing slightly at the end of each phase and declining at the beginning of the next phase. Piglets on a low plane of nutrition showed a consistently lower rate of new protein synthesis than their littermates on a higher level of feeding.

TABLE XIII: RATE OF PROTEIN SYNTHESIS -- HIGH PLANE

Piglet No.	Phase of protein growth	age, days	body weight, kg	Rate*
H1	1st - start	7	1.82	.085
	1st - end	26	5.55	.056
	2nd - start	30	7.30	.039
	2nd - end	42	13.15	.054
	3rd - start	44	14.10	.039
	3rd - end	55	20.79	.033
H2	1st - start			
	1st - end			
	2nd - start			
	2nd - end			
	3rd - start			
	3rd - end			
H3	1st - start	9	1.90	.093
	1st - end	21	4.32	.056
	2nd - start	25	5.40	.040
	2nd - end	43	12.65	.044
	3rd - start	46	14.01	.035
	3rd - end	54	18.40	.045
H4	1st - start	9	1.77	.082
	1st - end	22	3.94	.051
	2nd - start	24	4.51	.049
	2nd - end	43	12.63	.048
	3rd - start	46	14.39	.045
	3rd - end	53	18.64	.044
H5	1st - start	-	-	-
	1st - end	19	3.90	.059
	2nd - start	24	5.30	.030
	2nd - end	36	9.65	.049
	3rd - start	39	10.78	.039
	3rd - end	53	18.88	.044
H6	1st - start	-	-	-
	1st - end	-	-	-
	2nd - start	18	3.02	.045
	2nd - end	43	11.19	.048
	3rd - start	46	12.95	.026
	3rd - end	53	15.53	.038

*(g protein synthesised per g protein per unit time)

TABLE XIV: RATE OF PROTEIN SYNTHESIS -- LOW PLANE

Piglet No.	Phase of protein growth	age, days	body weight, kg	Rate*
L1	1st - start	8	2.63	.061
	1st - end	18	4.11	.050
	2nd - start	21	4.52	.020
	2nd - end	56	20.86	.039
L2	1st - start	20	1.945	.067
	1st - end	28	3.67	.074
	2nd - start	31	3.96	.031
	2nd - end	55	11.32	.037
L3	1st - start	7	1.99	.068
	1st - end	25	4.64	.044
	2nd - start	29	5.43	.034
	2nd - end	55	13.92	.045
L4	1st - start	9	1.45	.074
	1st - end	36	4.92	.037
	2nd - start	44	6.51	.041
	2nd - end	54	9.28	.038
L5	1st - start	16	2.84	.041
	1st - end	37	5.53	.038
	2nd - start	42	6.65	.021
	2nd - end	54	9.32	.034
L6	1st - start	13	1.55	.058
	1st - end	35	4.20	.035
	2nd - start	40	5.00	.030
	2nd - end	53	7.79	.034

*(g protein synthesised per g protein per unit time)

Some idea of the utilisation of dietary protein may be obtained: Consider a 6 kg pig on a high level of nutrition. Its maintenance requirement for protein is estimated at 15 grams of digestible protein per day (Brody 1945). In this study a 6 kg pig received 75 g of milk protein in one day and gained on average 44 g of body protein. 59 g of protein were used by the animal, so presumably 16 g in excess of requirements were deaminated and used as an energy source. A low plane pig at the same weight consumed 53 g of milk protein and gained about 26 g of protein.

Since polynomial equations were fitted to the protein:age curves it was possible to determine the protein composition of different pigs of the same weight. The protein contents (dry) of each animal at 3, 6, 9 kg and where applicable 12, 15 and 18 kg (high plane and L1) are presented in Table XV. This table allows some comparison to be made with McMeekan's classical dissection study (1940), the results of which are discussed earlier (p. 18). McMeekan (1940) slaughtered his animals at 200 pounds (91 kg) and noted differences in the quantities of muscle (amongst other things) in those subjected to low and high planes of nutrition. Those grown on a low plane appeared to contain a greater proportion of their body weight as muscle, there being approximately 5 kg difference at 200 lbs. Table XV indicates little difference at 3 kg body weight but a difference of 24 g of dry protein at 6 kg and 44 g (≡ approximately 200 g wet protein) at 9 kg. These differences were not however statistically significant. The differences reported by McMeekan are therefore confirmed as beginning early. The values for protein content agree well with *in vitro* work reported elsewhere (Spray and Widdowson 1950;

Manners and McCrea 1963).

Since body protein was determined from total body water, then by substituting the value of body protein at 3, 6 and 9 kg into the prediction equations, the total water content at these body weights can be calculated knowing the total water content, the total dry matter can be determined by subtraction. The total dry matters of the body at 3, 6, and 9 kg body weights are presented in Table XVI combining Tables XV and XVI in Table XVII, the body protein is expressed as a percentage of total dry matter. The results show the declining proportion of protein in the dry matter with age. At each body weight, the proportion of protein in the dry matter was not very different between treatments. In other words, a 6 kg pig raised on a low plane of nutrition has about the same proportion of protein in the dry matter as a pig raised on a higher plane although of course the low plane pig is chronologically older. Such a more or less uniform retardation of development supports Huxley's allometric theory of growth (1932).

TABLE XV: BODY PROTEIN (kg) AT DIFFERENT BODY WEIGHTS

Body weight, kg	Expt. I		Expt. II					Expt. I				Expt. II			
	H1	H2	H3	H4	H5	H6	Mean	L1	L2	L3	L4	L5	L6	Mean
3	-		0.432	0.490	0.458	0.401	0.460	0.450	0.425	0.485	0.451	0.453	0.457	0.454
6	-		0.854	0.846	0.859	0.780	0.835	0.846	0.871	0.841	-	-	0.879	0.859
9	1.196		1.227	1.220	1.200	1.210	1.211	1.279	1.201	1.360	1.270	1.100	1.322	1.255
12	1.586		1.690	1.617	1.590	1.670		1.785						
15	2.120		2.106	2.030	1.998	2.110		2.120						
18	2.540		2.650	2.525	2.495	-		2.589						

TABLE XVI: TOTAL DRY MATTER (kg) OF THE BODY AT DIFFERENT BODY WEIGHTS

Body weight, kg	Expt. I			Expt. II			Expt. I			Expt. II		
	H1	H2	H3	H4	H5	H6	L1	L2	L3	L4	L5	L6
3	-		0.794	0.562	0.689	0.920	0.711	0.825	0.850	0.717	0.712	0.693
6	-		1.648	1.685	1.623	1.995	1.685	1.568	1.709	-	-	1.530
9	4.067		3.925	3.957	4.047	4.002	3.687	4.043	3.320	3.730	4.506	3.493

TABLE XVII: BODY PROTEIN AS % OF TOTAL DRY MATTER OF THE BODY AT DIFFERENT BODY WEIGHTS

Body weight, kg	Expt. I		Expt. II				Expt. I			Expt. II		
	H1	H2	H3	H4	H5	H6	L1	L2	L3	L4	L5	L6
3	-		59.4	87.2	66.5	43.6	63.3	51.5	57.1	62.9	63.6	65.9
6	-		51.8	50.2	52.9	39.1	50.2	55.5	49.2	-	-	57.5
9	29.4		31.3	30.8	29.7	30.2	34.7	29.7	41.0	34.4	24.4	37.8

LIPID SYNTHESIS

During the early growth, the lipid content of the body tended to complement that of protein growth, as was to be expected, since throughout the period during which protein phases were noted, the piglets did not cut back on their food intake. Therefore, when the rate of synthesis of new protein decreased rather abruptly, more energy became available for lipid synthesis (presuming there was no sudden change in heat production). Figures 17 to 28 indicate an increase in rate of fat synthesis following protein discontinuities. Similarly, prior to the occurrence of a protein break, there was often a decrease in the rate of lipid synthesis as a larger proportion of net energy was used to meet the requirements of protein synthesis. In the only other *in vivo* study of this kind, Groves (1960) and Wood and Groves (1963) noted a distinct cycling of lipids in piglets raised on the dam. Considerable quantities of fat appeared to be laid down during the early part of each protein phase. Towards the end of the phase when rate of protein synthesis was increasing, synthesis of fat was checked and in some cases lipids were mobilised. This led to the suggestion that stored lipid energy was being used to support protein synthesis because of an inadequate energy intake from the dam. However, results presented in this study are only in partial agreement. Firstly, some of the piglets of Groves (1960) which exhibited marked cycling of lipid deposits were on a nutritional plane estimated from body weight and composition data to be comparable to the high plane animals of this study amongst which very marked cycling was not noted.

Secondly, piglets on a low nutritional plane in this study maintained a low level of fat which showed only limited cycling. On the other hand, the low nutritional plane imposed in this study was probably below any that the piglets of Groves (1960) were subjected to, and therefore, the fat deposits would be unlikely to rise to any considerable extent because of an energy deficit. Quantitatively however, the composition curves for piglets on the low plane of nutrition indicate that lipids were maintained at 10-15% of body weight and if nutritional factors had been the cause of the discontinuities in protein growth, then there appears to have been enough fat present (0.5 kg to 1.5 kg) to have exhibited a distinct cycling of energy reserves.

What then are the causes of discontinuous protein phases during early postnatal growth? The work of Romanoff (1829), Lerner (1939), Brody (1945) and others on the presence of growth phases in the embryo supports the belief that the growth pattern is genetically determined and dependent on nutritional plane only for its chronological timing since it is unlikely that the embryo is subjected to nutritional stress *in utero* (or *in ovo*). The work of Wood *et al* (1962) on the periodicity of growth of the black-tailed deer strongly suggests the operation of a hormonal influence since gross cycling of body weight in deer is coincidental with the rutting season. If such cycling is an "exaggeration" of early phasic postnatal growth, then a humoral factor may be responsible. An important effect of *thyroid* hormones is to control the rate of protein synthesis and

perhaps the kind of protein that is synthesised (Hoch 1971). The thyroid hormones are necessary for a normal rate of protein synthesis. Liver homogenates obtained from hypothyroid rats synthesise protein slowly (Stein and Gross 1962). Stimulation of protein synthesis via a direct thyroid hormone-mitochondrion interaction has been demonstrated by Sakoloff et al (1964). Thyroid hormone appears to stimulate mitochondria to produce a factor, Sakoloff's Factor, which stimulates ribosomal translation. Control of protein biosynthesis may lie in this direction. Clearly, some integration of detailed biochemical mechanisms into the growth pattern of the whole animal is required.

Bailey et al (1956) and Kitts et al (1956) studied changes in the carbohydrases of the digestive tract of the young piglet. They reported a decrease in lactase activity coincident with an increased sucrase activity in the region of 21 days of age. Groves (1960) suggested that such may account for an apparent growth break at about 20 days when fat deposits were mobilised to meet energy requirements which could not be met by the diet. However, this study does not indicate an extensive change in fat synthesis although a protein growth break occurs around 20 days. The possibility of a change in digestive proteinases thereby limiting the absorption of dietary amino acids is unlikely since many studies indicate a milk protein digestibility of 99 to 99.5% at many ages and weights during early postnatal growth (Hays et al 1959; Braude 1970). Suffice it to say that further characterisation of factors controlling the growth pattern awaits the work of others.

UTILISATION OF ENERGY FOR GROWTH

The energetic efficiencies of gain calculated each week from body composition data are presented in Table XVIII. Since low and high plane piglets differ considerably in body weight on any given day, the average weight during the period in which each efficiency figure was calculated is shown in relation to energetic efficiency in Table XIX. Energetic efficiency of gain was calculated as:

$$\frac{\text{Total caloric deposition over x days}}{\text{Total caloric intake over the same period}} \times 100$$

Tables LII to LXIII show the protein and fat gain from one analysis to the next for each piglet. From the calculated gain of body constituent, the energetic content of the gain was calculated, i.e. a method of indirect calorimetry was applied. To determine energy stored in the form of protein and fat in the body, a reasonably reliable estimate of the calorific value of average pork fat and protein was employed. Reid et al (1963) reported a composite value for the calorific value of fat and protein in sheep to be 9.405 and 5.379 kcal per g respectively and for cattle 9.499 and 5.447 kcal per g respectively. Pork fat and protein has been reported (Reid et al 1968) at 9.512 kcal per g and 5.584 kcal per g respectively. Fat however was calculated as "wet" fat containing from 6 to 12% water. Its energy value was calculated on the basis of 9 kcal per g.

Efficiencies of gain are quite high initially and generally decline with age. Table XIX allows a comparison of results calculated for high and low plane piglets at about the same body weight. Efficiency

of energetic gain of those piglets on a low plane of nutrition declines with increasing body weight at about the same rate as their high plane counterparts. Such an observation would lead one to argue that the maintenance requirements of the low plane piglets are no greater per unit of body weight than those of the high plane piglets. Supporting this view, there is good evidence that during a period of restricted nutrition, the metabolic rate per unit of body weight is lowered (Mount and McCance 1960) and a reduction of body temperature has frequently been noted (Roy et al 1958). Leche (1964) noted an actual decline in the heat production of undernourished calves and suggested a reduced basal metabolic rate to be the cause. Depression of basal metabolic rate was also noted by Blaxter and Wood (1951). It is therefore generally believed that undernutrition reduces the metabolic activity of animals and results in a lowered maintenance expense.

The net energy expressed as percentage of gross energy of a food declines as the intake of energy increases (Blaxter 1956) and the decrease is believed to be due to an increase in specific dynamic action (energy required to assimilate food especially by metabolic processes in the liver, e.g. deamination, transamination, glycogenesis, etc.). Blaxter (1956) showed the relationship between net energy and energy level to be curvilinear and when the efficiency of growth is measured as the energy per unit gain in weight, the efficiency increases as level of nutrition decreases.

The similarity in efficiencies of energy gain on both nutritional planes is therefore not surprising; one would in fact perhaps

have expected a better utilisation of energy for growth by the low plane group.

As can be seen from Appendix Tables LII to LXIII, calculation of the net energy retained for growth affords an indirect assessment of heat production as the difference between energy deposited and dietary energy absorbed. The digestibility of gross energy of milk was assumed to be 90% although the limitations of applying a constant figure were realised. When compared with the average body weight throughout the period when heat productions were calculated, the values for low plane animals do not appear to be significantly lower than those calculated for the high plane group as has been reported by various authors (Mount 1958; Leche 1964). Furthermore, the works of many authors (e.g. Osbourne and Wilson 1960; Braude et al 1970) indicate a lowered digestibility of energy at higher levels of feeding. Since the magnitude of this decrease of digestibility and its relation to feeding levels, caloric density, protein:calorie ratio, etc. has not been quantified, the use of a constant percent digestibility of energy in this study was considered justified. Heat production values at lower body weights were in agreement with published calorimetric determinations (Lucas and Lodge 1961). However above about 15 kg, values calculated in this study were generally higher than those reported elsewhere (Mount 1968).

The energy reserves of the piglet at birth are very limited (Mount 1968). They exist as glycogen of liver and muscles and a small quantity (about 1% body weight) of lipids much of which are membrane-

bound phosphoesters. Groves (1960) noted that lipids accumulated at a rate in excess of protein synthesis during the first ten days of life in suckling piglets. Figures 17 to 28 of this study are in agreement with this observation. It appears that the near-absence offat at birth resulting in poor thermoregulation necessitates rapid accretion of lipid insulation (Mount 1969).

TABLE XVIII: ENERGETIC EFFICIENCY OF GAIN (%) IN RELATION TO AGE

Piglet no. / Growth period (days)	H1	H2	Growth period (days)	H3	H4	H5	H6
9–15	47.0	40.3	10–16	58.3	26.7	49.2	40.9
16–22	50.7	45.6	17–23	46.9	52.6	46.5	47.3
23–29	36.5	51.7	24–30	40.7	45.3	41.6	38.8
30–36	47.3	31.5	31–37	41.6	55.3	42.6	42.7
37–43	37.0	28.4	38–44	41.9	55.4	49.0	39.4
44–50	35.3	23.8	45–51	35.7	34.0	38.5	22.7
51–57	30.4	26.8	52–58	20.5	22.0	31.5	31.1

Piglet no. / Growth period (days)	L1	L2	L3	Growth period (days)	L4	L5	L6
9–15	51.6	56.1	47.6	10–16	46.8	53.5	(23.4)
16–22	56.8	36.7	58.8	17–23	32.2	48.3	43.8
23–29	47.4	36.2	30.0	24–30	38.8	48.5	42.0
30–36	39.6	49.7	35.3	31–37	40.5	43.0	39.4
37–43	31.9	25.8	27.1	38–44	34.2	34.5	27.6
44–50	39.4	36.3	16.8	45–51	44.9	35.4	29.2
51–57	36.4	37.9	22.8	52–58	43.8	38.8	26.1
REALIMENTATION							
58–64	39.6	48.1	37.0	59–64	40.0	44.0	39.7
65–71	-	36.8	25.7	65–72	41.7	47.1	55.7
72–78	-	26.2	-	73–77	21.6	32.4	43.2

TABLE XIX: ENERGETIC EFFICIENCY OF GAIN (%) IN RELATION TO AVERAGE WEEKLY BODY WEIGHT

Piglet no.								
H1	Average body weight, kg:	2.54	3.72	5.74	8.54	12.11	15.71	20.16
	Efficiency :	47.0	50.7	36.5	47.3	37.0	35.3	30.4
H2	Average body weight, kg:	1.68	2.50	3.95	5.83	8.75	12.12	16.23
	Efficiency :	40.3	45.6	51.7	31.5	28.4	23.8	26.8
H3	Average body weight, kg:	2.70	4.12	6.05	8.56	11.66	15.04	19.20
	Efficiency :	58.3	46.9	40.7	41.6	41.9	35.7	20.5
H4	Average body weight, kg:	2.21	3.49	5.38	8.01	11.51	15.60	20.32
	Efficiency :	26.7	52.6	45.3	55.3	55.4	34.0	22.0
H5	Average body weight, kg:	2.78	4.14	6.21	8.78	11.75	15.51	20.26
	Efficiency :	49.2	46.5	41.6	42.6	49.0	38.5	31.5
H6	Average body weight, kg:	2.20	3.34	4.96	7.31	10.30	12.68	15.96
	Efficiency :	40.9	47.3	38.8	42.7	39.4	22.7	31.1
L1	Average body weight, kg:	3.08	3.84	5.56	8.55	11.26	15.04	19.42
	Efficiency :	51.6	56.8	47.4	39.6	31.9	39.4	36.4
L2	Average body weight, kg:	1.52	2.00	3.10	4.51	6.06	8.19	10.88
	Efficiency :	56.1	36.7	36.2	49.7	25.8	36.3	37.9
L3	Average body weight, kg:	2.42	3.30	4.66	6.28	8.15	10.22	13.36
	Efficiency :	47.6	58.8	30.0	35.3	27.1	16.8	22.8
L4	Average body weight, kg:	1.94	2.71	3.51	4.55	5.88	7.56	9.96
	Efficiency :	46.8	32.2	38.8	40.5	34.2	44.9	43.8
L5	Average body weight, kg:	2.48	3.24	4.02	5.02	6.30	7.78	9.50
	Efficiency :	53.5	48.3	48.5	43.0	34.5	35.4	38.8
L6	Average body weight, kg:	1.63	2.35	3.13	4.02	5.20	6.64	8.26
	Efficiency:	(23.4)	43.4	42.0	39.4	27.6	29.2	26.1

GROWTH AND BODY COMPOSITION FOLLOWING REALIMENTATION

An animal whose growth has been retarded exhibits, when the restriction is removed, a rate of growth greater than that which is normal in animals of the same chronological age. Osborne and Mendel (1915 a) noted:

> "Growth in the cases referred to, is resumed at a rate normal for the size of the animal at the time. It need not be slow and frequently exceeds the normal progress".

During realimentation of piglets on a low nutritional plane, efficiencies of liveweight gain were higher than during the period of restriction (Table XX). Many workers have noted that the composition of gain on realimentation following a period of undernutrition differs from that of normal animals, there being a markedly increased rate of fat deposition during the initial stages of recovery (McMeekan 1941; Keys et al 1950; Osbourne and Wilson 1960). The compositional changes following realimentation in this study are included in the compositional curves of Figures 17 to 28. A large increase in the rate of fat deposition is a salient feature of realimentation and in good agreement with the work of others, notably McMeekan (1941). In sheep and rats, Meyer and Clawson (1964) found that the composition of weight gain following realimentation did not differ from the composition of weight loss when undernutrition was imposed; and that the fat content of the "recovered" rats was closely related to the degree of previous undernutrition: the less the restriction, the greater was the fat content of the recovered animals. In most studies, the increased fattening after realimentation appears to be transient and not carried on into later life (Allden 1970).

The fattening effect may be related to the lowered basal metabolic rate of undernourished animals: on realimentation, basal metabolism does not immediately rise to levels commensurate with normal animals at the same body weight. Therefore excess energy is deposited as fat. Eckles and Swett (1918) proposed essentially the same thing by pointing out that maintenance requirements may be reduced during the early part of the realimentation period thereby increasing the efficiency of energy utilisation for body gain. The efficiencies of energy utilisation for growth are illustrated in Table XXI. There is a decisive increase in utilisation of energy for growth following realimentation (compare Table XVII). The effect declines over a period of two to three weeks.

Meyer and Clawson (1964) showed an increase in efficiency of food utilisation above the maintenance requirement (i.e. net energy requirement for gain) during periods of growth recovery.

The body compositional changes which were shown in Figures 17 to 28, indicate less change in protein synthesis immediately after realimentation than in fat synthesis which shows a rapid climb. This is reflected in a change in rate of increase of protein:water ratio only after about a week of realimentation (Figure 30). Such a delayed response in protein synthesis during recovery growth agrees well with a very recent publication by Howarth and Baldwin (1971 a). Rates of synthesis and accummulation of protein and nucleic acid in rat gastrocnemius muscles were measured during normal growth, restricted growth, and recovery from restricted growth. Food restriction was 50-60 percent of ad-libitum intake. Recovery growth was induced by refeeding ad-libitum after three weeks of restricted feeding. The amounts of DNA, RNA and

TABLE XX: EFFICIENCY OF LIVEWEIGHT GAIN FOLLOWING REALIMENTATION

Piglet no.	Period during which efficiency calculated (days)	Efficiency of liveweight gain (g liveweight gain per g dry matter feed)
L1	57-64	1.271
L2	57-78	0.997
L3	57-72	1.020
L4	58-77	0.921
L5	58-77	0.854
L6	58-77	0.940

TABLE XXI: EFFICIENCY OF UTILISATION OF NET ENERGY FOR GROWTH FOLLOWING REALIMENTATION (%)

Piglet no. Period throughout which utilisation calculated (days)	L1	L2	L3	Period throughout which calculated (days)	L4	L5	L6
58-64	39.6	48.1	37.0	59-64	40.0	44.0	39.7
65-71	-	36.8	25.7	65-73	41.7	47.1	55.7
72-78	-	26.2	-	73-77	21.6	32.4	43.2

TABLE XXII: RATE OF PROTEIN SYNTHESIS THROUGHOUT THE FIRST WEEK OF REALIMENTATION

Piglet no.	Rate of protein synthesis (g new protein per weight (g) protein per day)
L1	0.0305
L2	0.0310
L3	0.0440
L4	0.0500
L5	0.0500
L6	0.0400

protein in muscles from rats killed at intervals were measured to determine rates of accumulation. Rates of synthesis were measured *in vivo* as ^{32}P-orthophosphate incorporation into DNA and RNA, and L-^{14}C-leucine incorporation into protein. They found that food restriction inhibited synthesis and accumulation of nucleic acids and protein. Rates of DNA and RNA synthesis during recovery were greater than normal; however, recovery of protein synthesis following restriction was delayed for several days and there was little compensatory acceleration in protein synthesis and accumulation during recovery growth. Rate of muscle protein synthesis appeared to be determined by both the amount and activity of RNA in muscle. When changes in the activities of several oxidative enzymes and concentrations of several energy yielding metabolites were examined during restricted feeding, a close relationship to muscle growth was not shown (Howarth and Baldwin 1971 b).

Rates of protein synthesis during realimentation have been calculated for the seven days after the nutritional planes were changed and are shown in Table XXII. A comparison with Table XIV reveals little change in rate from that operating just prior to realimentation. On realimentation, increased energy absorbed appears to be primarily divided between an increased basal metabolism (Mount *et al* 1963), SDA, and fat deposition.

SUMMARY

1. Twelve piglets were separated from the dam on the day of birth and reared artificially on two planes of nutrition; a high plane approaching maximal growth and a low plane of 70% of the high plane. At age 56 days, those on a low plane of nutrition were realimented.

2. Throughout the growth period studied, daily body weight and feed intake were recorded and each week body composition was determined *in vivo* by isotope dilution.

3. Periods of discontinuous growth were observed in agreement with the observations of others. The mathematical treatment of such "phases" of growth was investigated. Use of the instantaneous relative growth rate constant to describe growth throughout each phase is criticised on the basis of feed efficiency calculations. A proposed alternative treatment, the fitting of a polynomial equation to each phase, appears to be a refinement over the growth constant expression.

4. Total body water, protein, lipid and ash were determined each week. Distinct phases of protein growth which coincided with the phases of liveweight growth were noted on both planes of nutrition. By application of a polynomial equation to each phase of protein growth, daily changes in body protein were predicted. Efficiencies of utilisation of dietary protein for growth and rates of new protein synthesis *in vivo* were calculated. Protein:water ratios were calculated and their values discussed in relation to the growth processes.

5. Unlike an earlier study, lipid deposits did not show a marked cycling throughout the growth period studied, although there were some changes in the rate of lipid synthesis coincidental with phasic protein growth in those animals on a low plane of nutrition.
6. The technique of use of body composition as a form of indirect calorimetry was employed enabling efficiencies of utilisation of energy for growth to be determined. Average figures for heat production were calculated by subtraction and found to be in agreement with published values at lower body weights but rather high values were obtained at body weights greater than about 15 kg.
7. Over the total experimental period, piglets on a low plane of nutrition showed higher efficiencies of feed conversion and higher efficiencies of energy utilisation. Calculated heat production values were only slightly depressed by restricted nutrition.
8. The composition of recovery growth following realimentation of animals on a low plane of nutrition was determined. An immediate increase in rate of lipid synthesis was noted but little change in rate of protein synthesis immediately following realimentation. The tendency towards fatness is in agreement with the observations of other workers. Feed efficiency and efficiency of utilisation of net energy increased during recovery growth.
9. The origins of the growth and composition patterns observed are discussed. Fundamental control of protein synthesis appears to operate relatively independently of nutritional plane and in a phasic manner as an extension into postnatal life of phasic

embryonic growth and development.

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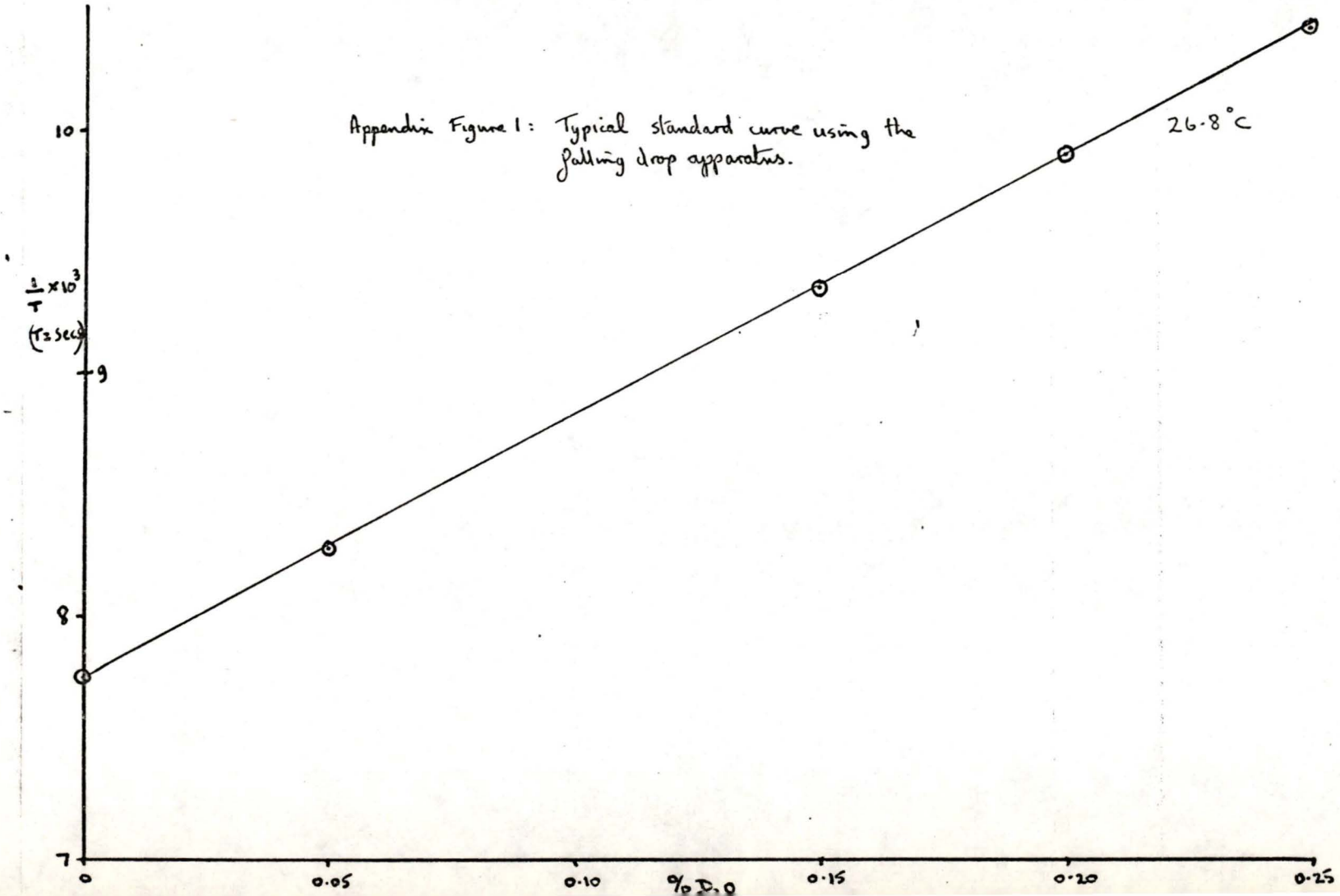
APPENDIX



Appendix Figure 1: Typical standard curve using the falling drop apparatus.

APPENDIX TABLE I: PHASIC POLYNOMIAL EQUATIONS: EXPERIMENT I

Growth Period (days)	
	H1
6-26	$W = 0.950 + 0.173t - 0.006t^2 + 0.00024t^3 \pm 0.023$ kg
28-38	$W = 66.83 - 5.653t + 0.168t^2 - 0.0015t^3 \pm 0.056$ kg
40-56	$W = 74.835 - 4.418t + 0.953t^2 - 0.000597t^3 \pm 0.089$ kg
	H2
8-39	$W = 1.287 - 0.0229t + 0.00405t^2 + 0.0000253t^3 \pm 0.039$ kg
41-56	$W = 57.165 - 3.575t + 0.079t^2 - 0.000506t^3 \pm 0.058$ kg
58-63	$W = 2181.14 - 102.67t + 1.611t^2 - 0.0083t^3 \pm 0.82$ kg
	L1
5-28	$W = 1.166 + 0.251t - 0.0113t^2 + 0.00036t^3 \pm 0.036$ kg
32-56	$W = 16.377 - 0.963t + 0.0266t^2 - 0.000144t^3 \pm 0.056$ kg
59-63	$W = 25201.2 - 1242.5t^2 + 20.415t^2 - 0.112t^3 \pm 0.097$ kg
	L2
8-18	$W = 2.433 - 0.311t + 0.0273t^2 - 0.00065t^3 \pm 0.017$ kg
20-28	$W = -118.97 + 15.02t - 0.620t^2 + 0.00859t^3 \pm 0.096$ kg
30-57	$W = 0.511 + 0.119t - 0.00196t^2 + 0.0000614t^3 \pm 0.061$ kg
59-76	$W = -800.13 + 36.49t - 0.549t^2 - 0.00278t^3 \pm 0.127$ kg
	L3
6-30	$W = 1.533 + 0.0628t - 0.00026t^2 + 0.000094t^3 \pm 0.013$ kg
32-56	$W = -17.703 + 1.520t - 0.0344t^2 + 0.000313t^3 \pm 0.044$ kg
60-68	$W = -6623.7 + 308.84t - 4.789t^2 + 0.0248t^3 \pm 0.086$ kg

APPENDIX TABLE II: PHASIC POLYNOMIAL EQUATIONS: EXPERIMENT II

Growth Period (days)	
	H3
5–15	$W = .0093 + .352t - .027t^2 + .00122t^3 \pm 0.023$ kg
17–36	$W = 2.467 - .0764t + .00837t^2 - .0000251t^3 \pm .056$ kg
38–54	$W = -84.983 + 5.734t - .119t^2 + .000892t^3 \pm .093$ kg
	H4
5–12	$W = .236 + .2717t - .0112t^2 \pm .024$ kg
14–22	$W = -4.386 + 1.061t - .0584t^2 - .00125t^3 \pm .035$ kg
24–38	$W = 14.290 - 1.276t + .046t^2 - .00041t^3 \pm .042$ kg
40–54	$W = 5.892 - .516t + .0215t^2 - .00014t^3 \pm .054$ kg
	H5
5–15	$W = 1.206 - .0457t + .0190t^2 - .00047t^3 \pm .010$ kg
17–34	$W = .498 + .112t + .00298t^2 + .000026t^3 \pm .018$ kg
36–54	$W = 45.193 - 2.921t + .071t^2 - .00048t^3 \pm .065$ kg
	H6
5–16	$W = .944 + .0165t + .0082t^2 - .000162t^3 \pm .011$ kg
18–36	$W = 3.788 - .237t + .0117t^2 - .000049t^3 \pm .016$ kg
38–54	$W = -234.55 + 15.61t - .335t^2 + .0024t^3 \pm .047$ kg
	L4
5–14	$W = .2516 + .3353t - .03747t^2 + .00166t^3 \pm .012$ kg
16–36	$W = .4989 + .144t - .00309t^2 + .000069t^3 \pm .036$ kg
38–54	$W = 28.810 - 1.758t + .0398t^2 - .000258t^3 \pm .049$ kg

APPENDIX TABLE II: PHASIC POLYNOMIAL EQUATIONS: EXPERIMENT II (cont'd)

Growth Period (days)	
	L5
5-14	$W = 1.487 - .1366t + .0287t^2 - .000946t^3 \pm .046$ kg
16-38	$W = .649 + .192t - .0049t^2 + .000088t^3 \pm .069$ kg
40-54	$W = 59.59 - 3.567t + .0759t^2 - .00050t^3 \pm .074$ kg
	L6
5-11	$W = 3.025 - .729t + .0956t^2 - .0039t^3 \pm .010$ kg
13-19	$W = -18.76 + 3.65t - .218t^2 + .00444t^3 \pm .014$ kg
21-35	$W = -4.367 + .654t - .0216t^2 + .00028t^3 \pm .042$ kg
37-54	$W = -2.002 + .199t - .0016t^2 + .0000254t^3 \pm .088$ kg

APPENDIX TABLE III: INSTANTANEOUS RELATIVE GROWTH RATE CONSTANTS

Experiment I:	High Plane			Low Plane	
	Growth period (days)	K*	Growth period (days)		K
H1:	6-26	5.590	L1:	5-28	4.851
	28-38	5.018		32-56	3.966
	40-56	3.524			
H2:	8-38	5.950	L2:	8-18	3.641
	40-56	4.220		20-28	7.130
				30-56	4.205
			L3:	6-30	4.560
				32-56	3.580
Experiment II:					
H3:	5-14	9.410	L4:	5-14	6.080
	16-37	5.280		16-36	3.760
	38-54	3.560		38-54	3.580
H4:	5-12	5.010	L5:	5-14	7.320
	14-22	5.890		16-38	3.130
	24-38	5.630		40-54	3.000
	40-54	4.020			
H5:	5-14	8.700	L6:	5-11	2.020
	16-34	5.560		13-19	5.660
	36-54	3.900		21-35	3.680
				37-54	3.480
H6:	5-16	7.190			
	18-36	5.600			
	38-54	3.140			

*K = instantaneous relative growth rate constant, per cent per day.

APPENDIX TABLE IV: ACTUAL AND PREDICTED BODY WEIGHT DATA - HI

a) Actual weight (kg)
b) Weight predicted by phasic polynomial equations (kg)
c) Weight predicted by growth rate constants (kg)

Age (days)	a	b	c	Age (days)	a	b	c
5	1.78	-	-	35	9.60	9.431	9.579
6	1.90	1.821	1.908	36	9.70	9.949	10.060
7	1.96	1.945	2.005	37	10.65	10.476	10.565
8	2.11	2.068	2.115	38	10.95	11.000	11.095
9	2.03	2.190	2.232	39	11.23	SE=0.056 kg	SE=0.095 kg
10	2.27	2.312	2.355	40	12.25	12.376	12.253
11	2.42	2.437	2.485	41	12.85	12.739	12.681
12	2.46	2.566	2.622	42	13.25	13.146	13.127
13	2.66	2.700	2.670	43	13.58	13.593	13.589
14	2.84	2.840	2.814	44	14.00	14.077	14.067
15	3.09	2.988	2.966	45	14.60	14.593	14.562
16	3.33	3.145	3.126	46	15.20	15.139	15.075
17	3.47	3.314	3.295	47	15.65	15.711	15.606
18	3.53	3.494	3.473	48	16.45	16.305	16.155
19	3.64	3.688	3.660	49	16.82	16.918	16.724
20	3.98	3.897	3.858	50	17.20	17.546	17.313
21	3.84	4.123	4.066	51	18.32	18.186	17.922
22	4.26	4.366	4.286	52	19.00	18.833	18.553
23	4.59	4.629	4.517	53	19.58	19.484	19.206
24	4.97	4.912	4.761	54	19.95	20.137	19.882
25	5.25	5.218	5.018	55	21.00	20.787	20.582
26	5.60	5.548	5.289	56	21.30	21.430	21.306
27	6.10	SE=0.023 kg	SE=0.051 kg			SE=0.089 kg	SE=0.117 kg
28	6.80	6.775	6.804				
29	6.90	6.986	7.141				
30	7.34	7.268	7.499				
31	7.60	7.613	7.875				
32	8.15	8.010	8.270				
33	8.20	8.452	8.685				
34	9.00	8.928	9.121				

APPENDIX TABLE V: ACTUAL AND PREDICTED BODY WEIGHT DATA - H2

a) Actual weight (kg)
b) Weight predicted by phasic polynomial equations (kg)
c) Weight predicted by growth rate constants (kg)

Age (days)	a	b	c	Age (days)	a	b	c
7	1.27	-	-	37	7.35	7.258	6.913
8	1.37	1.375	1.368	38	7.75	7.645	7.310
9	1.36	1.427	1.449	39	8.05	SE=0.039 kg	SE=0.043 kg
10	1.49	1.487	1.532	40	8.75	8.904	9.000
11	1.57	1.558	1.620	41	9.35	9.275	9.382
12	1.67	1.638	1.713	42	9.85	9.681	9.780
13	1.76	1.728	1.811	43	10.15	10.118	10.195
14	1.89	1.828	1.915	44	10.60	10.583	10.627
15	2.00	1.939	2.025	45	11.00	11.074	11.078
16	2.10	2.059	2.141	46	11.50	11.588	11.548
17	2.18	2.191	2.264	47	12.20	12.120	12.038
18	2.30	2.333	2.394	48	12.70	12.669	12.548
19	2.43	2.485	2.531	49	13.00	13.231	13.080
20	2.55	2.649	2.676	50	13.80	13.804	13.635
21	2.75	2.824	2.830	51	14.30	14.383	14.213
22	3.02	3.010	2.992	52	15.20	14.967	14.816
23	3.18	3.207	3.164	53	15.65	15.552	15.444
24	3.43	3.417	3.346	54	16.10	16.135	16.100
25	3.55	3.637	3.538	55	16.70	16.713	16.783
26	3.85	3.870	3.741	56	17.23	17.283	17.495
27	4.02	4.115	3.956	57	18.40	SE=0.058 kg	SE=0.080 kg
28	4.72	4.372	4.183	58	18.80		
29	4.74	4.641	4.423	59	19.00		
30	5.03	4.923	4.677	60	19.65		
31	5.13	5.217	4.945	61	20.10		
32	5.50	5.525	5.229	62	21.20		
33	5.75	5.845	5.530	63	22.21		
34	6.30	6.178	5.847				
35	6.40	6.524	6.183				
36	6.65	6.884	6.537				

APPENDIX TABLE VI: ACTUAL AND PREDICTED BODY WEIGHT DATA - L1

a) Actual weight (kg)
b) Weight predicted by phasic polynomial equations (kg)
c) Weight predicted by growth rate constants (kg)

Age (days)	a	b	c	Age (days)	a	b	c
5	2.24	2.183	2.237	35	9.40	9.115	9.160
6	2.38	2.342	2.349	36	9.35	9.498	9.524
7	2.47	2.491	2.463	37	10.10	9.904	9.902
8	2.63	2.633	2.582	38	10.45	10.331	10.295
9	2.65	2.769	2.707	39	10.85	10.778	10.704
10	2.90	2.902	2.838	40	11.35	11.246	11.129
11	2.99	3.034	2.976	41	11.50	11.731	11.571
12	3.14	3.166	3.120	42	11.90	12.235	12.030
13	3.29	3.303	3.272	43	12.70	12.756	12.508
14	3.43	3.443	3.430	44	13.20	13.295	13.005
15	3.63	3.592	3.597	45	14.10	13.845	13.521
16	3.79	3.751	3.771	46	14.20	14.411	14.058
17	3.99	3.921	3.954	47	14.90	14.991	14.616
18	4.12	4.105	4.146	48	15.80	15.584	15.196
19	4.39	4.305	4.347	49	16.40	16.198	15.799
20	4.61	4.524	4.558	50	16.70	16.804	16.426
21	4.74	4.763	4.778	51	17.20	17.430	17.078
22	5.01	5.024	5.011	52	18.20	18.065	17.756
23	5.27	5.310	5.254	53	18.95	18.708	18.461
24	5.63	5.623	5.508	54	19.30	19.359	19.194
25	5.85	5.965	5.775	55	20.10	20.017	19.956
26	6.16	6.339	6.055	56	20.50	20.680	20.748
27	6.71	6.745	6.349	57	21.70	SE=0.056 kg	SE=0.082 kg
28	7.40	7.188	6.657				
29	7.18	SE=0.036 kg	SE=0.056 kg				
30	8.00	-	-				
31	8.00	-	-				
32	8.00	8.106	8.150				
33	8.25	8.418	8.474				
34	8.85	8.755	8.810				

APPENDIX TABLE VII: ACTUAL AND PREDICTED BODY WEIGHT DATA - L2

a) Actual weight (kg)
b) Weight predicted by phasic polynomial equations (kg)
c) Weight predicted by growth rate constants (kg)

Age (days)	a	b	c	Age (days)	a	b	c
8	1.38	1.360	1.330	38	5.50	5.556	5.563
9	1.33	1.372	1.381	39	5.80	5.797	5.797
10	1.41	1.404	1.434	40	6.10	6.048	6.041
11	1.48	1.452	1.489	41	6.30	6.310	6.295
12	1.51	1.511	1.546	42	6.50	6.584	6.524
13	1.57	1.578	1.605	43	6.85	6.869	6.799
14	1.64	1.649	1.667	44	7.10	7.165	7.085
15	1.72	1.721	1.731	45	7.50	7.474	7.383
16	1.82	1.788	1.797	46	7.80	7.796	7.694
17	1.81	1.848	1.866	47	8.20	8.131	8.018
18	1.91	1.896	1.938	48	8.70	8.479	8.356
19	1.96	SE=0.017 kg	SE=0.052 kg	49	8.85	8.841	8.707
20	2.08	1.945	2.003	50	9.20	9.217	9.074
21	2.15	2.356	2.228	51	9.50	9.608	9.456
22	2.30	2.608	2.386	52	10.10	10.013	9.854
23	2.43	2.752	2.556	53	10.30	10.434	10.269
24	2.64	2.841	2.738	54	10.60	10.871	10.701
25	2.80	2.925	2.932	55	11.60	11.323	11.151
26	3.05	3.057	3.141	56	11.70	11.792	11.621
27	3.31	3.287	3.364	57	12.35	SE=0.061 kg	SE=0.080 kg
28	3.68	3.667	3.603				
29	3.73	SE=0.096 kg	SE=0.082 kg				
30	4.00	3.962	4.010				
31	4.12	4.132	4.168				
32	4.30	4.310	4.344				
33	4.36	4.496	4.527				
34	4.82	4.690	4.717				
35	4.95	4.893	4.916				
36	5.05	5.104	5.123				
37	5.35	5.325	5.338				

APPENDIX TABLE VIII: ACTUAL AND PREDICTED BODY WEIGHT DATA - L3

a) Actual weight (kg)
b) Weight predicted by phasic polynomial equations (kg)
c) Weight predicted by growth rate constants (kg)

Age (days)	a	b	c	Age (days)	a	b	c
6	1.93	1.921	1.933	36	6.90	7.024	6.932
7	2.00	1.992	2.016	37	7.25	7.284	7.181
8	2.08	2.067	2.107	38	7.50	7.545	7.438
9	2.09	2.146	2.201	39	7.85	7.809	7.705
10	2.24	2.229	2.300	40	8.30	8.077	7.982
11	2.33	2.317	2.403	41	8.45	8.351	8.269
12	2.37	2.411	2.511	42	8.75	8.634	8.565
13	2.50	2.512	2.623	43	8.95	8.926	8.873
14	2.64	2.619	2.741	44	9.10	9.231	9.191
15	2.77	2.733	2.863	45	9.50	9.550	9.521
16	2.90	2.856	2.991	46	9.60	9.884	9.863
17	3.00	2.987	3.125	47	10.10	10.237	10.217
18	3.09	3.127	3.265	48	10.60	10.608	10.584
19	3.24	3.276	3.412	49	11.05	11.001	10.964
20	3.53	3.436	3.564	50	11.60	11.418	11.357
21	3.58	3.607	3.724	51	11.85	11.859	11.765
22	3.75	3.788	3.891	52	12.50	12.328	12.187
23	3.92	3.982	4.065	53	12.80	12.826	12.625
24	4.25	4.188	4.247	54	13.30	13.354	13.078
25	4.35	4.407	4.437	55	14.00	13.916	13.547
26	4.60	4.640	4.636	56	14.40	14.511	14.033
27	4.98	4.887	4.844			SE=0.044 kg	SE=0.105 kg
28	5.30	5.149	5.061				
29	5.25	5.425	5.288				
30	5.75	5.718	5.525				
31	5.85	SE=0.013 kg	SE=0.081 kg				
32	6.02	5.594	6.020				
33	6.10	6.230	6.236				
34	6.60	6.499	6.460				
35	6.75	6.763	6.692				

APPENDIX TABLE IX: ACTUAL AND PREDICTED BODY WEIGHT DATA - H3

a) Actual weight (kg)
b) Weight predicted by phasic polynomial equations (kg)
c) Weight predicted by growth rate constants (kg)

Age (days)	a	b	c	Age (days)	a	b	c
5	1.30	1.244		35	9.05	8.974	9.086
6	1.33	1.409	1.421	36	9.40	9.397	9.570
7	1.52	1.564	1.554	37	9.80	SE=0.056 kg	SE=0.075 kg
8	1.74	1.715	1.699	38	10.30	10.159	10.149
9	1.95	1.870	1.858	39	10.65	10.704	10.510
10	2.04	2.038	2.042	40	11.00	11.220	10.954
11	2.20	2.223	2.233	41	11.85	11.713	11.344
12	2.45	2.436	2.441	42	12.10	12.187	11.748
13	2.60	2.681	2.669	43	12.60	12.649	12.166
14	3.02	2.968	2.918	44	13.10	13.102	12.945
15	3.30	3.302	3.190	45	13.60	13.554	13.406
16	3.27	SE=0.023 kg	SE=0.035 kg	46	14.20	14.008	13.883
17	3.50	3.465	3.444	47	14.65	14.471	14.377
18	3.65	3.658	3.627	48	14.50	14.948	14.908
19	3.85	3.866	3.820	49	15.50	15.444	15.439
20	4.00	4.087	4.023	50	16.35	15.964	15.989
21	4.40	4.323	4.237	51	16.50	16.514	16.558
22	4.50	4.572	4.462	52	16.83	17.100	17.147
23	4.95	4.834	4.699	53	17.43	17.725	17.757
24	5.12	5.109	4.949	54	18.70	18.397	18.389
25	5.30	5.398	5.212	55	19.10	SE=0.093 kg	SE=0.098 kg
26	5.70	5.700	5.490	56	20.20	-	-
27	6.05	6.014	5.790	57	21.20	-	-
28	6.30	6.341	6.101				
29	6.70	6.681	6.426				
30	7.18	7.033	6.992				
31	7.34	7.398	7.384				
32	7.65	7.774	7.777				
33	8.15	8.162	8.191				
34	8.50	8.562	8.627				

APPENDIX TABLE X: ACTUAL AND PREDICTED BODY WEIGHT DATA - H4

a) Actual weight (kg)
b) Weight predicted by phasic polynomial equations (kg)
c) Weight predicted by growth rate constants (kg)

Age (days)	a	b	c	Age (days)	a	b	c
5	1.38	1.314	1.380	35	8.45	8.435	8.221
6	1.40	1.463	1.449	36	8.90	8.877	8.683
7	1.50	1.589	1.522	37	9.25	9.322	9.272
8	1.70	1.693	1.598	38	9.80	9.768	9.788
9	1.91	1.774	1.678	39	10.20	SE=0.042 kg	SE=0.065 kg
10	1.83	1.833	1.762	40	10.65	10.945	11.300
11	1.80	1.870	1.850	41	11.80	11.499	11.754
12	1.90	1.884	1.943	42	12.25	12.062	12.227
13	2.11	SE=0.024 kg	SE=0.020 kg	43	12.70	12.634	12.719
14	2.42	2.436	2.426	44	13.20	13.213	13.230
15	2.60	2.589	2.563	45	13.60	13.799	13.762
16	2.78	2.737	2.714	46	14.20	14.392	14.315
17	2.85	2.887	2.874	47	14.90	14.989	14.890
18	3.06	3.048	3.043	48	15.54	15.591	15.489
19	3.19	3.226	3.222	49	16.25	16.196	16.112
20	3.40	3.430	3.412	50	17.25	16.804	16.760
21	3.76	3.666	3.613	51	17.50	17.414	17.434
22	3.90	3.942	3.826	52	17.70	18.026	18.135
23	4.25	SE=0.035 kg	SE=0.031 kg	53	18.61	18.637	18.864
24	4.50	4.510	4.500	54	19.30	19.248	19.622
25	4.75	4.751	4.753	55	20.22	SE=0.054 kg	SE=0.071 kg
26	5.05	5.022	5.021	56	21.00	-	-
27	5.35	5.322	5.304	57	22.20	-	-
28	5.55	5.647	5.603				
29	6.05	5.995	5.918				
30	6.40	6.364	6.251				
31	6.70	6.752	6.603				
32	7.12	7.155	6.975				
33	7.62	7.572	7.398				
34	8.00	7.999	7.783				

APPENDIX TABLE XI: ACTUAL AND PREDICTED BODY WEIGHT DATA - H5

a) Actual weight (kg)
b) Weight predicted by phasic polynomial equations (kg)
c) Weight predicted by growth rate constants (kg)

Age (days)	a	b	c	Age (days)	a	b	c
5	1.42	1.384	1.414	35	9.30	-	-
6	1.46	1.518	1.544	36	9.60	9.651	9.631
7	1.68	1.665	1.678	37	9.95	9.993	9.974
8	1.80	1.824	1.824	38	10.40	10.371	10.363
9	2.04	1.994	1.983	39	10.80	10.782	10.767
10	2.18	2.176	2.155	40	11.30	11.222	11.187
11	2.35	2.371	2.343	41	11.98	11.689	11.623
12	2.60	2.577	2.547	42	12.10	12.252	12.076
13	2.75	2.795	2.768	43	12.60	12.749	12.547
14	3.05	3.024	3.009	44	13.10	13.255	13.036
15	3.20	SE=0.010 kg	SE=0.010 kg	45	13.60	13.774	13.545
16	3.30	-	-	46	14.20	14.304	14.073
17	3.45	3.381	3.589	47	14.80	14.847	14.622
18	3.61	3.620	3.789	48	15.60	15.403	15.192
19	3.83	3.869	3.999	49	16.25	15.970	15.784
20	4.00	4.126	4.221	50	16.90	16.551	16.400
21	4.36	4.392	4.456	51	17.20	17.144	17.040
22	4.67	4.667	4.703	52	17.50	17.750	17.705
23	5.10	4.952	4.965	53	18.20	18.368	18.395
24	5.35	5.246	5.241	54	19.00	19.000	19.112
25	5.50	5.550	5.532	55	20.90	SE=0.045 kg	SE=0.083
26	5.85	5.864	5.840	56	21.00	-	-
27	6.25	6.187	6.165	57	22.00	-	-
28	6.35	6.521	6.508				
29	6.85	6.865	6.870				
30	7.30	7.220	7.252				
31	7.60	7.585	7.655				
32	7.90	7.961	8.081				
33	8.38	8.348	8.530				
34	8.75	8.746	9.004				
		SE=0.018 kg	SE=0.055 kg				

APPENDIX TABLE XII: ACTUAL AND PREDICTED BODY WEIGHT DATA - H6

a) Actual weight (kg)
b) Weight predicted by phasic polynomial equations (kg)
c) Weight predicted by growth rate constants (kg)

Age (days)	a	b	c	Age (days)	a	b	c
5	1.24	1.212	1.240	35	7.80	7.690	7.648
6	1.26	1.304	1.326	36	8.07	8.097	8.076
7	1.40	1.407	1.421	37	8.40	SE=0.016 kg	SE=0.024 kg
8	1.54	1.519	1.523	38	8.90	8.738	9.420
9	1.65	1.640	1.633	39	9.30	9.398	9.716
10	1.74	1.769	1.750	40	9.65	9.959	10.210
11	1.90	1.904	1.876	41	10.68	10.435	10.531
12	2.13	2.045	2.011	42	10.74	10.841	10.733
13	2.15	2.191	2.156	43	11.10	11.190	11.077
14	2.30	2.340	2.311	44	11.70	11.499	11.425
15	2.50	2.493	2.477	45	11.90	11.780	11.784
16	2.66	2.645	2.655	46	12.30	12.050	12.154
17	2.83	SE=0.011 kg	SE=0.010 kg	47	11.97	12.323	12.536
18	2.96	3.015	3.030	48	12.50	12.612	12.930
19	3.22	3.160	3.199	49	12.80	12.934	13.336
20	3.40	3.322	3.378	50	13.60	13.302	13.755
21	3.50	3.502	3.567	51	13.70	13.731	14.187
22	3.60	3.699	3.767	52	14.10	14.236	14.632
23	3.90	3.913	3.978	53	14.95	14.831	15.091
24	4.15	4.144	4.201	54	15.50	15.531	15.565
25	4.30	4.391	4.436	55	16.40	SE=0.047 kg	SE=0.069 kg
26	4.75	4.653	4.684	56	17.00	-	-
27	5.00	4.932	4.946	57	17.10	-	-
28	5.15	5.226	5.223	58	18.10	-	-
29	5.60	5.535	5.515	59	17.10	-	-
30	5.90	5.859	5.824	60	17.80	-	-
31	6.15	6.197	6.150	61	17.90	-	-
32	6.50	6.550	6.494	62	17.50	-	-
33	6.95	6.917	6.858	63	17.80	-	-
34	7.20	7.297	7.242	64	18.30	-	-

APPENDIX TABLE XIII: ACTUAL AND PREDICTED BODY WEIGHT DATA - L4

a) Actual weight (kg)
b) Weight predicted by phasic polynomial equations (kg)
c) Weight predicted by growth rate constants (kg)

Age (days)	a	b	c	Age (days)	a	b	c
5	1.20	1.199	1.205	35	4.75	4.728	4.738
6	1.30	1.274	1.273	36	4.90	4.915	4.916
7	1.30	1.333	1.350	37	5.05	SE=0.036 kg	SE=0.057 kg
8	1.34	1.387	1.432	38	5.25	5.304	5.261
9	1.49	1.447	1.519	39	5.40	5.463	5.438
10	1.55	1.521	1.611	40	5.70	5.640	5.633
11	1.63	1.620	1.709	41	6.00	5.836	5.835
12	1.75	1.753	1.813	42	6.10	6.047	6.044
13	1.87	1.932	1.923	43	6.30	6.273	6.254
14	2.20	2.165	2.040	44	6.45	6.512	6.484
15	2.30	SE=0.012 kg	SE=0.027 kg	45	6.65	6.762	6.716
16	2.27	2.294	2.350	46	6.90	7.023	6.956
17	2.43	2.393	2.438	47	7.25	7.291	7.205
18	2.48	2.493	2.530	48	7.65	7.567	7.463
19	2.60	2.594	2.625	49	7.85	7.848	7.730
20	2.67	2.696	2.724	50	8.20	8.132	8.007
21	2.85	2.801	2.826	51	8.40	8.419	8.294
22	2.87	2.908	2.932	52	8.80	8.706	8.591
23	3.05	3.019	3.042	53	9.00	8.992	8.899
24	3.15	3.132	3.156	54	9.20	9.276	9.218
25	3.21	3.250	3.275	55	9.40	SE=0.049 kg	SE=0.061 kg
26	3.35	3.372	3.398	56	10.30	-	-
27	3.51	3.498	3.526				
28	3.60	3.630	3.659				
29	3.80	3.767	3.797				
30	3.93	3.910	3.940				
31	4.05	4.059	4.088				
32	4.20	4.215	4.242				
33	4.40	4.378	4.401				
34	4.53	4.549	4.566				

APPENDIX TABLE XIV: ACTUAL AND PREDICTED BODY WEIGHT DATA - L5

a) Actual weight (kg)
b) Weight predicted by phasic polynomial equations (kg)
c) Weight predicted by growth rate constants (kg)

Age (days)	a	b	c	Age (days)	a	b	c
5	1.43	1.405	1.430	35	5.20	5.165	5.119
6	1.44	1.498	1.535	36	5.40	5.342	5.280
7	1.60	1.615	1.647	37	5.50	5.529	5.445
8	1.70	1.750	1.768	38	5.70	5.726	5.615
9	1.86	1.896	1.897	39	5.85	SE=0.069 kg	SE=0.082 kg
10	2.00	2.049	2.036	40	6.20	6.232	6.197
11	2.20	2.203	2.185	41	6.45	6.345	6.386
12	2.39	2.352	2.345	42	6.40	6.487	6.578
13	2.48	2.490	2.517	43	6.65	6.654	6.775
14	2.61	2.612	2.701	44	6.85	6.844	6.978
15	2.85	SE=0.046 kg	SE=0.059 kg	45	7.05	7.053	7.187
16	2.85	2.835	2.858	46	7.25	7.279	7.403
17	2.95	2.938	2.939	47	7.60	7.519	7.625
18	3.00	3.040	3.031	48	7.80	7.768	7.854
19	3.14	3.142	3.126	49	7.95	8.026	8.090
20	3.20	3.244	3.224	50	8.30	8.288	8.333
21	3.39	3.347	3.325	51	8.50	8.551	8.583
22	3.48	3.451	3.429	52	8.85	8.813	8.840
23	3.50	3.557	3.536	53	9.10	9.070	9.105
24	3.70	3.666	3.647	54	9.30	9.320	9.378
25	3.82	3.777	3.761	55	9.60	SE=0.074 kg	SE=0.095 kg
26	3.95	3.892	3.879	56	10.20	-	-
27	4.05	4.010	4.000				
28	4.00	4.133	4.126				
29	4.25	4.262	4.255				
30	4.37	4.395	4.388				
31	4.55	4.535	4.525				
32	4.65	4.681	4.667				
33	4.85	4.835	4.813				
34	5.00	5.000	4.964				

APPENDIX TABLE XV: ACTUAL AND PREDICTED BODY WEIGHT DATA - L6

a) Actual weight (kg)
b) Weight predicted by phasic polynomial equations (kg)
c) Weight predicted by growth rate constants (kg)

Age (days)	a	b	c	Age (days)	a	b	c
5	1.30	-	-	35	4.20	4.203	4.231
6	1.21	-	-	36	4.30	SE=0.042 kg	SE=0.079 kg
7	1.30	-	-	37	4.45	4.435	4.480
8	1.33	-	-	38	4.61	4.620	4.636
9	1.38	-	-	39	4.79	4.808	4.797
10	1.38	-	-	40	4.95	4.998	4.964
11	1.41	-	-	41	5.25	5.191	5.137
12	1.50	-	-	42	5.40	5.381	5.316
13	1.57	1.551	1.620	43	5.60	5.573	5.501
14	1.68	1.737	1.712	44	5.80	5.771	5.692
15	1.90	1.859	1.807	45	6.00	5.973	5.890
16	1.97	1.944	1.904	46	6.20	6.181	6.095
17	1.98	2.020	2.010	47	6.40	6.394	6.307
18	2.12	2.112	2.122	48	6.55	6.612	6.526
19	2.25	2.247	2.240	49	6.90	6.835	6.753
20	2.36	SE=0.014 kg	SE=0.014 kg	50	7.10	7.064	7.000
21	2.47	2.472	2.550	51	7.30	7.299	7.251
22	2.58	2.590	2.644	52	7.60	7.539	7.543
23	2.70	2.702	2.741	53	7.80	7.785	7.805
24	2.84	2.810	2.842	54	8.00	8.037	8.077
25	2.81	2.915	2.947	55	8.20	SE=0.088 kg	SE=0.098 kg
26	3.13	3.020	3.055	56	8.70	-	
27	3.10	3.125	3.168				
28	3.22	3.233	3.285				
29	3.35	3.345	3.406				
30	3.50	3.463	3.531				
31	3.55	3.589	3.661				
32	3.70	3.724	3.796				
33	3.90	3.871	3.936				
34	4.03	4.029	4.081				

APPENDIX TABLE XVI: EFFICIENCY OF LIVEWEIGHT GAIN - H1
(GMS GAIN/GM MILK DRY MATTER)

Age (days)	By phasic equation	By growth constant	Age (days)	By phasic equation	By growth constant
7	.879	.801	39	-	-
8	.822	.799	40	-	-
9	.771	.810	41	.580	.601
10	.731	.811	42	.637	.602
11	.713	.816	43	.685	.605
12	.701	.818	44	.724	.606
13	.695	.825	45	.753	.608
14	.694	.828	46	.777	.611
15	.700	.830	47	.794	.613
16	.709	.835	48	.803	.614
17	.728	.837	49	.807	.616
18	.740	.841	50	.806	.618
19	.760	.848	51	.799	.619
20	.779	.851	52	.790	.622
21	.801	.853	53	.775	.623
22	.818	.860	54	.759	.625
23	.841	.864	55	.738	.627
24	.857	.866	56	.714	.629
25	.878	.872			
26	.896	.875			
27	-	-			
28	-	-			
29	.452	.813			
30	.688	.816			
31	.801	.820			
32	.892	.824			
33	.959	.828			
34	.994	.832			
35	1.011	.836			
36	1.002	.839			
37	.982	.843			
38	.941	.846			

APPENDIX TABLE XVII: EFFICIENCY OF LIVEWEIGHT GAIN - H2

Age (days)	By phasic equation	By growth constant	Age (days)	By phasic equation	By growth constant
9	.477	.812	42	.653	.706
10	.531	.811	43	.676	.708
11	.606	.817	44	.690	.710
12	.654	.821	45	.700	.713
13	.703	.822	46	.703	.717
14	.744	.829	47	.700	.719
15	.784	.833	48	.691	.721
16	.804	.835	49	.680	.724
17	.837	.841	50	.666	.726
18	.851	.845	51	.648	.729
19	.860	.847	52	.629	.732
20	.876	.854	53	.720	.734
21	.882	.860	54	.714	.738
22	.884	.864	55	.704	.739
23	.885	.867	56	.691	.743
24	.889	.872			
25	.879	.874			
26	.880	.878			
27	.874	.884			
28	.867	.887			
29	.859	.892			
30	.852	.897			
31	.842	.899			
32	.837	.906			
33	.825	.912			
34	.816	.913			
35	.806	.920			
36	.798	.921			
37	.789	.930			
38	.778	.933			
39	-	-			
40	-	-			
41	.619	.655			

APPENDIX TABLE XVIII: EFFICIENCY OF LIVEWEIGHT GAIN - L1

Age (days)	By phasic equation	By growth rate constant	Age (days)	By phasic equation	By growth rate constant
6	1.530	1.024	39	1.045	.954
7	1.345	1.025	40	1.050	.957
8	1.212	1.026	41	1.046	.961
9	1.103	1.032	42	1.045	.962
10	1.030	1.036	43	1.041	.968
11	.979	1.045	44	1.031	.970
12	.941	1.046	45	1.024	.975
13	.932	1.056	46	1.010	.978
14	.930	1.051	47	.998	.981
15	.946	1.064	48	.984	.983
16	.971	1.065	49	.969	.987
17	.998	1.070	50	.952	.991
18	1.038	1.074	51	.936	.994
19	1.082	1.077	52	.919	.997
20	1.134	1.083	53	.900	1.001
21	1.183	1.086	54	.883	1.004
22	1.233	1.092	55	.865	1.008
23	1.287	1.096	56	.845	1.011
24	1.339	1.097			
25	1.389	1.105			
26	1.438	1.109			
27	1.478	1.116			
28	1.526	1.119			
29	-	-			
30	-	-			
31	-	-			
32	-	-			
33	.907	.936			
34	.947	.937			
35	.976	.940			
36	1.001	.944			
37	1.022	.947			
38	1.034	.951			

APPENDIX TABLE XIX: EFFICIENCY OF LIVEWEIGHT GAIN - L2

Age (days)	By phasic equation	By growth rate constant	Age (days)	By phasic equation	By growth rate constant
9	.178	.775	41	.991	.966
10	.470	.777	42	.995	.972
11	.691	.778	43	1.001	.975
12	.823	.779	44	1.002	.976
13	.902	.784	45	1.001	.980
14	.919	.788	46	1.006	.985
15	.894	.791	47	1.008	.988
16	.800	.793	48	1.009	.993
17	.693	.795	49	1.009	.994
18	.538	.796	50	1.010	1.000
19	-	-	51	1.010	1.002
20	-	-	52	1.011	1.006
21	-	-	53	1.009	1.010
22	4.405	1.492	54	1.010	1.012
23	2.262	1.509	55	1.006	1.016
24	1.178	1.517	56	1.005	1.022
25	.693	1.518			
26	.635	1.537			
27	.973	1.540			
28	1.628	1.550			
29	-	-			
30	-	-			
31	.948	.930			
32	.950	.939			
33	.957	.940			
34	.962	.941			
35	.966	.948			
36	.972	.950			
37	.973	.951			
38	.980	.958			
39	.986	.959			
40	.989	.963			

APPENDIX TABLE XX: EFFICIENCY OF LIVEWEIGHT GAIN - L3

Age (days)	By phasic equation	By growth rate constant	Age (days)	By phasic equation	By growth rate constant
7	.768	.926	39	.820	.840
8	.784	.941	40	.806	.844
9	.799	.944	41	.799	.845
10	.811	.946	42	.801	.846
11	.831	.947	43	.805	.851
12	.857	.948	44	.812	.852
13	.888	.952	45	.824	.856
14	.906	.954	46	.836	.859
15	.929	.960	47	.857	.861
16	.964	.962	48	.872	.864
17	.986	.967	49	.894	.866
18	1.012	.971	50	.918	.868
19	1.033	.975	51	.938	.872
20	1.063	.980	52	.964	.874
21	1.090	.985	53	.988	.878
22	1.102	.987	54	1.007	.879
23	1.129	.988	55	1.036	.882
24	1.146	.993	56	1.057	.885
25	1.163	.996			
26	1.181	1.003			
27	1.197	1.007			
28	1.208	1.009			
29	1.214	1.014			
30	1.229	1.018			
31	-	-			
32	-	-			
33	1.064	.824			
34	.994	.827			
35	.939	.830			
36	.895	.831			
37	.861	.835			
38	.837	.836			

APPENDIX TABLE XXI: EFFICIENCY OF LIVEWEIGHT GAIN - H3

Age (days)	By phasic equation	By growth rate constant	Age (days)	By phasic equation	By growth rate constant
6	1.626	1.152	39	1.085	.726
7	1.391	1.176	40	.987	.731
8	1.252	1.212	41	.910	.735
9	1.198	1.233	42	.848	.737
10	1.215	1.253	43	.801	.740
11	1.253	1.299	44	.763	.750
12	1.350	1.311	45	.741	.752
13	1.447	1.344	46	.726	.759
14	1.577	1.370	47	.722	.765
15	1.698	-	48	.725	.771
16	-	-	49	.736	.778
17	.872	.821	50	.752	.784
18	.902	.828	51	.776	.791
19	.918	.839	52	.803	.797
20	.940	.850	53	.837	.804
21	.951	.859	54	.876	.810
22	.958	.869	55	-	.816
23	.963	.881	56	-	.824
24	.972	.893			
25	.974	.904			
26	.971	.914			
27	.971	.927			
28	.969	.939			
29	.964	.951			
30	.962	.961			
31	.953	.973			
32	.947	.984			
33	.941	1.000			
34	.935	1.009			
35	.925	1.024			
36	-	1.035			
37	-	-			
38	-	-			

APPENDIX TABLE XXII: EFFICIENCY OF LIVEWEIGHT GAIN - H4

Age (days)	By phasic equation	By growth rate constant	Age (days)	By phasic equation	By growth rate constant
15	1.136	1.129	48	.803	.848
16	1.037	1.133	49	.777	.850
17	.998	1.138	50	.754	.852
18	1.017	1.139	51	.730	.854
19	1.070	1.142	52	.708	.855
20	1.161	1.148	53	.684	.858
21	1.267	1.151	54	.663	.860
22	1.393	1.329	55	-	-
23	-	-	56	-	-
24	-	-			
25	1.000	1.114			
26	1.071	1.121			
27	1.124	1.125			
28	1.153	1.127			
29	1.167	1.129			
30	1.170	1.133			
31	1.163	1.136			
32	1.142	1.140			
33	1.119	1.144			
34	1.086	1.148			
35	1.053	1.149			
36	1.014	1.151			
37	.974	1.157			
38	.931	1.160			
39	-	-			
40	-	-			
41	.994	.835			
42	.964	.837			
43	.936	.839			
44	.907	.841			
45	.882	.842			
46	.855	.844			
47	.827	.846			

APPENDIX TABLE XXIII: EFFICIENCY OF LIVEWEIGHT GAIN - H5

Age (days)	By phasic equation	By growth rate constant	Age (days)	By phase equation	By growth rate constant
6	1.276	1.159	39	.770	.758
7	1.300	1.171	40	.799	.763
8	1.304	1.192	41	.820	.768
9	1.306	1.217	42	.835	.773
10	1.290	1.227	43	.840	.780
11	1.292	1.255	44	.843	.785
12	1.272	1.272	45	.839	.792
13	1.253	1.289	46	.831	.799
14	1.238	1.312	47	.818	.804
15	-	-	48	.807	.808
16	-	-	49	.782	.814
17	-	-	50	.761	.822
18	1.106	.877	51	.737	.828
19	1.092	.883	52	.712	.833
20	1.068	.895	53	.682	.838
21	1.049	.905	54	.652	.845
22	1.032	.912	55	-	-
23	1.018	.923	56	-	-
24	1.001	.933			
25	.987	.943			
26	.975	.953			
27	.959	.962			
28	.950	.970			
29	.937	.985			
30	.929	.990			
31	.916	1.004			
32	.907	1.013			
33	.898	1.024			
34	.888	1.033			
35	-	-			
36	-	-			
37	.679	.733			
38	.729	.751			

APPENDIX TABLE XXIV: EFFICIENCY OF LIVEWEIGHT GAIN - H6

Age (days)	By phasic equation	By growth rate constant	Age (days)	By phasic equation	By growth rate constant
6	.962	.937	39	1.610	.711
7	1.020	.985	40	1.300	.718
8	1.049	1.006	41	1.054	.724
9	1.072	1.030	42	.869	.731
10	1.080	1.041	43	.726	.736
11	1.068	1.065	44	.628	.742
12	1.057	1.085	45	.560	.747
13	1.038	1.106	46	.528	.755
14	1.007	1.124	47	.525	.761
15	.985	1.143	48	.517	.766
16	.935	1.166	49	.599	.774
17	-	-	50	.672	.780
18	-	-	51	.767	.786
19	.775	.953	52	.883	.793
20	.836	.965	53	1.012	.799
21	.895	.979	54	1.156	.805
22	.943	.992			
23	.983	1.007			
24	1.018	1.024			
25	1.044	1.037			
26	1.060	1.053			
27	1.082	1.065			
28	1.093	1.083			
29	1.100	1.099			
30	1.106	1.115			
31	1.107	1.130			
32	1.109	1.147			
33	1.106	1.164			
34	1.101	1.178			
35	1.095	1.198			
36	1.091	1.215			
37	-	-			
38	-	-			

APPENDIX TABLE XXV: EFFICIENCY OF LIVEWEIGHT GAIN - L4

Age (days)	By phasic equation	By growth rate constant	Age (days)	By phasic equation	By growth rate constant
6	1.245	1.285	39	.682	.862
7	.929	1.292	40	.739	.866
8	.816	1.297	41	.794	.869
9	.873	1.304	42	.829	.870
10	1.036	1.311	43	.860	.872
11	1.325	1.319	44	.879	.875
12	1.681	1.328	45	.889	.877
13	2.105	1.333	46	.893	.880
14	2.506	1.340	47	.889	.883
15	-	-	48	.885	.887
16	-	-	49	.871	.889
17	.912	.838	50	.852	.893
18	.886	.840	51	.833	.895
19	.862	.843	52	.807	.898
20	.840	.846	53	.780	.902
21	.834	.853	54	.752	.904
22	.828	.858			
23	.823	.861			
24	.810	.864			
25	.818	.865			
26	.818	.866			
27	.816	.873			
28	.827	.878			
29	.830	.878			
30	.838	.879			
31	.843	.880			
32	.853	.886			
33	.861	.885			
34	.873	.889			
35	.883	.892			
36	.889	.894			
37	-	-			
38	-	-			

APPENDIX TABLE XXVI: EFFICIENCY OF LIVEWEIGHT GAIN - L5

Age (days)	By phasic equation	By growth rate constant	Age (days)	By phasic equation	By growth rate constant
6	1.339	1.577	39	-	-
7	1.590	1.577	40	-	-
8	1.712	1.597	41	.418	.733
9	1.718	1.597	42	.517	.734
10	1.675	1.613	43	.596	.735
11	1.572	1.621	44	.662	.738
12	1.422	1.631	45	.710	.740
13	1.244	1.645	46	.747	.744
14	1.042	1.650	47	.770	.745
15	-	-	48	.776	.747
16	-	-	49	.781	.750
17	.781	.713	50	.770	.751
18	.750	.716	51	.750	.752
19	.727	.719	52	.726	.753
20	.705	.721	53	.693	.756
21	.690	.723	54	.657	.758
22	.678	.726			
23	.672	.728			
24	.672	.729			
25	.666	.734			
26	.672	.737			
27	.671	.738			
28	.680	.739			
29	.694	.740			
30	.696	.742			
31	.712	.746			
32	.722	.747			
33	.740	.748			
34	.770	.749			
35	.773	.751			
36	.778	.753			
37	.796	.754			
38	.812	-			

APPENDIX TABLE XXVII: EFFICIENCY OF LIVEWEIGHT GAIN - L6

Age (days)	By phasic equation	By growth rate constant	Age (days)	By phasic equation	By growth rate constant
14	2.445	1.227	47	.791	.850
15	1.447	1.233	48	.785	.852
16	.948	1.235	49	.772	.855
17	.814	1.245	50	.766	.856
18	.951	1.252	51	.757	.860
19	1.340	1.256	52	.751	.861
20	-	-	53	.746	.865
21	-	-	54	.737	.867
22	1.014	.828			
23	.923	.829			
24	.856	.837			
25	.803	.838			
26	.776	.840			
27	.752	.843			
28	.750	.847			
29	.754	.847			
30	.770	.848			
31	.796	.851			
32	.826	.853			
33	.870	.864			
34	.903	.866			
35	.958	.867			
36	-	-			
37	-	-			
38	.931	.826			
39	.914	.827			
40	.890	.832			
41	.873	.835			
42	.857	.836			
43	.845	.840			
44	.830	.841			
45	.815	.845			
46	.805	.847			

APPENDIX TABLE XXVIII: BODY COMPOSITION - H1

Age (days)	Body weight (kg)	% Body Water	kg body water	kg protein	g Ash	FFDM (kg)	kg fat	Protein:H_2O
2	1.935	75.63	1.4634	.2939	69.805	.3486	.0898	(.2008)
8	2.199	74.91	1.7594	.3227	74.170	.4254	.1269	.1834
15	3.288	71.06	2.3365	.4624	93.695	.5777	.3743	.1979
22	4.800	65.43	3.1406	.6729	127.790	.7949	.8693	.2142
29	7.180	66.23	4.7560	.9850	205.836	1.2439	1.1842	.2071
36	10.165	64.30	6.5361	1.3266	273.512	1.7525	1.8774	.2029
43	14.050	64.92	9.1213	1.9048	386.330	2.5108	2.4110	.2088
50	17.880	65.21	11.6596	2.4868	498.610	3.2669	3.0785	.2132
57	22.170	64.72	14.4779	3.1481	624.446	4.1362	3.7634	.2174

APPENDIX TABLE XXIX: BODY COMPOSITION - H2

Age (days)	Body weight (kg)	% Body water	kg body water	kg Protein	g Ash	kg FFDM	kg fat	Protein:H_2O
2	1.355	75.31	1.0204	.1635	47.88	.2363	.0984	.1602
8	1.450	74.61	1.0818	.1759	50.19	.2518	.1164	.1625
15	2.174	71.52	1.5548	.2779	67.33	.3722	.2467	.1787
22	3.301	69.25	2.2860	.4515	93.98	.5641	.4445	.1975
29	5.035	67.21	3.3840	.7403	134.26	.8615	.7890	.2185
36	7.090	67.14	4.7605	.9412	194.38	1.2432	1.0860	.1977
43	10.640	68.80	7.3209	1.5024	287.31	1.9810	1.3380	.2052
50	14.290	69.23	9.8941	2.0775	393.35	2.7432	1.6552	.2099
57	18.050	68.56	12.3750	2.6578	503.67	3.4888	2.1900	.2147
64	22.210	69.98	15.5425	3.4037	620.24	4.4619	2.2055	.2189

APPENDIX TABLE XXX: BODY COMPOSITION - L1

Age (days)	Body weight (kg)	% Body Water	kg Body Water	kg Protein	g Ash	kg FFDM	kg Fat	Protein:H_2O
2	2.480	78.80	1.9542	.3708	72.06	0.4444	0.0505	.1897
8	2.703	74.30	2.0083	.3835	82.87	0.4844	0.2043	.1909
15	3.851	71.40	2.7488	.5700	106.97	0.6901	0.4121	.2073
22	5.340	66.15	3.5320	.7891	131.99	0.9569	0.9010	.2234
29	7.670	66.23	5.0780	.9842	205.41	1.3745	1.2602	.1938
36	9.895	65.99	6.5305	1.3514	277.99	1.7732	1.6164	.2069
43	13.285	67.46	8.9632	1.8047	366.24	2.3087	1.8500	.2013
50	17.050	66.32	11.3076	2.4102	483.01	3.0554	2.5750	.2131
57	21.600	66.82	14.4331	3.1414	622.19	3.8707	3.2490	.2176
64	26.370	67.02	17.0799	3.7718	741.09	4.7255	4.3446	.2208

= realimentation commenced.

APPENDIX TABLE XXXI: BODY COMPOSITION - L2

Age (days)	Body weight (kg)	% Body water	kg Body water	kg Protein	g Ash	kg FFDM	kg Fat	Protein:H_2O
2	1.482	75.42	1.1177	.1833	51.51	.2608	.1035	.1639
8	1.401	84.93	1.1900	.1984	54.19	.2789	-	.1667
15	1.823	72.31	1.3182	.2257	61.20	.3114	.1934	.1712
22	2.469	71.41	1.7631	.3256	84.58	.4275	.2785	.1846
29	3.855	73.20	2.8218	.5885	109.14	.7082	.3244	.2085
36	5.230	70.94	3.7101	.8314	151.96	.9516	.5697	.2240
43	7.050	71.06	5.0100	.9947	210.94	1.3155	.7365	.1985
50	9.430	69.94	6.5953	1.2807	274.50	1.7694	1.0649	.1941
57	12.380	69.72	8.6313	1.7960	358.50	2.3663	1.3903	.2080
64	16.980	67.21	11.413	2.4333	487.7	3.1975	2.3741	.2132
71	20.000	65.32	13.064	2.8184	560.6	3.6992	3.2420	.2157
78	24.290	66.35	16.116	3.5420	697.8	4.6402	3.5801	.2197

= realimentation commenced.

APPENDIX TABLE XXXII: BODY COMPOSITION - L3

Age (days)	Body weight (kg)	% Body water	kg Body water	kg Protein	g Ash	kg FFDM	kg Fat	Protein:H_2O
2	2.000	-	-	-	-	.3584	-	
8	2.160	74.70	1.6135	.2910	69.40	.3875	.1595	.1803
15	2.896	71.60	2.0735	.3994	85.03	.5079	.3146	.1926
22	3.985	73.50	2.7290	.5642	118.50	.6830	.5729	.2067
29	5.660	69.91	3.9572	.7697	162.49	1.020	.6826	.1945
36	7.140	68.90	4.9190	.9757	203.57	1.290	.9310	.1983
43	9.580	70.02	6.7079	1.3660	280.92	1.803	1.0714	.2036
50	11.650	71.12	8.2854	1.7187	349.69	2.263	1.1070	.2074
57	15.100	72.08	10.885	2.3124	464.30	3.040	1.2191	.2124
64	19.850	70.10	13.9175	3.0205	599.57	3.963	1.9854	.2170
71	23.050	69.49	16.0183	3.5178	693.14	4.620	2.4112	.2196

= realimentation commenced.

APPENDIX TABLE XXXIII: BODY COMPOSITION - H3

Age (days)	Body weight (kg)	% Body water	kg Body water	kg Protein	g Ash	kg FFDM	kg Fat	Protein:H_2O
9	1.95	77.84	1.518	.2697	66.06	.3628	.0596	.1776
16	3.37	72.70	2.450	.4929	97.37	.6080	.3161	.2011
23	4.98	68.67	3.420	.7503	139.6	.8547	.7036	.2193
30	7.25	66.82	4.845	.9592	200.4	1.2684	1.1368	.1979
37	10.02	65.70	6.584	1.3389	275.6	1.7664	1.6704	.2033
44	13.40	65.71	8.805	1.8358	372.5	2.4170	2.2937	.2084
51	16.74	66.40	11.116	2.3643	479.1	3.1078	2.5160	.2126
58	21.20	69.60	14.752	3.2157	641.3	4.2170	2.2310	.2179

APPENDIX TABLE XXXIV: BODY COMPOSITION - H4

Age (days)	Body weight (kg)	% Body water	kg Body water	kg Protein	g Ash	kg FFDM	kg Fat	Protein:H_2O
9	1.90	78.26	1.487	.2629	64.3	.3405	.0725	.1767
16	2.80	79.00	2.212	.4334	89.7	.5018	.0862	.1959
23	4.25	71.17	3.025	.6429	122.9	.7795	.4455	.2125
30	6.50	69.00	4.485	.8825	185.1	1.1648	.8502	.1967
37	9.51	65.85	6.263	1.2691	261.6	1.7042	1.5428	.2026
44	13.43	63.70	8.555	1.7797	361.6	2.4056	2.4695	.2080
51	17.69	64.46	11.404	2.4279	487.3	3.1700	3.1160	.2128
58	22.30	67.18	14.982	3.2709	646.7	3.9960	3.3220	.2183

APPENDIX TABLE XXXV: BODY COMPOSITION - H5

Age (days)	Body weight (kg)	% Body water	kg Body water	kg Protein	g Ash	kg FFDM	kg Fat	Protein:H_2O
9	2.06	77.18	1.590	.2858	68.6	.3692	.1008	.1797
16	3.35	73.28	2.455	.5275	97.6	.6003	.2950	.2148
23	5.12	68.51	3.508	.7748	143.5	.9175	.6945	.2208
30	7.39	66.75	4.933	.9783	204.5	1.3243	1.1327	.1983
37	10.18	65.65	6.684	1.3610	280.0	1.8243	1.6717	.2036
44	13.42	63.32	8.498	1.7667	359.0	2.4049	2.5170	.2078
51	17.41	63.07	10.982	2.3349	468.6	3.1199	3.3081	.2126
58	22.50	65.00	14.625	3.1454	630.8	4.0320	3.8430	.2150

APPENDIX TABLE XXXVI: BODY COMPOSITION - H6

Age (days)	kg Body weight	% Body water	kg Body water	kg Protein	g Ash	kg FFDM	kg Fat	Protein:H_2O
9	1.69	68.34	1.155	.1906	52.92	.3028	.232	.1650
16	2.78	69.89	1.943	.3676	80.70	.4892	.348	.1891
33	3.99	64.91	2.590	.5297	101.84	.7152	.685	.2041
30	5.98	66.02	3.948	.7599	162.10	1.0716	1.000	.1924
37	8.61	65.05	5.601	1.1232	233.00	1.5429	1.466	.2005
44	11.80	65.26	7.701	1.5880	324.35	2.1146	1.984	.2062
51	13.90	66.18	9.200	1.9273	390.00	2.4910	2.206	.2094
58	17.40	66.98	11.655	2.4967	499.00	3.1180	2.627	.2142
64	19.05	67.46	12.852	2.7684	551.62	3.4138	2.780	.2154

APPENDIX TABLE XXXVII: BODY COMPOSITION - L4

Age (days)	Body weight (kg)	% Body water	kg Body water	kg protein	g Ash	kg FFDM	kg Fat	Protein:H_2O
9	1.47	81.90	1.204	.2013	54.71	.2634	.030	.1671
16	2.30	76.43	1.758	.3245	74.38	.4123	.1300	.1845
23	3.06	74.86	2.291	.4529	92.20	.5484	.2210	.1976
30	3.98	72.66	2.892	.6074	111.37	.7132	.3748	.2100
37	5.12	68.76	3.521	.7782	143.97	.9175	.6810	.2210
44	6.41	68.67	4.402	.8645	181.43	1.1666	.8414	.1963
51	8.46	66.98	5.667	1.1374	235.85	1.5340	1.259	.2007
58	10.90	65.46	7.136	1.4612	299.51	1.9533	1.8107	.2047
64	14.00	64.87	9.082	1.8997	384.77	2.5088	2.4092	.2091
72	18.60	64.25	11.952	2.5577	511.84	3.3331	3.3150	.2139
77	20.70	65.39	13.537	2.9307	582.03	3.7194	3.4400	.2164

= realimentation commenced

APPENDIX TABLE XXXVIII: BODY COMPOSITION - L5

Age (days)	Body weight (kg)	% Body water	Body water (kg)	kg Protein	g Ash	kg FFDM	kg Fat	Protein:H_2O
9	1.93	79.01	1.525	.2713	66.29	.3459	.0590	.1779
16	2.90	74.65	2.165	.4217	89.73	.5197	.2153	.1947
23	3.77	70.55	2.660	.5467	106.04	.6756	.4344	.2055
30	4.45	71.61	3.187	.6865	129.82	.7974	.4656	.2154
37	5.60	77.78	3.889	.8821	160.00	1.0035	.7075	.2268
44	7.25	68.92	4.997	.9918	207.00	1.2454	1.0076	.1984
51	8.66	66.74	5.780	1.1623	240.69	1.5519	1.3281	.2010
58	11.00	66.28	7.291	1.4958	306.40	1.9533	1.7557	.2051
64	13.65	64.41	8.793	1.8341	371.91	2.4461	2.4110	.2085
72	17.90	61.45	11.00	2.3384	469.37	3.2077	3.6900	.2125
77	21.50	62.19	13.371	2.8927	574.62	3.8976	4.2300	.2163

= realimentation commenced.

APPENDIX TABLE XXXIX: BODY COMPOSITION - L6

Age (days)	Body weight	% Body water	Body water (kg)	kg Protein	g Ash	kg FFDM	kg Fat	Protein:H_2O
9	1.34	84.70	1.135	.1870	52.17	.2401	-	.1647
16	1.93	81.24	1.568	.2809	67.80	.3458	.0162	.1791
23	2.74	77.15	2.114	.4093	86.40	.4910	.1350	.1936
30	3.53	73.37	3.590	.5287	101.84	.6326	.3074	.2041
37	4.53	71.47	3.238	.7004	131.95	.8118	.4802	.2163
44	5.90	71.18	4.200	.8212	172.78	1.0573	.6427	.1955
51	7.60	72.07	5.478	1.0962	227.67	1.3440	.7780	.2001
58	9.20	71.84	6.610	1.3450	276.71	1.6307	.9600	.2034
64	11.55	68.83	7.951	1.6440	335.26	2.0698	1.5300	.2067
72	16.50	64.53	10.648	2.2581	454.16	2.9568	2.8950	.2120
77	19.90	64.31	12.798	2.7580	549.67	3.5661	3.5360	.2155

= realimentation commenced.

APPENDIX TABLE XL: EFFICIENCY OF PROTEIN SYNTHESIS - H1

Age, days	Predicted body weight, kg	Milk protein consumed, kg d.m.	Pig protein kg d.m.	Protein gain, kg d.m.	Efficiency of protein gain
6	1.821	.0299	.3090	-	-
7	1.945	.0317	.3352	.0262	.88
8	2.068	.0336	.3622	.0270	.85
9	2.190	.0354	.3899	.0277	.82
10	2.312	.0372	.4184	.0285	.81
11	2.437	.0390	.4475	.0291	.78
12	2.566	.0409	.4772	.0297	.76
13	2.700	.0428	.5073	.0301	.74
14	2.840	.0448	.5382	.0309	.72
15	2.988	.0469	.5700	.0318	.71
16	3.145	.0492	.6020	.0320	.68
17	3.314	.0516	.6345	.0325	.66
18	3.494	.0541	.6679	.0334	.65
19	3.688	.0569	.7020	.0341	.63
20	3.897	.0598	.7368	.0348	.61
21	4.123	.0630	.7723	.0355	.59
22	4.366	.0663	.8092	.0369	.58
23	4.629	.0700	.8478	.0386	.58
24	4.912	.0739	.8886	.0408	.58
25	5.218	.0781	.9307	.0421	.57
26	5.548	.0825	.9750	.0443	.57
27				.0461	.56
29	6.986	.1019	.9768	.0420	
30	7.268	.1022	1.0110	.0342	.34
31	7.613	.1056	1.0500	.0390	.38
32	8.010	.1094	1.0938	.0438	.41
33	8.452	.1136	1.1425	.0487	.45
34	8.928	.1181	1.1960	.0535	.47
35	9.431	.1227	1.2543	.0583	.49
36	9.949	.1274	1.3174	.0631	.51
37	10.476	.1321	1.3853	.0679	.53
38	11.000	.1367	1.4580	.0727	.55
39	-	-	1.5356	.0776	.57
40	12.376	.1485	1.6180	.0824	-
41	12.739	.1516	1.7052	.0872	.59
42	13.146	.1550	1.7972	.0920	.61
43	13.593	.1586	1.8941	.0969	.63
44	14.077	.1626	1.9843	.0902	.57
45	14.593	.1667	2.0642	.0799	.49
46	15.139	.1711	2.1457	.0815	.49
47	15.711	.1756	2.2289	.0832	.49
48	16.305	.1803	2.3137	.0848	.48
49	16.918	.1850	2.4002	.0865	.48
50	17.546	.1898	2.4884	.0882	.48
51	18.185	.1946	2.5782	.0898	.47
52	18.833	.1994	2.6697	.0915	.47
53	19.484	.2043	2.7628	.0931	.47
54	20.137	.2090	2.8576	.0948	.46
55	20.787	.2138	2.9540	.0964	.46
56	21.430		3.0521	.0981	.46

APPENDIX TABLE XLII: EFFICIENCY OF PROTEIN SYNTHESIS - H3

Age, days	Body weight kg	Milk protein consumed, kg d.m.	Pig protein kg d.m.	Protein gain kg d.m.	Efficiency of protein gain
9	1.870	.033	.268		
10	2.038	.035	.299	.031	.94
11	2.223	.037	.330	.031	.89
12	2.436	.040	.361	.031	.84
13	2.681	.043	.393	.032	.80
14	2.968	.047	.426	.033	.77
15	3.302	.049	.459	.033	.70
16	-	-	.493	.034	.69
17	3.465	.052	.528	.035	-
18	3.658	.055	.563	.035	.67
19	3.866	.057	.599	.036	.65
20	4.087	.060	.636	.037	.65
21	4.323	.062	.673	.037	.62
22	4.572	.065	.711	.038	.61
24	5.109	.071	.775		
25	5.398	.074	.797	.022	.31
26	5.700	.077	.824	.027	.36
27	6.014	.080	.854	.030	.39
28	6.341	.083	.889	.035	.44
29	6.681	.086	.927	.038	.46
30	7.033	.090	.969	.042	.49
31	7.398	.094	1.014	.045	.50
32	7.774	.098	1.063	.049	.52
33	8.162	.101	1.115	.052	.53
34	8.562	.105	1.169	.054	.53
35	8.974	.108	1.227	.058	.55
36	9.397	.112	1.288	.061	.56
37	-	-	1.351	.063	.56
38	10.159	.119	1.416	.065	-
39	10.704	.124	1.484	.068	.57
40	11.220	.129	1.554	.070	.56
41	11.713	.133	1.626	.072	.56
42	12.187	.137	1.700	.074	.56
43	12.649	.141	1.775	.075	.55
45	13.554	.148	1.899	.077	.53
46	14.008	.152	1.962	.073	.49
47	14.471	.156	2.031	.069	.46
48	14.948	.160	2.106	.075	.48
49	15.444	.164	2.189	.083	.52
50	15.964	.168	2.278	.089	.54
51	16.514	.173	2.374	.096	.57
52	17.100	.177	2.476	.102	.59
53	17.725	.181	2.586	.110	.62
54	18.397	.185	2.702	.116	.64
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57					
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APPENDIX TABLE XLIII: EFFICIENCY OF PROTEIN SYNTHESIS - H4

Age, days	Body weight kg	Milk protein consumed, kg d.m.	Pig protein kg d.m.	Protein gain, kg d.m.	Efficiency of protein gain
9	1.774	.0276	.2609	-	
10	1.833	.0283	.2876	.0267	.96
11	1.870	.0287	.3136	.0260	.92
12	1.884	.0289	.3392	.0256	.89
13	-	-	.3644	.0252	.87
14	2.436	.0355	.3894	.0250	-
15	2.589	.0373	.4144	.0250	.71
16	2.737	.0390	.4394	.0250	.67
17	2.887	.0407	.4649	.0255	.65
18	3.048	.0429	.4906	.0257	.63
19	3.226	.0445	.5170	.0264	.62
20	3.430	.0468	.5441	.0271	.61
21	3.666	.0493	.5721	.0280	.60
22	3.942	.0523	.6010	.0289	.59
24	4.510	.0582	.6626	.0313	-
25	4.751	.0607	.6957	.0331	.57
26	5.022	.0634	.7304	.0347	.57
27	5.322	.0665	.7669	.0365	.57
28	5.647	.0697	.8053	.0384	.58
29	5.995	.0732	.8458	.0405	.58
30	6.364	.0768	.8886	.0428	.58
31	6.752	.0805	.9338	.0452	.59
32	7.155	.0843	.9815	.0477	.59
33	7.572	.0882	1.0320	.0505	.60
34	7.999	.0922	1.0853	.0533	.60
35	8.435	.0962	1.1416	.0563	.61
36	8.877	.1002	1.2012	.0596	.62
37	9.322	.1043	1.2641	.0629	.63
38	9.768	.1082	1.3302	.0661	.63
39	-	-	1.3989	.0687	.63
40	10.945	.1186	1.4694	.0705	-
41	11.499	.1234	1.5419	.0725	.61
42	12.062	.1282	1.6166	.0747	.61
43	12.634	.1330	1.6938	.0772	.60
45	13.799	.1463	1.8559	.0825	.60
46	14.392	.1520	1.9412	.0853	.58
47	14.989	.1577	2.0296	.0884	.58
48	15.591	.1635	2.1214	.0918	.58
49	16.196	.1692	2.2166	.0952	.58
50	16.804	.1750	2.3155	.0989	.58
51	17.414	.1807	2.4182	.1027	.59
52	18.026	.1865	2.5249	.1067	.59
53	18.637	.1922	2.6358	.1109	.59
54	19.248		2.7511	.1153	.59
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APPENDIX TABLE XLIV: EFFICIENCY OF PROTEIN SYNTHESIS - H5

Age, days	Body weight kg	Milk protein kg d.m.	Pig protein kg	Protein gain, kg d.m.	Efficiency of protein gain
5	1.384	.025	.151		
6	1.518	.027	.184	.033	-
7	1.665	.029	.218	.034	-
8	1.824	.031	.252	.034	-
9	1.994	.033	.286	.034	-
10	2.176	.035	.320	.034	-
11	2.371	.038	.355	.035	-
12	2.577	.041	.389	.034	-
13	2.795	.044	.423	.035	-
14	3.024	.047	.458	.035	
15	-	-	.492	.034	
16	-	-	.527	.035	
17	3.381	.0482	.562	.035	
18	3.620	.0510	.597	.035	.73
19	3.869	.0537	.632	.035	.69
20	4.126	.0566	.668	.036	.67
21	4.392	.0595	.703	.035	.63
22	4.667	.0625	.738	.035	.60
24	5.246	.0687	.793	-	
25	5.550	.0719	.815	.022	.32
26	5.864	.0752	.841	.026	.38
27	6.187	.0785	.870	.029	.39
28	6.521	.0819	.903	.033	.42
29	6.865	.0854	.939	.036	.44
30	7.220	.0889	.979	.040	.47
31	7.585	.0926	1.023	.044	.50
32	7.961	.0963	1.070	.047	.51
33	8.348	.1001	1.121	.051	.53
34	8.746	.1039	1.176	.055	.55
35	-	-	1.234	.058	.56
36	9.651	.1125	1.295	.061	-
38	10.371	.1203	1.375	-	-
39	10.782	.1231	1.426	.051	.42
40	11.222	.1271	1.481	.055	.45
41	11.689	.1314	1.540	.059	.46
42	12.180	.1358	1.603	.063	.48
43	12.691	.1404	1.669	.067	.49
44	13.221	.1451	1.739	.070	.50
45	13.766	.1499	1.813	.074	.51
46	14.324	.1548	1.891	.078	.52
47	14.894	.1598	1.973	.082	.53
48	15.464	.1647	2.059	.086	.54
49	16.041	.1697	2.149	.090	.55
50	16.619	.1746	2.243	.094	.55
51	17.195	.1795	2.341	.098	.56
52	17.767	.1843	2.443	.102	.57
53	18.330	.1890	2.548	.106	.58
54	18.882	.1936	2.657	.109	.58
55			2.770	.113	.58

APPENDIX TABLE XLV: EFFICIENCY OF PROTEIN SYNTHESIS - H6

Age, days	Body weight kg	Milk protein consumed, kg d.m.	Pig protein kg d.m.	Protein gain, kg d.m.	Efficiency of protein gain
16	2.645	.0381	.3713	-	
17	-	-	.3852	.0139	
18	3.015	.0420	.4013	.0161	-
19	3.160	.0434	.4196	.0183	.44
20	3.322	.0451	.4400	.0204	.47
21	3.502	.0468	.4626	.0226	.50
22	3.699	.0488	.4873	.0247	.53
23	3.913	.0508	.5143	.0270	.55
24	4.144	.0530	.5433	.0290	.57
25	4.391	.0553	.5745	.0312	.59
26	4.653	.0578	.6078	.0333	.60
27	4.932	.0603	.6434	.0356	.62
28	5.226	.0629	.6811	.0377	.63
29	5.536	.0657	.7210	.0399	.63
30	5.859	.0685	.7630	.0420	.64
31	6.197	.0713	.8072	.0442	.65
32	6.550	.0743	.8535	.0463	.65
33	6.917	.0774	.9020	.0485	.65
34	7.297	.0805	.9527	.0507	.66
35	7.690	.0836	1.0055	.0527	.65
36	8.097	.0869	1.0605	.0550	.66
37	-	-	1.1176	.0571	.66
38	8.738	.0919	1.1769	.0593	-
39	9.398	.0970	1.2384	.0615	.67
40	9.959	.1012	1.3020	.0636	.65
41	10.435	.1047	1.3678	.0658	.65
42	10.841	.1077	1.4357	.0679	.65
43	11.190	.1103	1.5058	.0701	.65
44	11.499	.1125	1.5781	.0723	.655
46	12.050	.1165	1.6876	.0398	.35
47	12.323	.1184	1.7322	.0446	.38
48	12.612	.1204	1.7814	.0492	.42
49	12.934	.1227	1.8354	.0540	.45
50	13.302	.1253	1.8940	.0586	.48
51	13.731	.1282	1.9574	.0634	.51
52	14.236	.1317	2.0254	.0680	.53
53	14.831	.1357	2.0982	.0728	.55
54	15.531	.1404	2.1756	.0774	.57

APPENDIX TABLES XLVI: EFFICIENCY OF PROTEIN SYNTHESIS - L1

Age, days	Body weight kg	Milk protein consumed, kg d.m.	Pig protein kg d.m.	Protein gain, kg d.m.	Efficiency of protein gain
7	2.491	.0316		-	
8	2.633	.0332	.384	-	
9	2.769	.0348	.408	.024	.76
10	2.902	.0363	.433	.025	.71
11	3.034	.0378	.459	.026	.72
12	3.166	.0393	.486	.027	.71
13	3.302	.0409	.513	.027	.69
14	3.443	.0424	.542	.029	.73
15	3.592	.0441	.570	.028	.67
16	3.751	.0459	.600	.030	.68
17	3.921	.0478	.630	.030	.65
18	4.105	.0499	.661	.031	.65
		.0521		-	
20	4.524	.0545	.766	-	
21	4.763	.0571	.777	.011	.21
22	5.024	.0600	.789	.012	.22
23	5.310	.0631	.808	.019	.32
24	5.623	.0665	.829	.021	.33
25	5.965	.0702	.854	.025	.37
26	6.339	.0741	.882	.028	.40
27	6.745	.0785	.913	.031	.42
28	7.188	-	.948	.035	.44
	same protein phase, discontinuous growth.				
32	8.106	.0928	1.124	-	-
33	8.418	.0960	1.174	.050	.54
34	8.755	.0995	1.233	.059	.61
35	9.115	.1033	1.293	.060	.60
36	9.498	.1072	1.351	.068	.66
37	9.904	.1114	1.422	.071	.67
38	10.331	.1158	1.493	.071	.65
39	10.778	.1203	1.567	.074	.64
40	11.246	.1254	1.641	.077	.64
41	11.731	.1300	1.725	.084	.67
42	12.235	.1351	1.810	.085	.66
43	12.756	.1404	1.897	.087	.65
		.1457	1.865		
45	13.845	.1512	1.946	.081	.55
46	14.411	.1569	2.030	.084	.56
47	14.991	.1626	2.117	.087	.56
48	15.584	.1685	2.205	.088	.57
49	16.189	.1744	2.297	.092	.57
50	16.804	.1805	2.410	.098	.57
51	17.430	.1866	2.485	.100	.56
52	18.065	.1918	2.589	.104	.56
53	18.708	.1950	2.684	.105	.56
54	19.359	.199	2.790	.106	.54
55	20.017	.223	2.903	.107	.54
56	20.680		3.012	.109	.54

APPENDIX TABLE XLVII: EFFICIENCY OF PROTEIN SYNTHESIS - L2

Age, days	Body weight kg	Milk protein consumed, kg d.m.	Pig protein kg d.m.	Protein gain, kg d.m.	Efficiency of protein gain
5 - 18 = scouring problems.					
20	1.945	.025	.285	-	
21	2.356	.030	.304	.019	.76
22	2.608	.033	.326	.022	.73
23	2.752	.035	.350	.024	.73
24	2.841	.036	.376	.026	.74
25	2.925	.037	.405	.029	.81
26	3.057	.038	.436	.031	.84
27	3.287	.041		.033	.86
28	3.667				
30	3.962	.048	.663	-	-
31	4.132	.050	.683	.020	.42
32	4.310	.052	.702	.019	.38
33	4.496	.054	.719	.017	.33
34	4.690	.056	.736	.017	.31
35	4.893	.059	.751	.019	.34
36	5.104	.061	.772	.021	.36
37	5.325	.063	.795	.023	.38
38	5.556	.066	.820	.025	.40
39	5.797	.068	.847	.027	.41
40	6.048	.071	.875	.028	.41
41	6.310	.074	.904	.029	.41
42	6.584	.077	.934	.030	.41
43	6.869	.080	.966	.032	.42
44	7.165	.083	.999	.033	.42
45	7.474	.086	1.033	.034	.41
46	7.796	.090	1.068	.035	.41
47	8.131	.093	1.105	.037	.42
48	8.479	.097	1.143	.038	.42
49	8.841	.100	1.183	.040	.42
50	9.217	.104	1.225	.042	.42
51	9.608	.108	1.268	.043	.42
52	10.013	.113	1.313	.045	.42
53	10.434	.117	1.360	.047	.42
54	10.871	.121	1.379	.049	.41
55	11.323	.126	1.430	.051	.42
56	11.792	-		.054	.43

APPENDIX TABLE XLVIII: EFFICIENCY OF PROTEIN SYNTHESIS - L3

Age, days	Body weight kg	Milk protein consumed, kg d.m.	Pig protein kg d.m.	Protein gain kg d.m.	Efficiency of protein gain
7	1.992	.0230	.280	-	-
8	2.067	.0236	.299	.019	.83
9	2.146	.0242	.318	.019	.82
10	2.229	.0251	.337	.019	.80
11	2.317	.0260	.357	.020	.78
12	2.411	.0270	.377	.020	.76
13	2.512	.0280	.3975	.0205	.75
14	2.619	.0291	.419	.021	.74
15	2.733	.0303	.440	.021	.73
16	2.856	.0315	.462	.022	.73
17	2.987	.0328	.485	.023	.72
18	3.127	.0342	.509	.024	.72
19	3.276	.0356	.533	.024	.71
20	3.436	.0372	.558	.025	.70
21	3.607	.0390	.584	.026	.70
22	3.788	.0407	.612	.028	.72
23	3.982	.0426	.639	.027	.67
24	4.188	.0446	.668	.029	.68
25	4.407	.0468	.699	.031	.70
26	4.640	.0489		.031	.68
28	5.149	.0539	.731	-	-
29	5.425	.0565	.756	.025	.46
30	5.718	.0580	.781	.025	.44
31	-	-	.806	.025	.43
32	5.954	.0615	.832	.026	-
33	6.230	.0641	.860	.028	.45
34	6.499	.0666	.890	.030	.47
35	6.763	.0691	.923	.033	.50
36	7.024	.0715	.959	.036	.52
37	7.284	.0740	1.000	.041	.57
38	7.545	.0763	1.043	.043	.58
39	7.809	.0788	1.093	.050	.66
40	8.077	.0812	1.148	.055	.70
41	8.351	.0837	1.209	.061	.75
42	8.634	.0863	1.276	.067	.80
43	8.926	.0890	1.350	.074	.86
	9.231	.0917	1.411	-	-
45	9.550	.0946	1.452	.041	.45
46	9.884	.0976	1.497	.045	.48
47	10.237	.1008	1.548	.051	.52
48	10.608	.1042	1.603	.055	.55
49	11.001	.1077	1.664	.061	.59
50	11.418	.1114	1.729	.065	.60
51	11.859	.1153	1.800	.071	.64
52	12.328	.1194	1.875	.075	.65
53	12.826	.1239	1.956	.081	.68
54	13.354	.1285	2.041	.085	.69
55	13.916	.1334	2.132	.091	.71
56	14.511		2.227	.095	.72

APPENDIX TABLE XLIX: EFFICIENCY OF PROTEIN SYNTHESIS - L4

Age, days	Body weight kg	Milk protein consumed, kg d.m.	Pig protein kg d.m.	Protein gain kg d.m.	Efficiency of protein gain
9	1.447	.017	.198	-	
10	1.521	.018	.214	.016	.94
11	1.620	.019	.230	.016	.89
12	1.753	.020	.237	.017	.89
13	1.932	.022	.254	.017	.85
14	2.165	.023	.273	.018	.82
15	-	-	.291	.018	.78
16	2.295	.026	.310	.019	-
17	2.343	.027	.329	.019	.73
18	2.493	.028	.348	.019	.70
19	2.594	.029	.368	.020	.71
20	2.696	.030	.388	.020	.69
21	2.801	.031	.409	.021	.70
22	2.908	.032	.430	.021	.68
23	3.019	.033	.451	.021	.66
24	3.132	.034	.473	.022	.67
25	3.250	.035	.495	.022	.65
26	3.372	.036	.518	.023	.66
27	3.498	.037	.541	.023	.64
28	3.630	.038	.564	.023	.62
29	3.767	.039	.588	.024	.63
30	3.910	.040	.612	.024	.62
31	4.059	.041	.637	.025	.63
32	4.215	.043	.662	.025	.61
33	4.378	.044	.687	.025	.58
34	4.549	.045	.713	.026	.59
35	4.728	.047	.739	.026	.58
36	4.915	.048	.766	.027	.57
38	5.304	.050	-	-	-
39	5.463	.052	-	-	-
40	5.640	.053	-	-	-
41	5.836	.055	-	-	-
42	6.047	.057	-	-	-
43	6.273	.059	-	-	-
44	6.512	.060	.862	-	-
45	6.762	.062	.897	.035	.58
46	7.023	.064	.934	.037	.60
47	7.291	.066	.972	.038	.59
48	7.567	.068	1.010	.038	.58
49	7.848	.070	1.050	.040	.59
50	8.132	.072	1.091	.041	.59
51	8.419	.074	1.133	.042	.58
52	8.706	.076	1.176	.043	.58
53	8.992	.078	1.220	.044	.58
54	9.276				

APPENDIX TABLE L: EFFICIENCY OF PROTEIN SYNTHESIS - L5

Age, days	Body weight kg	Milk protein consumed, kg d.m.	Pig protein kg d.m.	Protein gain kg d.m.	Efficiency of protein gain
16	2.835	.031	.419	-	-
17	2.938	.032	.437	.018	.58
18	3.040	.033	.455	.018	.56
19	3.142	.034	.472	.017	.52
20	3.244	.035	.489	.017	.50
21	3.347	.036	.506	.017	.49
22	3.451	.037	.523	.017	.47
23	3.557	.038	.541	.018	.49
24	3.666	.039	.558	.017	.45
25	3.777	.0405	.576	.018	.46
26	3.892	.0417	.595	.019	.47
27	4.010	.043	.614	.019	.465
28	4.133	.044	.634	.020	.465
29	4.262	.045	.654	.020	.45
30	4.395	.0466	.676	.022	.49
31	4.535	.048	.699	.023	.49
32	4.681	.049	.723	.024	.50
33	4.835	.051	.748	.025	.51
34	5.000	.052	.775	.027	.53
35	5.165	.054	.803	.028	.54
36	5.342	.056	.833	.030	.56
37	5.529	.0575	.865	.032	.57
38	5.726		-	-	-
40	6.232	.058	-	-	-
41	6.345	.059	-	-	-
42	6.487	.060	.876	-	
43	6.654	.061	.888	.012	.20
44	6.844	.063	.901	.013	.21
45	7.053	.064	.915	.014	.22
46	7.279	.066	.931	.016	.25
47	7.519	.068	.948	.017	.26
48	7.768	.070	.968	.020	.29
49	8.026	.072	.989	.021	.30
50	8.288	.074	1.014	.025	.35
51	8.551	.076	1.041	.027	.36
52	8.813	.078	1.071	.030	.39
53	9.070	.080	1.105	.034	.44
54	9.320	.082	1.143	.038	.48
55					

APPENDIX TABLE LI: EFFICIENCY OF PROTEIN SYNTHESIS - L6

Age, days	Body weight kg	Milk protein consumed, kg d.m.	Pig protein kg d.m.	Protein gain kg d.m.	Efficiency of protein gain
13	1.551	.018	.240	-	-
14	1.737	.020	.254	.014	.78
15	1.859	.021	.269	.015	.75
16	1.944	.022	.284	.015	.72
17	2.020	.023	.300	.016	.73
18	2.112	.024	.316	.016	.70
19	2.247	.025	.332	.017	.70
20	-	-	.348	.016	.64
21	2.472	.0276	.365	.017	-
22	2.590	.029	.383	.018	.65
23	2.702	.030	.401	.018	.62
24	2.810	.031	.419	.018	.60
25	2.915	.032	.438	.019	.61
26	3.020	.033	.457	.019	.59
27	3.125	.034	.477	.020	.61
28	3.233	.035	.497	.020	.59
29	3.345	.036	.517	.020	.57
30	3.463	.0375	.538	.021	.58
31	3.589	.039	.559	.021	.56
32	3.724	.040	.581	.022	.56
33	3.871	.0415	.603	.022	.55
34	4.029	.042	.626	.023	.55
35	4.203	.043	.649	.023	.53
36	-	-	.672	.023	.53
38	4.620	.046	-	-	-
39	4.808	.047	.728	-	-
40	4.998	.049	.750	.022	.47
41	5.191	.050	.773	.023	.47
42	5.387	.051	.797	.024	.48
43	5.587	.053	.822	.025	.49
44	5.790	.055	.849	.027	.51
45	5.996	.056	.8765	.0275	.50
46	6.206	.058	.905	.0285	.51
47	6.419	.060	.936	.031	.53
48	6.637	.061	.967	.031	.52
49	6.858	.063	.9995	.0325	.53
50	7.084	.065	1.033	.0335	.53
51	7.314	.066	1.068	.035	.54
52	7.549	.068	1.105	.037	.56
53	7.789	.069	1.142	.037	.55
54	8.033		1.181	.039	.57

APPENDIX TABLE LII: ENERGETIC CONTENT OF GAIN - HI

Growth period (days)	Protein gain (g)	X 5.6 (Cals.)	Fat gain (g)	X 9.0 (Cals.)	Cals. stored	Caloric intake	Digestible Cals.	Heat Production (Cals.)	HP/ 24 hrs	Mean body weight (kg)
3-8	28.8	161	37	333	494	2784	2506	2012	335	1.896
9-15	139.7	782	247	2223	3005	6395	5756	2751	393	2.54
16-22	210.1	1176	495	4455	5632	9285	8356	2725	389	3.72
23-29	312.1	1748	315	2835	4583	12570	11211	6628	946	5.74
30-36	341.6	1913	693	6237	8150	17240	15516	7367	1052	8.53
37-43	578.2	3238	534	4806	8044	21700	19530	11487	1641	12.11
44-50	582.0	3259	668	6012	9271	26274	23646	14375	2054	15.71
51-57	661.3	3703	685	6165	9868	32436	29192	19324	2761	20.16

APPENDIX TABLE LIII: ENERGETIC CONTENT OF GAIN - H2

Growth period (days)	Protein gain (g)	X 5.6 (Cals.)	Fat gain (g)	X 9.0 (Cals.)	Energy stored (Cals.)	Energy intake (Cals.)	X .9 (=DE)	HP/ period	HP/ 24 hrs	Mean body weight (kg)
3-8	12.4	69.44	18	162	231	2115.6	1904.0	1673	279	1.257
9-15	102.0	571.2	130	1170	1741	4321.2	3889.1	2148	307	1.68
16-22	173.6	972.1	198	1782	2754	6041.5	5437.3	2683	383	2.50
23-29	288.8	1617.3	345	3105	4722	9123.3	8211.0	3489	498	3.95
30-36	200.9	1125.0	297	2673	3798	12051.4	10846.3	7048	1007	5.83
37-43	561.2	3142.7	252	2268	5411	19044.9	17140.4	11729	1675	8.75
44-50	555.0	3080.0	317	2853	5933	24978.0	22480.0	16547	2364	12.12
51-57	580.3	3249.7	535	4815	8065	30075.1	27013.6	18943	2707	16.23
58-64	745.9	417.8	15	135	4313	30146.4	27131.8	22818	3259	20.25

APPENDIX TABLE LIV: ENERGETIC CONTENT OF GAIN - L1

Age (days)	Protein gain (g)	X 5.6 (Cals.)	Fat gain (g)	X 9.0 (Cals.)	∴ Energy stored (Cals.)	Energy intake (Cals.)	X .9 (digest. Cals.)	∴ HP (total) (Cals.)	HP/ day (Cals.)	Mean body weight (kg)
3-8	12.70	71.1	153.8	1384	1455	2765.8	2489.3	1034	172	2.33
9-15	186.5	1044.4	207.8	1870	2914	5644.6	5080.2	2166	309	3.08
16-22	219.1	1227.0	488.9	4401	5628	8420.0	7578.0	1950	278	3.84
23-29	283.5	1587.6	359.2	3231	4819	10168.9	9152.0	4333	619	5.56
30-36	367.2	2056.3	356.2	3204	5260	13279.7	11951.7	6692	956	8.55
37-43	453.3	2538.5	233.6	2106	4645	16624.0	14961.6	10317	1474	11.26
44-50	605.5	3390.8	725.0	6525	9916	21851.9	19666.7	11970	1710	15.04
51-57	731.2	4038.7	674.0	6066	10105	27727.1	24954.4	14849	2121	19.42
58-64	630.4	3530.2	1095.6	9864	13394	33818.1	30436.2	17042	2435	23.80

= realimentation commenced.

APPENDIX TABLE LV: ENERGETIC CONTENT OF GAIN - L2

Growth period (days)	Protein gain (g)	X 5.6 (Cals.)	Fat gain (g)	X 9.0 (Cals.)	Energy stored (Cals.)	Caloric intake (Cals.)	Digestible Cals.	Heat production (Cals.)	HP/ day	Mean body weight
3-8	15.10	84.6	-103	-927	-842	1234	1110.6	1962	(321.1)	1.323
9-15	27.30	152.9	193	1737	1890	3370.4	3033.4	1143	164	1.523
16-22	99.90	559.4	85	765	1324	3605.4	3244.8	1921	274	2.004
23-29	262.90	1472.2	45	405	1877	5186.7	4668.0	2791	388	3.091
30-36	242.90	1360.2	245	2205	3565	7180.2	6462.2	2897	414	4.514
37-43	163.30	914.48	166	1494	2409	9330.1	8397.1	5988	855	6.06
44-50	286.00	1601.6	328	2952	4553	12544.0	11289.6	6737	962	8.19
51-57	515.30	2885.7	345	3105	5991	15822.7	14240.4	8249	1178	10.88
58-64	637.0	3567.2	984	8856	12423	25849.6	23264.6	10841	1549	15.11
65-71	385.1	2156.6	868	7812	9969	27116.5	24404.8	14435	2062	18.11
72-78	723.6	4052.2	338	3042	7094	27108.9	24398.0	17304	2472	22.32

= realimentation commenced.

APPENDIX TABLE LVI: ENERGETIC CONTENT OF GAIN - L3

Growth period (days)	Protein gain (g)	X 5.6 (Cals.)	Fat gain (g)	X 9.0 (Cals.)	.˚. Energy stored (Cals.)	Energy intake (Cals.)	Digestible Energy (Cals.)	Heat production (Cals.)	HP/ day	Mean body weight
3-8	-	-	-	-	-	2162.9	1946.6	-	-	1.917
9-15	108.4	607.04	155	1395	2002	4202.2	3781.9	1780	254	2.42
16-22	164.8	922.90	258	2322	3245	5521.0	4968.9	1723	246	3.299
23-29	205.5	1150.80	110	990	2141	7137.5	6423.8	4283	612	4.664
30-36	206.0	1153.6	249	2241	3395	9624.0	8661.6	5267	752	6.28
37-43	390.3	2185.7	140	1260	3446	12718.0	11446.2	8000	1043	8.15
44-50	352.7	1975.1	63	567	2542	15138.8	13624.9	11083	1583	10.22
51-57	593.7	3325.7	112	1008	4334	19025.1	17122.5	12788	1827	13.36
58-64	708.1	2965.4	776	6984	9949	26887.5	24198.8	14250	2036	17.53
65-71	497.3	2784.9	426	3834	6619	25796.2	23216.5	16597	2371	20.57

= realimentation commenced.

APPENDIX TABLE LVII: ENERGETIC CONTENT OF GAIN - H3

Growth period (days)	Protein gain (g)	X 5.6 (Cals.)	Fat gain (g)	X 9.0 (Cals.)	.˙. Cals. stored	Caloric intake	Digestible Cals.	Heat production (Cals.)	HP/ day (Cals.)	Mean body Weight (kg)
10-16	223.2	1250	256	2304	3554	6092	5483	1929	275	2.697
17-23	257.4	1441	388	3492	4933	10517	9464	4531	647	4.12
24-30	208.9	1170	433	3897	5067	12455	11210	6143	877	6.05
31-37	379.7	2126	534	4806	6932	16655	14990	8058	1151	8.56
38-44	496.9	2783	623	5607	8390	20024	18022	9632	1376	11.66
45-51	528	2957	223	5326	8283	23210	20889	12606	1800	15.04
52-58	951	5326	-285	-2565	2761	26388	23750	20989	2992	19.20

APPENDIX TABLE LVIII: ENERGETIC CONTENT OF GAIN - H4

Growth period (days)	Protein gain (g)	X 5.6 (Cals.)	Fat gain (g)	X 9.5 (Cals.)	∴ Cals. stored	Caloric intake	Digestible Cals.	∴ Heat production (Cals.)	HP/ day (Cals.)	Mean body weight (kg)
10-16	170.5	955	13.8	131	1086	4063	3656	2570	367	2.21
17-23	209.5	1173	359.3	3413	4586	8709	7839	3253	465	3.49
24-30	239.6	1342	404.7	3845	5187	11442	10298	5111	730	5.38
31-37	385.6	2159	692.6	6580	8739	15809	14228	5589	800	8.01
38-44	511.6	2865	926.7	8804	11668	21040	18936	7268	1038	11.51
45-51	647.6	3627	606.6	5763	9390	27590	24831	15441	2206	15.60
52-58	843.6	4724	206.0	1957	6681	30347	27312	20631	2947	20.32

APPENDIX TABLE LIX: ENERGETIC CONTENT OF GAIN - H5

Growth period (days)	Protein gain (g)	X 5.6 (Cals.)	Fat gain (g)	X 9.0 (Cals.)	∴ Energy stored	Caloric intake	Digestible Cals.	∴ Heat production (Cals.)	HP/ day (Cals.)	Mean body weight (kg)
10-16	241.7	1353	194.2	1845	3198	6501	5851	2653	379	2.78
17-23	217.3	1217	399.5	3795	5012	10772	9695	4683	669	4.14
24-30	203.5	1140	438.2	4163	5302	12747	11472	6170	881	6.21
31-37	382.7	2143	539.0	5121	7264	17054	15322	8058	1151	8.78
38-44	405.7	2272	845.3	8030	10302	21023	18921	8619	1231	11.75
45-51	568.2	3182	791.1	7515	10699	27775	24997	14300	2043	15.51
52-58	810.5	4539	534.9	5082	9621	30505	27455	17834	2548	20.26

APPENDIX TABLE LX: ENERGETIC CONTENT OF GAIN - H6

Growth period (days)	Protein gain (g)	X 5.6 (Cals.)	Fat gain (g)	X 9.0 (Cals.)	∴ Cals. stored	Caloric intake	Digestible Cals.	∴ Heat production	HP/ day	Mean body weight (kg)
10-16	177	991	116	1044	2035	4970	4473	2438	348	2.20
17-23	161	902	335	3015	3917	8281	7453	3536	505	3.34
24-30	231	1294	315	2835	4129	10630	9567	5438	777	4.98
31-37	366	2038	466	4194	6244	14606	13146	6902	986	7.31
38-44	465	2604	520	4680	7304	18523	16671	9367	1338	10.30
45-51	339	1898	220	1980	3878	17111	15400	11522	1646	12.68
52-58	570	3192	421	3789	6981	22449	20204	13353	1909	15.96
59-64	272	1523	153	1377	2900	18393	16554	14052	2275	18.01

APPENDIX TABLE LXI: ENERGETIC CONTENT OF GAIN - L4

Growth period (days)	Protein gain (g)	X 5.6 (Cals.)	Fat gain (g)	X 9.0 (Cals.)	.˙. Cals. stored	Caloric intake	Digestible Cals.	.˙. Heat production	HP/ day (Cals.)	Mean body weight (kg)
10-16	123	689	100	900	1589	3392	3052	1464	209	1.94
17-23	128	717	90	810	1527	4746	4271	2744	392	2.71
24-30	155	868	154	1386	2254	5806	5226	2972	424	3.51
31-37	178	997	207	1863	2860	7054	6348	3488	498	4.55
38-44	86	482	260	2340	2822	8243	7418	4596	656	5.88
45-51	273	1529	419	3771	5300	11790	10611	5311	759	7.56
52-58	324	1814	452	4068	5882	13414	12073	6191	884	9.96
59-64	439	2458	599	5393	7851	19650	17684	9833	1404	12.73
65-72	658	3685	906	8154	11839	28368	25531	13692	1711	16.02
73-77	373	2089	125	1125	3216	14882	13394	10178	2035	20.00

= realimentation commenced.

APPENDIX TABLE LXII: ENERGETIC CONTENT OF GAIN - L5

Growth period (days)	Protein gain (g)	X 5.6 (Cals.)	Fat gain (g)	X 9.0 (Cals.)	Cals. stored	Caloric intake	Digestible Cals.	.˙. Heat production	HP/ day (Cals.)	Mean body weight (kg)
10-16	150	840	156	1404	2244	4193	3774	1530	219	2.48
17-23	125	700	219	1971	2671	5530	4977	2306	329	3.24
24-30	141	790	312	2808	3598	7411	6670	3072	439	4.02
31-37	197	1103	242	2178	3281	7623	6860	3579	511	5.02
38-44	109	610	300	2700	3310	9592	8638	5323	760	6.30
45-51	234	1310	321	2889	4199	11860	10674	6475	925	7.78
52-58	334	1870	428	3852	5722	14737	13264	7542	1077	9.50
59-64	339	1898	656	5904	7802	17744	15969	8167	1166	12.15
65-72	504	2822	1279	11511	14333	30457	27412	13079	1868	15.54
73-77	435	2436	540	4860	7296	22545	20290	12994	2166	19.90

= realimentation commenced.

APPENDIX TABLE LXIII: ENERGETIC CONTENT OF GAIN - L6

Growth period (days)	Protein gain (g)	X 5.6 (Cals.)	Fat gain (g)	X 9.0 (Cals.)	∴ Cals. stored	Caloric intake	Digestible Cals.	∴ Heat production	HP/ day (Cals.)	Mean body weight (kg)
10-16	94	526	(16.2)	146	672	2874	2587	-	-	1.63
17-23	128	717	119	1062	1779	4059	3653	1874	268	2.35
24-30	119	666	172	1548	2214	5277	4749	2535	362	3.13
31-37	172	963	173	1557	2520	6390	5751	3231	462	4.02
38-44	121	678	163	1467	2145	7772	6995	4850	693	5.20
45-51	275	1540	136	1224	2764	9459	8513	5749	821	6.64
52-58	249	1394	182	1638	3032	11628	10465	7433	1062	8.26
59-64	299	1675	540	4860	6535	16452	14806	8271	1182	10.55
65-72	614	3438	1365	12285	15723	28227	25405	9682	1383	13.71
73-77	500	2800	641	5769	8569	19820	17838	9269	1853	18.61

= realimentation commenced.

APPENDIX TABLE LXIV: COMPOSITION OF CONDENSED MILK

	Batch I	Batch II
Total solids (%)	27.02	26.67
Protein (%)	6.40	6.52
Fat (%)	7.20	7.10
Energy (Cals. per 100 g)	144	
Energy (Cals. per kg d.m.)	5300	
density ρ = 1.06 g/cc		ρ = 1.06 g/cc

APPENDIX TABLE LXV: BLOOD HAEMOGLOBIN LEVELS -- EXPERIMENT II

Age (days) \ Piglet no.	g per 100 cc whole blood						
	L4	L5	L6	H3	H4	H5	H6
9	12.2	11.0	11.2	12.2	-	11.2	12.0
16	12.2	12.4	12.0	11.8	11.2	13.0	12.8
23	12.4	12.6	11.8	11.4	12.8	13.2	12.8
37	-	-	12.6	-	13.4	12.6	-
44	13.0	12.4	14.0	12.6	10.0	11.8	13.0
51	12.2	16.6	-	-	14.2	-	13.2
58	12.6	12.8	10.8	12.8	13.0	13.2	13.0
76	12.4	12.0	13.0	-	-	-	-

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