HGCA

## RESEARCH REVIEW No. 39

# THE NUTRITIONAL VALUE TO FARM LIVESTOCK OF LOW BUSHEL WEIGHT WHEAT

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# THE NUTRITIONAL VALUE TO FARM LIVESTOCK OF LOW BUSHEL WEIGHT WHEAT

by

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# Contents

**Page**

# 1. Summary

Bushel weight is a measure of grain density which is affected by the level of filling of the grain, by grain morphology and by grain dry matter. Variations in bushel weight due to level of filling are reflected in changes in chemical composition. Bushel weight is used as the international standard for the trading of wheat, and also for the assessment of "quality" at the point of entry to both flour and animal feed mills. The relationship between bushel weight and the composition of wheat is variable, with bushel weight being related closest to cell wall and starch and poorest to protein, soluble non-starch polysaccharides and oil.

There is no clear picture of the relationship between bushel weight and energy value for pigs and poultry, though it is generally recognised that poultry are sensitive to non-starch polysaccharides (NSP). Thus, if low bushel weight wheats also contain elevated levels of NSP giving rise to problems with digesta viscosity, reduced energy value to poultry might occur. Bushel weight was not found to be a good predictor of the nutritive value of wheat. However, determination of an alternative reliable predictor will require substantial commitment and investment.

It is apparent from the literature that the relationship between the chemical composition of wheat and its quality is not simple. The key components which contribute to variation in nutritive value in wheat, over a wide range of bushel weight, should be determined. Areas which should be investigated include viscosity, amino acid availability, and bushel weight determined on ground material. Rapid and accurate prediction of feed value should then be feasible at the point of entry of wheat to the feed mill and payments by compounders to producers should then reflect true variations in the nutritional quality of wheat.

## *2. Acknowledgements*

*We are grateful to the Home-Grown Cereals Authority for commissioning this review, and to all those who assisted us with the provision of information, opinion and advice. We recognise the sensitivity of the topic of the bushel weight of wheat, and that producers, merchants, processors and end users have different objectives and approaches to the issues surrounding the factors affecting nutritional value of wheat for farm livestock - either actual or perceived.*

*We have consulted many individuals and organisations, most with positive results. We thank them for their time and assistance, which has been valuable. Where confidentiality has been requested, we have acceded to the request. Thus we know that pertinent information exists which we have been unable to include in this review. We hope that our understanding of the situation represents a balanced view of the state of knowledge at the time of writing (June 1998). If, however, we have omitted significant facts which are already in the public domain, we have done so unintentionally and trust that our sponsor will be furnished with the relevant information with which to update this document.*

*Our special thanks to Dr Mike Bedford, Finnfeeds Ltd, for provision of Figures 1 and 2.*

*Helen Miller*
*Michael Wilkinson*
*Leeds*
*June 1998*

# 3. Abbreviations

ADF - Acid detergent fibre
AME - Apparent metabolisable energy
AMEn - Apparent metabolisable energy corrected for endogenous nitrogen excretion
CP - Crude protein
DE - Digestible energy
DM - Dry matter
FCR - Feed conversion ratio
GE - Gross energy
ME - Metabolisable energy
ND - Not determined
NDF - Neutral detergent fibre
NIR - Near infra-red reflectance spectroscopy
NSP - Non-starch polysaccharides
TME - True metabolisable energy
TMEn - True metabolisable energy corrected for endogenous nitrogen excretion
VFA - Volatile fatty acids

# 4. Introduction

## 4.1 Objectives

*This review was commissioned to guide the HGCA in determining future research*

This review was commissioned by the HGCA to investigate the scientific evidence on the factors affecting the nutritional value of low bushel weight wheat, and thus to provide guidance in determining its future research strategy. The review concentrates primarily on the nutritive value of low bushel weight wheat for poultry because poultry utilise more than 50 % of feed wheat grown in the UK and they are also considered to be more sensitive to variations in wheat quality than are pigs or ruminants.

## 4.2 Bushel weight and "quality"

***Bushel weight is the international benchmark of wheat "quality"***

Traditionally, bushel weight has been considered a measure of wheat quality and as such it is the international trading description for wheat. There is however little evidence relating bushel weight to grain quality for either the flour or feed milling industries. The failure of the milling industries to come up with a better easily measured assessment of wheat reflects the difficulty of predicting wheat quality from its physical and chemical components. Therefore wheat continues to be traded on the basis of bushel weight. The minimum specification for the bushel weight of wheat was set for the UK by UKASTA and internationally by GAFTA as being 72 kg/hectolitre for feed wheat and 76 kg/hl for exportable wheat for bread and biscuit manufacture. The latter standard is based on French wheat which typically has an average bushel weight of 76 kg/hl.

### 4.3 Bushel weight and price discounts

***Low bushel weight wheats are discounted in national and international trade***

Total UK production of wheat is around 15 million tonnes of which 11 million tonnes is used by the UK market with the remaining 4 million tonnes going for export. Most UK wheat is lower in bushel weight than French wheat, so to export the material, its price has to be discounted. In 1997/8 the discount was $20/tonne (£12.50) for 72 kg/hl wheat compared to French wheat of 76 kg/hl. Further discounts were applied (£1.00 to £2.00/specific weight point, depending on the market situation) to UK wheats of less than 72 kg/hl. The size of the price discounts depend totally on supply and demand, and on the proportion of total production which is of low bushel weight.

The justification for applying price discounts is that they exist in the international market. The international and national specifications of 76 kg/hl for milling wheats and 72 kg/hl for feed wheats are relatively high in comparison with average UK wheat. For the UK to succeed in exporting its surplus wheat, price discounts have to be applied and these discounts are operated similarly on the domestic market. A further justification is that millers consider low bushel weight wheats to be more difficult to process than high bushel weight material.

## 4.4 The livestock feed industry

***The livestock feed industry is the largest user of wheat in the UK***

The livestock feed industry is the largest user of wheat in the UK with 6 million tonnes per annum being utilised in animal feeds. Of this tonnage 53.0 % is used in poultry feeds, 28.9 % in pig feeds and only 18.1 % in ruminant feeds (Poultry World, October 1997). In order to optimise the utilisation of wheat as a nutrient resource, wheat should be assessed accurately for nutritional quality and then assigned appropriately to the correct class of livestock. In this way, wheat would be utilised more efficiently, particularly if large differences exist between different types of livestock in their ability to utilise wheat of low bushel weight. The feed industry compromises its nutritive assessment by, in general, determining moisture content and bushel weight as quality predictors, neither of which are direct measures of nutritive value.

On the UK domestic market, animal feed compounders usually accept a wide range of bushel weights, even accepting bushel weights as low as 62 kg/hl in some years. Wheat below 62 kg/hl is not normally traded, or is blended with higher bushel weight material before being offered for sale.

Feed compounders discount the price of low bushel weight wheats because of a widely held belief that such wheats have low nutritive value. There is some controversy as to whether or not this belief is correct. Farmers are concerned that they may not always receive a fair price for their product, particularly if bushel weight is actually a poor predictor of nutritive value for livestock feed.

One of the major problems of the current system of classifying wheat on the basis of bushel weight is that samples of different bushel weights are blended in order to achieve the standard weight of 72 kg/hl. This is both time consuming and potentially inefficient since blending reduces opportunity for accurate assessment of nutritive value .

# 5. Characteristics of low bushel weight wheat

## 5.1 Composition

*Low bushel weight wheats typically contain relatively low concentrations of starch and relatively high concentrations of fibre.*

Bushel weight (also variously known as specific weight, volume weight, kilo weight and bulk density) is a measure of the weight of a particular volume of air-dry grain, expressed in terms of kg per hectolitre. By definition therefore low bushel weight wheat is wheat of a low density. There are two main reasons why wheat may have a low bushel weight. It may be due to the level of maturity and therefore the degree of filling of the grains or to the grain shape and morphology since shape affects packing characteristics (Baker et al., 1965). This is clearly illustrated by comparing the shape of grains in Figure 1. In addition some grains may develop with an air pocket trapped within them (Figure 2). These grains appear to have a low density but after grinding will have similar composition to higher bushel weight grains. With grains of similar morphology, density is a measure of the ratio of the endosperm and germ of the grain to the pericarp. Bushel weight in part reflects variety since this is one of the determinants of kernel shape and size, and of the ratio of endosperm to pericarp. However, within variety, low grain density results from immature inadequately filled grains as a result of poor growing conditions. Low bushel weight grain is therefore normally characterised by a reduced ratio of endosperm to the other grain components and this is reflected in its chemical composition. The composition of low and high bushel weight wheat is shown in Table 1. Low bushel weight wheat generally has higher levels of protein, fat and fibre, including non-starch polysaccharides, than high bushel weight wheat but has significantly lower levels of starch (Sibbald and Price, 1976; Batterham et al., 1980; Hickling, 1994; Dalgety Agriculture Ltd., personal communication). Starch is one of the last components to be deposited in the grain. Reduced deposition of starch is reflected in increases in the concentration of other grain components as these make up a greater proportion of the grain.

It is notable that most workers failed to provide a complete description of the composition of the materials with which they worked (e.g. Table 1).

**Table 1.** **Composition of low and high bushel weight wheat**

| Bushel wt kg/hl | DM % | Starch % DM | CP % DM | NDF % DM | Fat % DM | Ash % DM | GE MJ/kg | Reference |
|---|---|---|---|---|---|---|---|---|
| 45-57 | ND | 49.9 | 16.8 | 18.5 | 3.0 | ND | ND | |
| 72 | ND | 61.2 | 14.3 | 11.7 | 2.7 | ND | ND | Hickling, 1994 |
| 76-82 | ND | 64.1 | 15.1 | 10.0 | 2.3 | ND | ND | |
| 50-60 | 86.9 | ND | 14.8 | 14.5 | 1.8 | 2.1 | 19.3 | |
| 72 | 87.5 | ND | 16.3 | 12.7 | 1.6 | 1.8 | 19.9 | Batterham, et al.,19 |
| 61-66 | 82.2 | 54.0 | ND | 10.4 | ND | ND | ND | |
| 72 | 86.7 | 59.9 | ND | 8.7 | ND | ND | ND | Dalgety Agriculture Ltd., 1998 |

The greatest differences in composition between low and high bushel weight wheats are in the starch and fibre fractions. In Hickling's data based on 22 wheat samples collected from various sites across Canada as bushel weight declined starch content fell by an average of 0.5

percentage units per density point (Figure 3) whilst NDF increased by approximately 0.3 percentage units (Figure 4).

Oil content also clearly differed between low and high bushel weight wheats (Figure 5), however, although low specific weight wheats may have 50% more oil than high specific weight wheats, this amounts to a change of only 1 % in the overall grain composition and therefore will be responsible for a change in gross energy value of around 0.2 MJ/kg.

Crude protein values are interesting because although there is a tendency for these to be higher in low bushel weight wheats than in high bushel weight wheats it is evident that there is huge variability in this trait and considerable overlap in crude protein content regardless of bushel weight (Figure 6). Crude protein content *per se* is of only limited value as a descriptor of the feeding value of wheat. Amino acid content and more particularly amino acid availabilities are of much greater importance. Thus as the protein content of wheat increases the balance of amino acids becomes less favourable since the proportions of the individual proteins change. In general, as crude protein content increases there is a relative increase in gluten, a storage protein in the endosperm, relative to the structural and functional globulins and albumins (Dubetz et al., 1979). Each of these proteins has a different amino acid profile with gluten containing less lysine and methionine but more tryptophan than do the albumins and globulins (Bushuk and Wrigley, 1974). Therefore increases in gluten relative to other specific proteins will change the balance of amino acids in the overall wheat protein (Eppendorf, 1978: Mossé et al., 1985). However this generalisation may not apply to low bushel weight wheats in which increased protein content is a reflection of poor grain filling so that proteins make up a greater proportion of the grain but may not have an increased ratio of gluten to globulins and albumins.

Wiseman and McNab (1995) demonstrated that as crude protein content of wheat increased so did protein digestibility and hence presumably amino acid availability. This may reflect greater deposition of protein in the endosperm in high protein wheats, where it is readily accessible to enzyme breakdown. If protein is at lower concentrations in the grain it may be primarily associated with structural components and hence less available for enzymatic breakdown (Green et al., 1987). Again this observation may not apply to low bushel weight wheats in which increased protein content is due to poor grain filling rather than changing ratios of specific proteins. The lowest bushel weight wheat analysed by Wiseman and McNab was 69.5 kg/hl, which is not particularly low.

There is little information in the literature about amino acid content or availability in low bushel weight wheats. This is clearly an area that requires investigation since wheat frequently makes up 50% or more of poultry diets and up to 40% of pig diets and therefore may contribute more than 35% of the dietary protein (Wiseman and Inborr, 1990). McNab (Personal communication) has found that amino acid availability in wheats generally is extremely variable. The factors affecting amino acid availability in wheat have yet to be defined although work at Nottingham University has suggested that variety, and in particular the presence of the rye gene may reduce amino acid digestibility (Short et al., 1997).

Soluble non-starch polysaccharides (NSP) are believed to be higher in low bushel weight wheats than in high bushel weight wheats but Hickling (1994) found that this trait was largely independent of bushel weight (Figure 7). The major NSP occurring in wheats are the arabinoxylans and these have been shown to be negatively related to the nutritive value of wheat (Annison, 1993; see Section 5).

The specific gravity of a dry grain of wheat is typically in the range 1.25 to 1.45 (Lockwood, 1960). Thus moisture content may be expected to have an influence on bushel weight, with higher moisture content material having lower bushel weight than drier grain. Addition of water to dry grain is associated with a decrease in bushel weight, likewise drying of grain increases bushel weight (Hook, 1984). This decrease is greater at lower initial moisture contents than at higher grain moisture contents - 1 to 1.5 kg/hl per percentage increase in moisture content up to 12% moisture, 0.7 kg/hl per percentage increase in moisture in the range 12 to 18% moisture and 0.44 kg/hl per percent increase in moisture above 18% grain moisture content (Lockwood, 1960). Dry grain is hygroscopic. The outer bran layer of the seed (the pericarp) is lighter than the endosperm and it expands as it absorbs moisture until it reaches equilibrium with the surrounding atmosphere. Thus it follows that wheat harvested in wet weather and dried to 14 or 15% moisture content is likely to have a lower bushel weight than wheat harvested in very dry weather at 12% moisture content, unless the surrounding atmosphere is humid when the dry grain is likely to show a gradual reduction in bushel weight as it equilibrates with the surrounding air of relatively higher moisture content.

In this section we have discussed the chemical composition of low bushel weight wheat relative to high bushel weight wheat. The differences described here have not been reported by all workers. In a comprehensive Canadian study looking at 8 wheat cultivars grown at 12 sites over 3 years with bushel weights varying from 56.1 to 84.5 kg/hl, Campbell et al. (1995) found little relationship between bushel weight and starch, oil or protein contents. They did find a significant negative correlation between bushel weight and fibre content of the grain (NDF and ADF) and suggested that bushel weight could be used to predict fibre content. Similarly, Stewart et al. (1997) reported no differences in chemical composition of 4 sprouted wheat samples varying between 60.2 and 71.8 kg/hl bushel weight (starch content was not reported). This may be due to morphological differences between different samples causing different packing density.

In conclusion therefore, bushel weight may be expected to reflect the chemical composition of the grain since it is itself determined in part by the level of grain filling and hence the ratio between the component parts of the grain. However, bushel weight is also likely to be affected by morphological differences which would be expected to influence the level of grain packing and which may not have any effect at all on grain composition. Dry matter of the grain will also affect bushel weight and must be taken into account before bushel weight can be used as a predictor of nutrient content (Campbell et al., 1995).

# 6. Expected effects of low bushel weight on nutritional value to farm livestock

*Low bushel weight wheat may be expected to have a lower nutritional value for pigs and poultry, but not for ruminants*

As mentioned in Section 5 above, low bushel weight wheat is characterised by a change in the proportions of complex carbohydrates within the grain with increased concentrations of fibre and reduced concentrations of starch. Such a change has obvious implications for the type of animal to which the grain is fed. Non-ruminant animals such as pigs and poultry can readily digest starch but have limited ability to digest fibre. This is particularly true for young rapidly growing animals such as young broiler chickens or piglets. It would therefore be expected that the ME value of low bushel weight wheats would be lower than the ME of high bushel weight wheats for non-ruminants and that this effect would be magnified in young animals which are less well able to digest fibre.

In contrast, ruminant animals should be able to digest either form of complex carbohydrate equally well. It would therefore be expected that the ME value of wheat will be little affected by bushel weight when fed to ruminants. Indeed higher fibre grains may be advantageous to ruminant feeding since they will encourage rumen fermentation and reduce the likelihood of acidosis occurring as can be the case on high starch diets. We might conclude that low bushel weight wheats would be well-suited for ruminant diets.

Gross energy expressed on a dry matter basis is normally quite uniform across wheat samples regardless of bushel weight (Sibbald and Price, 1976; McNab, 1991). Lower starch content and higher oil and/or protein content might be expected to result in a higher gross energy value in the grain. Assuming that the extra gross energy is available to the animal, then increases in both DE and in ME would follow. However because the increase in oil content is so small relatively the difference in energy content is marginal. If, however, fibre is elevated and its digestibility is lower than that of starch, then the overall effect of increased oil and protein may not be evident in terms of DE or ME, at least for non-ruminants.

Higher crude protein contents may be expected to be reflected in higher levels of available amino acids, provided the composition of the crude protein remains similar between wheat of lower and higher bushel weight. Low bushel weight wheat is not necessarily characterised by high protein content since this trait is highly variable between wheats regardless of bushel weight.

Higher ash content in low bushel weight wheat, presumably associated with a greater proportion of the total dry matter in the pericarp of the grain relative to the endosperm and embryo, might be reflected in an increase in the supply of essential minerals. Sibbald and Price (1976) found no association with increased phosphorus, phytin phosphorus or calcium, although they had few low bushel weight samples in their study. Increased ash content would marginally reduce energy content since ash has no energy value.

Soluble NSP concentrations can vary widely between wheats regardless of bushel weight. In poultry, wheat NSPs (primarily arabinoxylans) are associated with reduced digestibility of starch, protein and lipid (Annison, 1993) resulting in reduced growth rates and, in some cases, reduced feed intake. Choct and Annison (1990) demonstrated that it was the soluble fraction of the NSPs which are responsible for this decline in animal performance. Soluble NSP are believed to exert their negative effects on digestibility by increasing the viscosity of the digesta. This in turn reduces rate of digestion and absorption, slows passage rate, increases intestinal size and hence animal maintenance costs, and changes the balance of the microbial population in the intestinal tract. These effects have been discussed in detail by Bedford (1996).

We would expect that wheats high in soluble NSP would have reduced energy value in poultry.

Problems with digesta viscosity as a result of feeding wheat are not generally encountered in pigs or ruminants. Therefore we would not expect soluble NSP concentration to affect energy availability to pigs and ruminant livestock.

## 7. Observed effects of low bushel weight on nutritional value

*Bushel weight cannot be considered to be a reliable indicator of the nutritive value of wheat.*

Despite the volume of scientific literature concerning the nutritive value of wheat for farm livestock, there is surprisingly little which relates nutritive value to bushel weight and even less which includes wheats of low bushel weight. This is so despite the fact that bushel weight continues to be the main criterion upon which the feed industry bases its assessment of wheat quality! Such references as there are provide conflicting evidence. In some trials low bushel weight wheats perform poorly relative to high bushel weight wheats (e.g. Batterham, 1980; McNab, 1991; Hickling, 1994) and in others there is no difference (e.g. Sibbald and Price, 1976; Quintin and McCracken, 1993; Stewart et al., 1997).

The importance of wheat as a feed ingredient is normally assessed in terms of its contribution to the energy value of the diet. In poultry diets wheat may contribute up to 80% of the metabolisable energy whilst contributing only 30 to 40 % of the protein. In the UK the energy value of wheat is normally measured in terms of ME for poultry and in terms of DE for pigs. Various methods have been used to estimate ME in poultry but the two most commonly used are AME or AMEn (if corrected for endogenous nitrogen secretion), which is normally measured in young growing birds, and TME or TMEn if corrected for endogenous nitrogen secretion), which is normally measured in adult cockerels. Both of these methods have problems associated with them (see Section 7). It is apparent from the literature that the method of measurement and the type of animal used in the assessment of energy value can both affect the result obtained.

Whilst a number of workers have investigated the relationship between bushel weight and energy value either as ME or DE (e.g. March and Biely, 1973; Bhatty et al., 1974; Coates et al., 1977; Wiseman and McNab, 1995), very few of these have looked at low bushel weight wheats. Of those who have, Batterham (1980), McNab (1991) de Lange et al. (1993) and Salmon and O'Neil (1977) have all demonstrated a significant relationship between energy value and bushel weight which became particularly apparent at bushel weights below 65 kg/hl (see Figures 9 to 12). In contrast, Sibbald and Price (1976), Quintin and McCracken (1993) and Stewart et al. (1997) have failed to find any relationship between bushel weight and DE in pigs or AME in chickens even at low bushel weights. Hickling (1994) investigated the nutritive value of 22 samples of wheat of bushel weights ranging from 45 to 82 kg/hl. He found a poor relationship between bushel weight and AMEn measured in two week old male broilers ($R^2 = 0.04$) with very high variability in AMEn for the high bushel weight wheats (Figure 13). In contrast he found a strong relationship between bushel weight and TMEn measured with adult cockerels ($R^2 = 0.89$; Figure 14). However, with the TMEn data it can be seen that there is much greater variation in energy content at low bushel weights than at high bushel weights.

Wiseman and McNab (1995) confirmed Hickling's finding that AME measured in young chicks was not correlated to bushel weight whereas TME measured in adult cockerels was correlated to bushel weight within the range 69.5 to 81.5 kg/hl. The poor relationship between bushel weight and AME may reflect the greater sensitivity of young birds to variations in grain composition. Hickling (1994) found that the best single correlation to AMEn was soluble NSP concentration, although the predictive accuracy was still low ($R^2$ =

0.23). He suggested that young birds are more susceptible to the negative effects of soluble NSP than are adult birds. McNab (1991) has suggested that another reason for poor correlations with AME may be due to problems with the methodology. He argued that replacement of part of a known ME basal diet with wheat introduces considerable bias into the estimation of the wheat's ME value. However, Wiseman and McNab (1995) found that estimating AME from feeding all wheat diets (supplemented with minerals and vitamins) gave highly variable results. McNab (1991) concluded that TME is the most appropriate method for assessing ME value of wheat for poultry. This suggestion does overlook the fact that young birds are less able to digest dietary components such as fibre and NSP than are older birds and therefore are likely to derive less ME from the diet.

McNab (1991) obtained significant prediction equations for TMEn from bushel weight within the year of harvest. However he found that the prediction equations differed between years so that he was unable to recommend a prediction equation for general use across years. In addition, for wheat samples from 1985 the relationship only became significant below 70 kg/hl, but this only represented three samples. McNab's predictive values differ between years and differ from Hickling's and therefore question the validity of bushel weight as a predictor of the energy value of wheat.

Further evidence that bushel weight is a poor predictor of energy value comes from the work of Sibbald and Price (1976), Quintin and McCracken (1993) and Stewart et al. (1997) who demonstrated no difference between bushel weight and energy value of wheat fed to poultry or pigs. Stewart et al (1997) reported DE values for pigs which were derived from prediction equations based on chemical composition of the grain and therefore were of limited value. However, the growth performance of pigs was not different regardless of bushel weight, supporting the idea that the wheats were of similar feeding value. This work used sprouted wheats and surprisingly reported no differences in chemical composition regardless of bushel weight. This suggests that bushel weight differences reflect a kernel morphology effect on packing density rather than differences in grain maturity.

Australian work suggests that AME for poultry can be predicted from the concentration of soluble NSP in wheat (Annison, 1991). In this work there was no correlation between AME and insoluble NSP. However, British and Canadian work failed to find a correlation between AME and soluble NSP (Nicol et al., 1993; Austin and Cheeson, 1996; Scott, 1996). It is clear that the particular type of NSP is also of importance (Austin and Cheeson, 1996) and in some varieties digestibility of starch may override the effects of NSP on energy value (Nicol et al., 1993).

Because of the detrimental effects which digesta viscosity has on bird performance it has been suggested that measurement of the viscosity of the wheat itself, using a method which simulates chick digestion, might provide a better estimate of the potential nutrient value of the wheat than either NSP (Dusel et al., 1997) or starch digestibility. In trials at Finnfeeds viscosity *in vitro* has been shown to account for between 50 and 80% of the variation in the feeding value of wheat *in vivo* (Bedford, personal communication).

There is evidence to suggest that adverse effects of NSPs can be counteracted by the judicious use of enzymes such as pentosanases and ß-glucanases (Pettersson and Aman, 1988, 1989; Classen and Campbell 1990). Consequently many feed companies now routinely include appropriate enzymes in their formulations for poultry. Although enzymes can produce dramatic improvements to the feeding value of wheat, their effects are variable (Bedford and Morgan, 1996) and unpredictable depending on genotype and growing conditions (Bedford, personal communication). The use of enzymes in improving the nutritive value of low bushel weight wheats has not been evaluated. There is no apparent relationship between low bushel weight wheat and viscosity (Figure 8; Hickling, 1994).

In conclusion, whilst a number of trials show an overall trend for poorer nutritive value for non-ruminant animals of low bushel weight wheats, it is evident that this effect is more apparent for wheats below 65 to 70 kg/hl, and that some wheats perform equally well regardless of bushel weight. Therefore bushel weight cannot be considered to be a reliable predictor of the nutrient value of wheat.

We were unable to find any scientific literature about the nutritive value of low bushel weight wheat for ruminants.

# 8. Methods for assessing the composition and feed value of low bushel weight wheat

## 8.1 Composition at point of entry to the animal feed mill

The current position is that most feed compounders assess dry matter and bushel weight routinely for each truck load at intake to the mill. Wheat which does not meet the specified moisture and bushel weight criteria is rejected and does not enter the mill. Wheat which is accepted is assigned to appropriate bins according to bushel weight (see Section 8 below). On the other hand flour millers assess protein at intake by near infra red reflectance spectroscopy (NIR) in addition to moisture and bushel weight. The additional assessment of protein by the flour millers probably reflects the general relationship between total protein and the yield and quality of the gluten in the wheat. Gluten is also assessed routinely, but not rapidly at the point of intake and is therefore not used as a criterion for rejection.

Bushel weight developed as a single simple test of the proportion of endosperm and embryo to pericarp as a substitute for the laborious wet chemistry involved in determining starch and crude protein. Today the use of NIR is accepted as a reasonable, rapid method for the assessment of several parameters of quality in feeds, including animal factors such as digestibility and viscosity.

## 8.2 Feed value in animal trials

Animal feeding trials have, in general, been too empirical in their approach to the assessment of the nutritional value of wheat. Extensive laboratory analysis should precede diet formulation to produce diets of equal total nitrogen concentration and (isonitrogenous) and of equal predicted ME value (isoenergetic). Comparison of low versus high bushel weight wheat under such conditions might then reveal unexpected differences related to anti-nutritional factors, or limiting amino acids. As it is, in many experiments differences between types of grain are confounded by differences in dietary protein to dietary energy content (e.g. Quintin and McCracken, 1993; Collier et al., 1996) Whilst such work does investigate the compounders' requirement for wheat to be included in a diet at a set level it fails to assess accurately the nutrient value of the wheat and will be unable to determine whether any undetected anti-nutritional factors exist in the material.

### 8.2.1 Assessment of energy value for poultry

It is widely recognised that wheats, regardless of bushel weight, have extremely variable energy values for poultry (Mollah et al., 1983). This is particularly true when energy is measured as AME. AME is normally measured in young broilers of 2 to 3 weeks of age. The birds are fed on the test diet *ad libitum* and total excreta are collected over four days. Total feed intake and total excreta output are recorded and the energy content of both feed and excreta are measured. AME is calculated from the following equation:

$$\text{AME} = \frac{(\text{Energy intake - Energy excreted})}{\text{Feed DM Intake}}$$

The value obtained may be corrected for endogenous nitrogen secretion (AMEn). This estimate of metabolisable energy has the advantage that it is measured in birds which have grown accustomed to the diet and it therefore represents likely performance of the ingredient within a commercial diet, particularly if the level of the ingredient in the test diet is similar to that which would be fed commercially. There are a number of problems with this method however;

- age - the ability of the digestive tract to digest food increases with age (Krogdahl *et al.*, 1989; Nir *et al.*, 1993),
- feed intake - intake of birds fed *ad libitum* varies widely causing high variation in AME measurement (Wiseman and McNab, 1995),
- basal diet interactions - the test ingredient may interact with the basal diet to give a higher or lower value for AME than if the ingredient had been fed alone (McNab, 1992),
- differences in gut size and microbial populations - ingredients which increase digesta viscosity increase the relative size of the digestive tract (Brenes *et al.*, 1993) and change the intestinal microbial population (Bedford, 1996). This changes the partitioning of energy both within the bird and between the bird and its microbial population (Muramatsu *et al.*, 1994).

Therefore AME may not truly reflect the energy available to the bird for metabolism.

Because of the problems associated with AME measurement, in particular its variability, some researchers and feed compounders prefer to use true metabolisable energy (TME) which generally produces more repeatable results. TME is normally measured in adult cockerels which are starved for at least 24 h prior to tube feeding a known, and therefore controlled, weight of the test diet (usually 50 g of the pure wheat ground) directly into the crop. Excreta is then collected over the next 48 h. TME is calculated in the same way as AME and corrected for endogenous energy and nitrogen losses (TMEn).

The advantages of using TME as an estimate of energy availability to the bird are that the ingredient can be studied in isolation so that interactive factors with the basal diet are avoided. Values obtained are very repeatable and therefore the coefficient of variation of the estimate is low.

However there are a number of disadvantages associated with the TME technique, the most significant of which is that the estimate is made in birds treated in a very artificial way and therefore may differ widely from what would be observed in a commercial situation. This explains why the correlation between AME and TME is frequently poor. The bird has no opportunity to become acclimatised to the diet, with the associated changes in gut structure and function and microbial population that might result. Further, the bird is fasted prior to test and therefore is in an abnormal physiological state. The estimate is made in adult birds which are far more tolerant of anti-nutritional factors than are young birds and therefore may give a poor estimate for growing birds.

While estimation of net energy would appear to be the ideal solution, the very definition of net energy precludes its estimation from simple equations particularly as it relates primarily to the animal which is receiving the feed rather than to the feed itself. Therefore it would seem for the present to be a rather elusive parameter to define accurately on a routine basis, despite current optimism from the feed industry!

It has been suggested that for the present perhaps the best estimate of energy availability to the chicken can be obtained from AME calculated from terminal ileal digest samples since these reflect the bulk of the energy which is available to the bird (Bedford, personal communication). Such estimates fail to account for the contribution of VFA and other products liberated by bacterial digestion in the hind gut. This contribution could be quite significant for birds which had considerable quantities of undigested material e.g. starch, entering the hind gut. Although VFA are used less efficiently than sugars their contribution to energy status should not be overlooked.

In summary, the estimation of energy availability remains something of a minefield with AME maintaining the greatest creditability since it is readily measured in an appropriate animal model.

It has been reported that AME is not closely correlated to FCR (Bedford, 1996) however such a correlation can only be expected if the trial diets are equally balanced for the ratio of available energy to available amino acids. In much of the reported literature this has not been the case.

# 9. Perceptions by the animal feed industry

*The animal feed industry desires consistency in the composition of wheat and recognises the sensitivity of poultry to variation in wheat quality.*

## 9.1 Purchase of wheat

Wheat is purchased by feed companies on the basis of bushel weight and dry matter content, both of which are measured prior to acceptance of the grain by the mill and can be measured rapidly at the point of entry to the mill. In addition some companies purchase on the basis of variety, for example Dalgety Agriculture Ltd. pay a premium for the variety 'Buster' which they believe has an inherently higher energy value for livestock.

No price discount is applied to wheats with bushel weight ≥ 72 kg/hl. The general strategy adopted by the feed industry is to discount the price of grain by a particular amount for each point below the standard and to allocate the wheat to various categories depending upon its bushel weight.

It is not normal for the animal feed industry to purchase wheats with bushel weights below 65 kg/hl, indeed some compounders prefer not to buy below 68 kg/hl. However, wheats as low as 62.0 kg/hl may be purchased in some seasons. Wheats of <62 kg/hl are not usually purchased by the major feed companies.

Discounts are not the same for all classes of livestock - some feed compounders will accept low bushel weight material at a higher price than others. The amount of information on the attributes of low bushel weight wheat varies from compounder to compounder - some, e.g. the integrated users have detailed information on individual varieties of wheat.

Whilst it will be interesting to have more information on the nutritional value of low bushel weight wheats, it is the perception of some in the industry that the information will have no effect on price discounts because of the international trading situation (Section 4.2). The international nature of the wheat market will become more important in the future as the UK market moves closer to world prices and as Agenda 2000 proposals exert an influence on European prices for wheat.

It is considered that traceability and storage characteristics will become more important in the future in determining the price paid to the producer, but any premium for improved traceability and cleanliness will be small compared to the influence of bushel weight on price.

## 9.2 Assessment of wheat composition and nutritional value

Wheats of lower bushel weight are assumed to have lower ME and amino acid contents. Each company has its own prediction equations to estimate nutritive value from bushel weight and wheat is segregated into different storage bins according to broad categories of bushel weight. For example, one feed compounder segregates wheat into three different groups according to bushel weight.

The decision to consider low bushel weight wheat as a lower quality product is in part supported by the scientific literature (see Section 7) since the literature suggests that such wheat is either of equivalent or poorer energy value compared to that of higher bushel weight material. However what is really required is a true measure of feeding value and this cannot be determined from bushel weight alone.

Accuracy in assessing wheat composition is considered to be important for two reasons:

a) Millers and feed compounders do not want to have to change the specifications of their processing machinery and formulations frequently. Limited stock space means that more storage bins are needed if quality changes are frequent.

b) Blending takes place at all stages from farm to mill to reduce variability in bushel weight and in other traits. The composition of blends may vary considerably at similar bushel weights.

It is generally recognised that young chicks, particularly broilers, are most susceptible to variations in the nutritive value of wheats. Pigs are considered to be more tolerant than poultry to variations in nutritive content. In contrast, ruminants are extremely tolerant of wide variations in grain quality. However, because of the constraints on grain storage at the mill, wheats are purchased and classified relative to their perceived value for monogastrics, primarily poultry.

# 10. Conclusions and recommendations

*Assess variation in components of wheat to determine which are responsible for changes in nutritional value; develop techniques for rapid determination of relevant components.*

Bushel weight is a poor measure of wheat quality, however, currently there is no accurate rapid method of assessing the nutritive value of wheat at the point of purchase or entry to the feed mill. Near infra red reflectance spectroscopy offers this alternative but has yet to be refined to the point of providing all the necessary information.

The assessment of the nutritive value of low bushel weight wheat is essentially the same as that of assessing any wheat. As wheat is the dominant cereal used in diets for monogastrics, it is capable in contributing high levels of variation to the overall diet. It is only by identifying interactions between chemical constituents and defining these through regression equations that we will be able to estimate wheat quality correctly. Clearly the factors determining the nutritive value of wheats are not straightforward or the answer would have been identified already. To achieve the correct prediction of nutritive value of all wheats, including those of low bushel weight, will require a very substantial commitment of research effort and appropriate funding.

Bushel weight does give some indication of the starch and fibre content of wheat (Figures 3 and 4), however as currently measured, grain morphology can too easily affect bushel weight and reduce the accuracy of the measure. An easily instigated method of distinguishing between poorly filled grain and that which has poor packing characteristics would be to determine the specific volume of ground grain. Assuming that the method and degree of grinding were to be standardised precisely at the outset, this should then reflect differences in grain composition rather than in grain shape and should give a better prediction of quality. Such a measurement might be one useful parameter within a prediction equation for grain quality and a useful first step to improving the present situation.

Protein content and protein quality vary widely regardless of bushel weight (Figure 6) and it is surprising that protein content is not measured routinely at the point of mill entry as it is by the flour milling industry. We recommend that the content of crude protein in wheat should be measured routinely and also incorporated into a general prediction equation for quality. However this is only a limited step forward since what is really required is a prediction of the content of available amino acids.

Poultry are more sensitive to variation in wheat composition than other livestock. Much of this variation in the value of wheat for poultry is associated with high viscosity in the digesta largely due to the presence of soluble NSP. It is current practice to add enzymes at a set level to all wheats destined for poultry to reduce the incidence of increased digesta viscosity. Improved prediction of viscosity would allow more judicious enzyme usage and more efficient use of wheat in poultry diets.

The importance of variety should not be overlooked since this determines fundamentally wheat composition and response to enzymes or other treatments. We welcome recent moves by the animal feed industry to develop closer links with plant breeders in an attempt to define more closely the quality criteria in wheat destined for use in animal feeds.

In conclusion, bushel weight is not a good measure of quality in wheat and there is an urgent need to develop a better predictor. Future research effort should be concentrated on identifying the key criteria which determine the nutritive value to livestock of wheat of a wide range of bushel weights, and then developing rapid techniques for predicting such criteria. It is evident that this is not a straightforward task, since substantial investment has already been made in this area with relatively little progress being made to date.

# 11. References

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Figure 1, Variation in shape between wheat grains of different varieties

Figure 2, Wheat grains containing air pockets

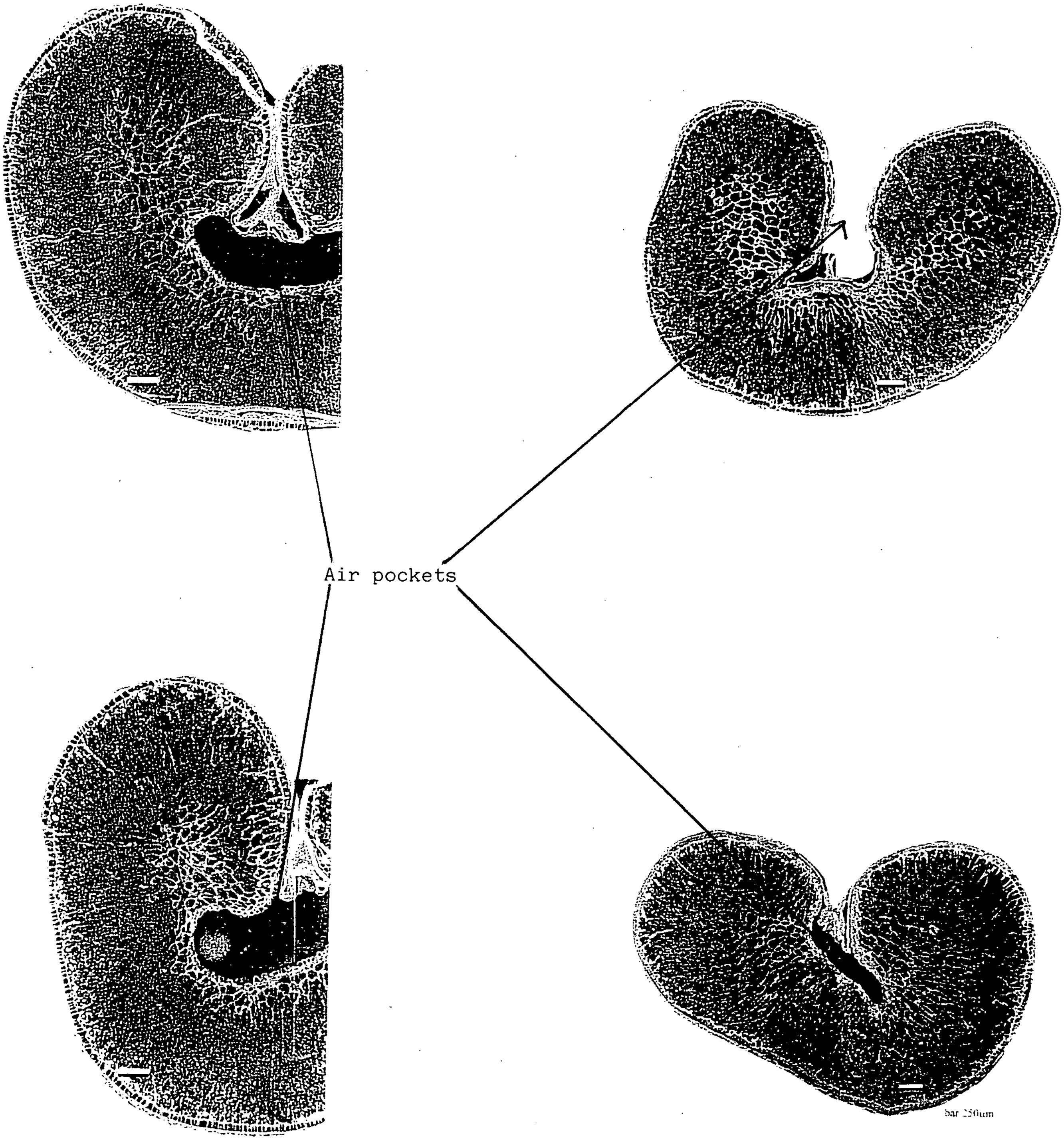
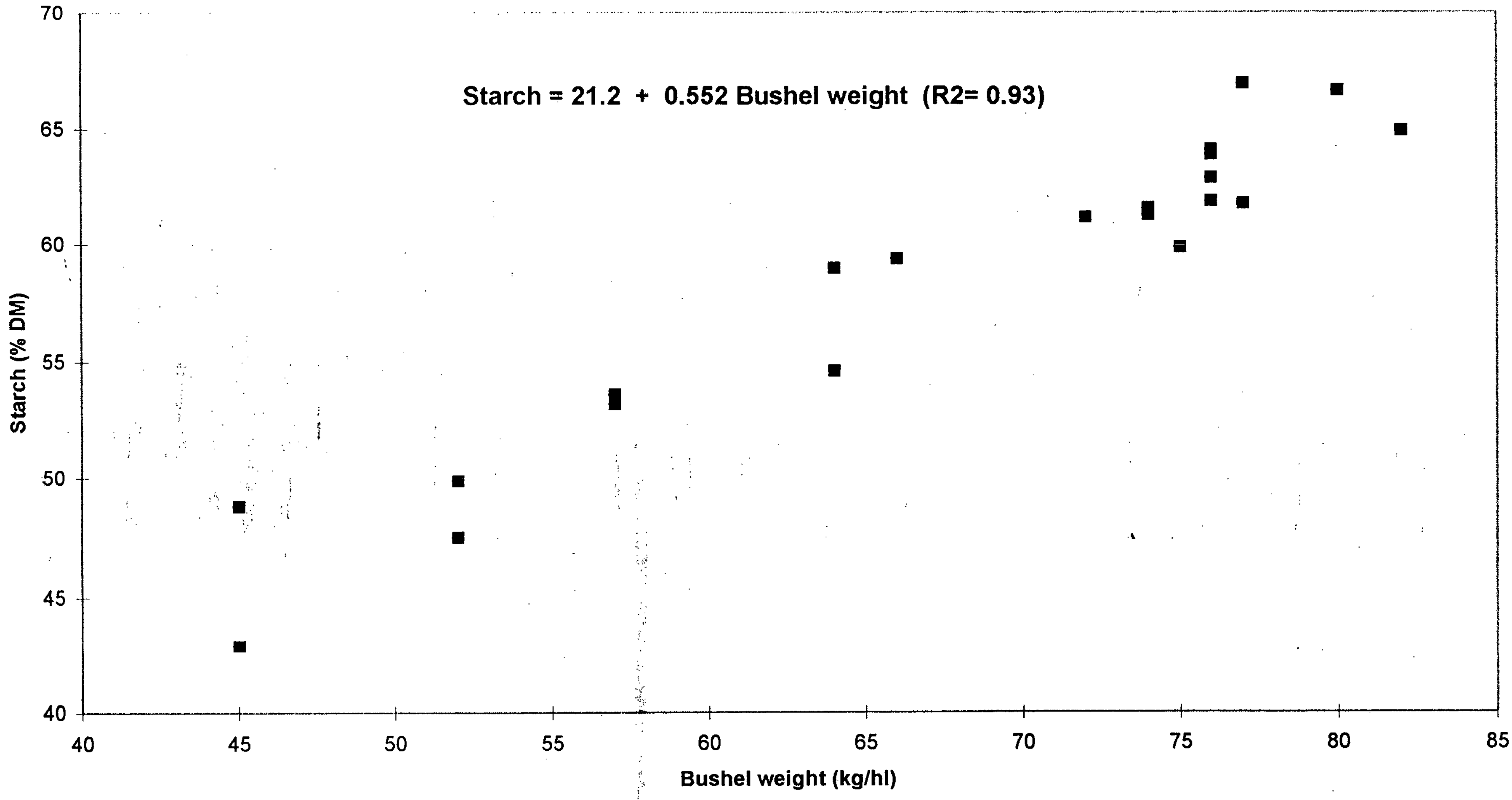


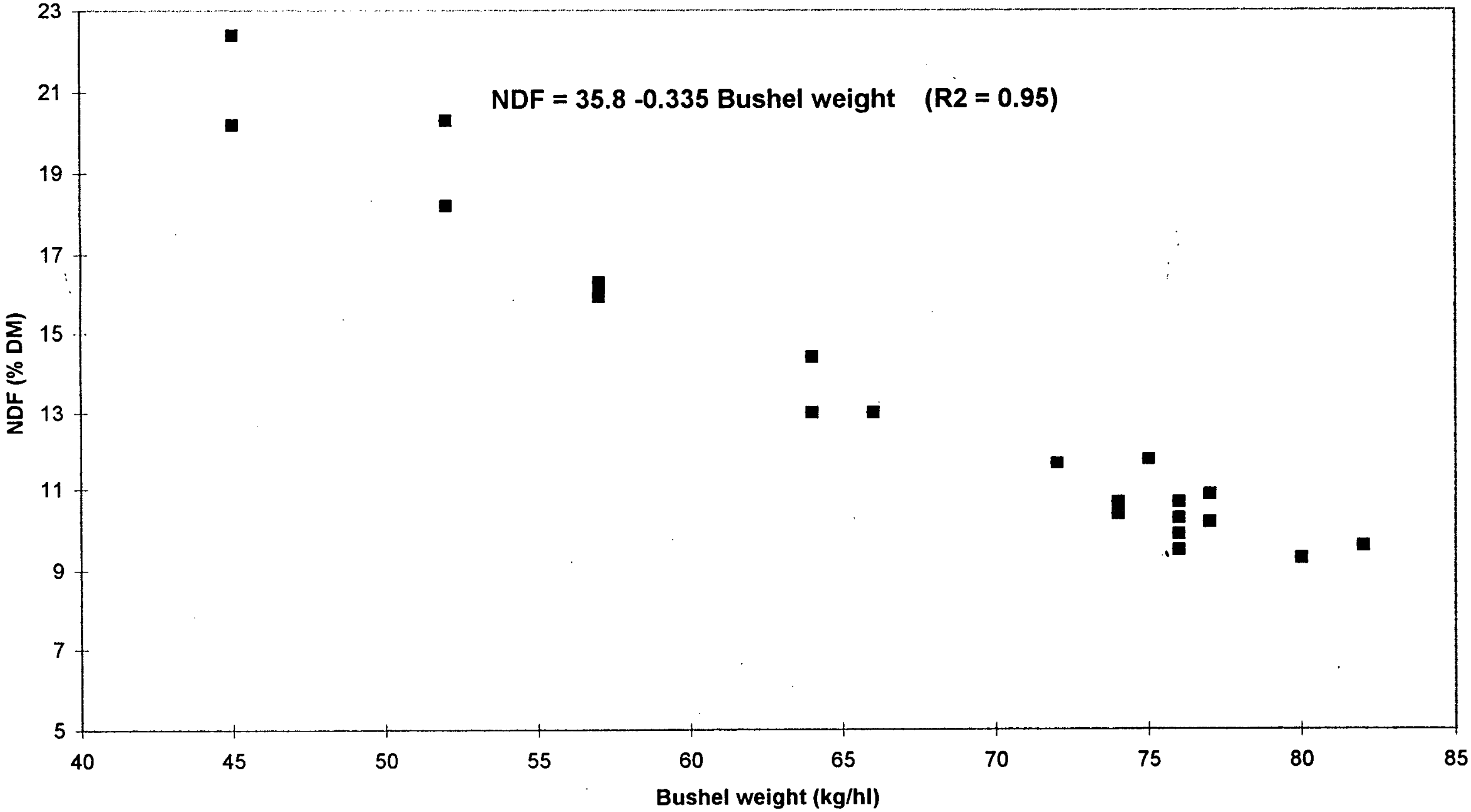
Figure 3 Relationship between bushel weight and starch content in wheat



Starch = 21.2 + 0.552 Bushel weight (R2= 0.93)

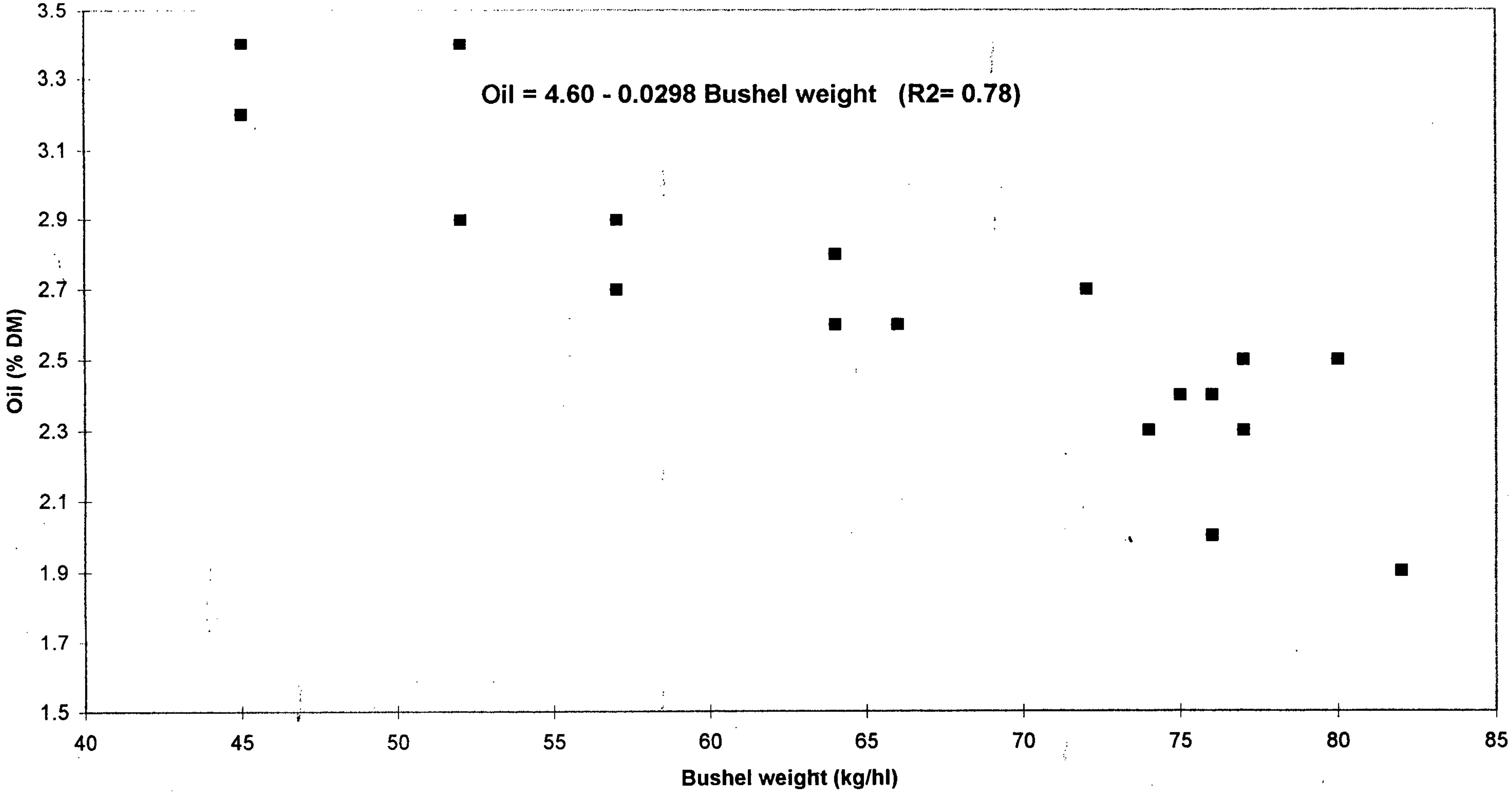
From Hickling (1994)

Figure 4 Relationship between bushel weight and neutral detergent fibre (NDF) in wheat



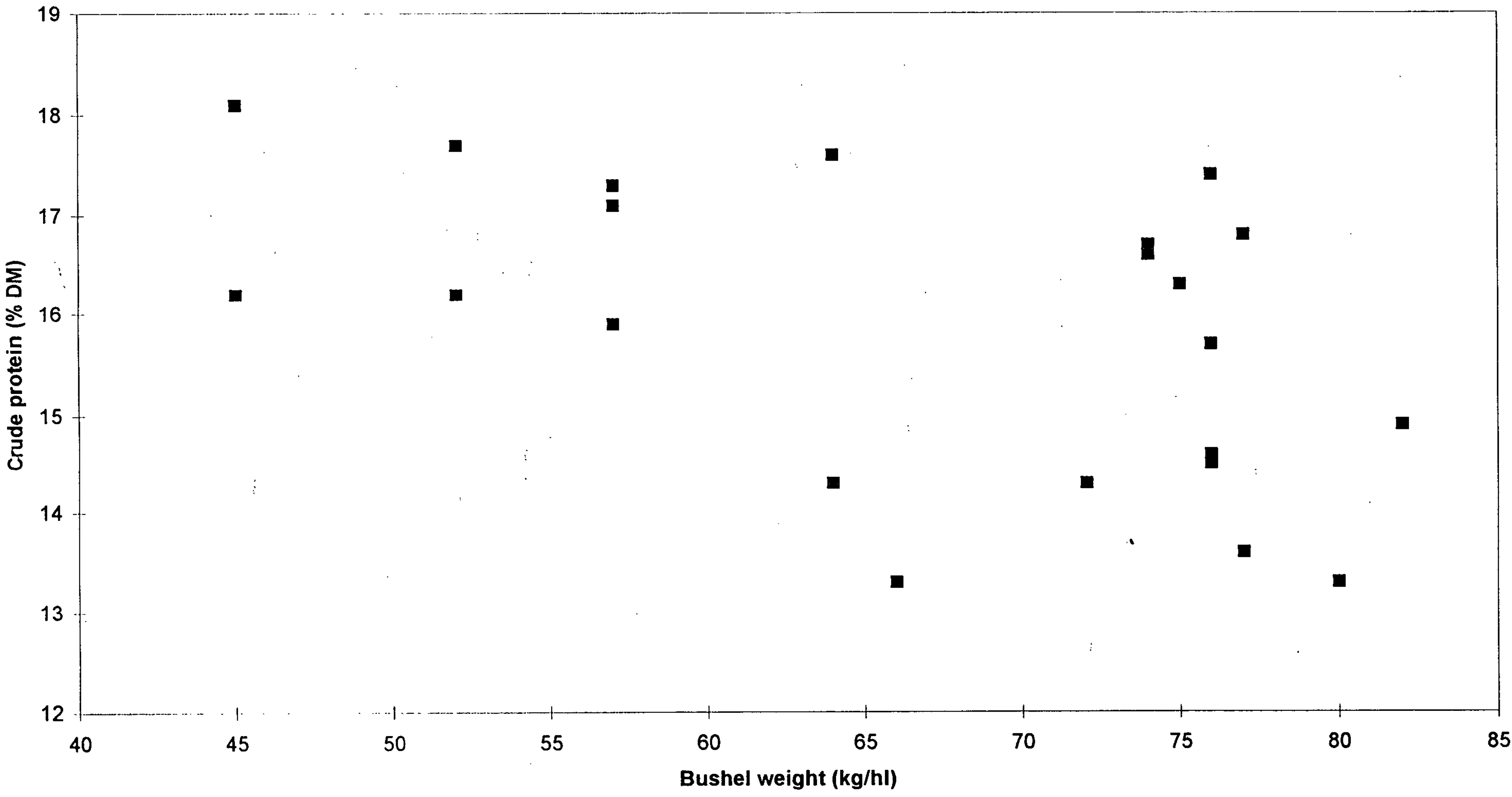
From Hickling (1994)

Figure 5 Relationship between bushel weight and oil content of wheat



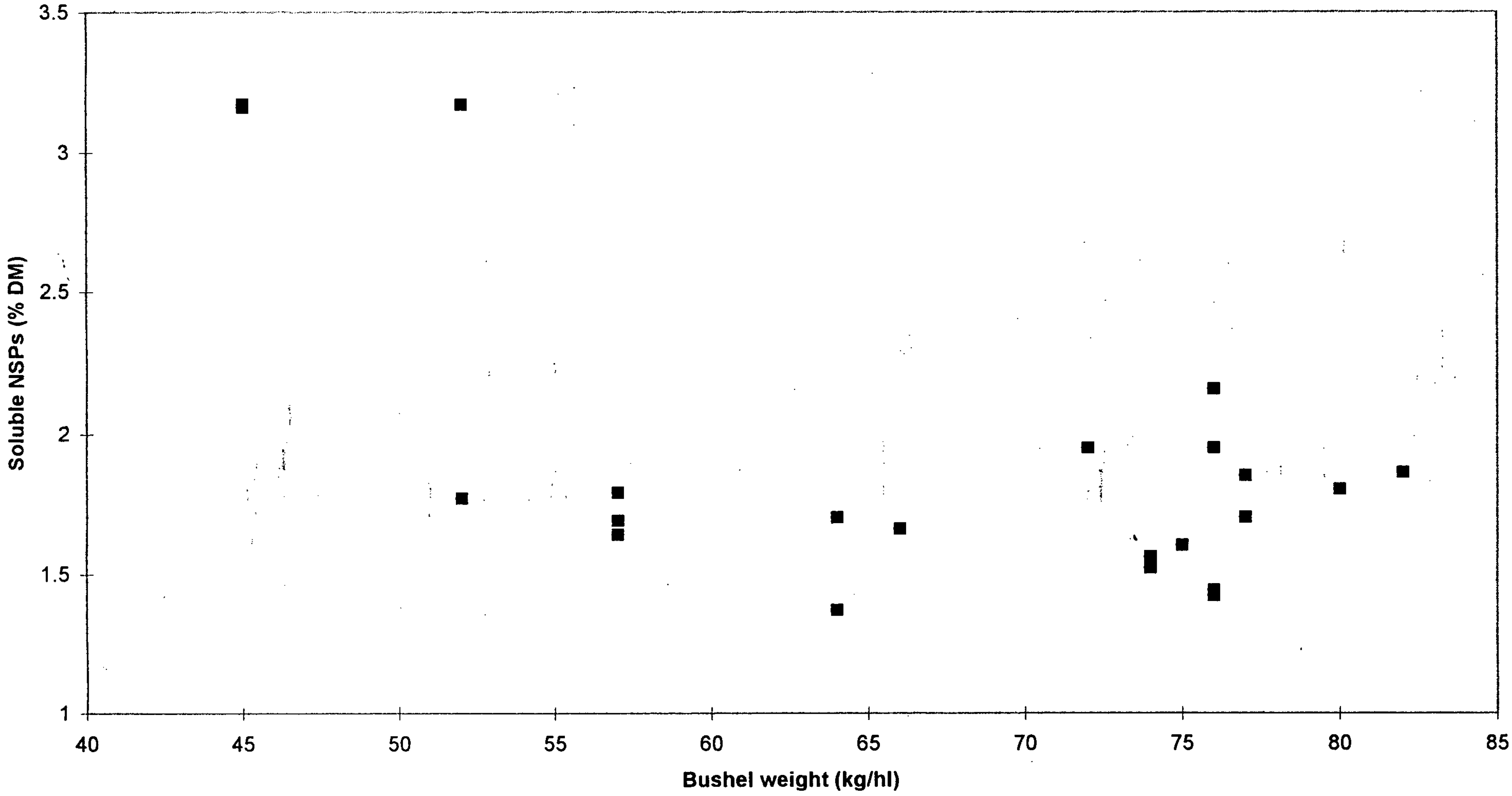
From Hickling 1994

Figure 6  Relationship between bushel weight and protein content in wheat



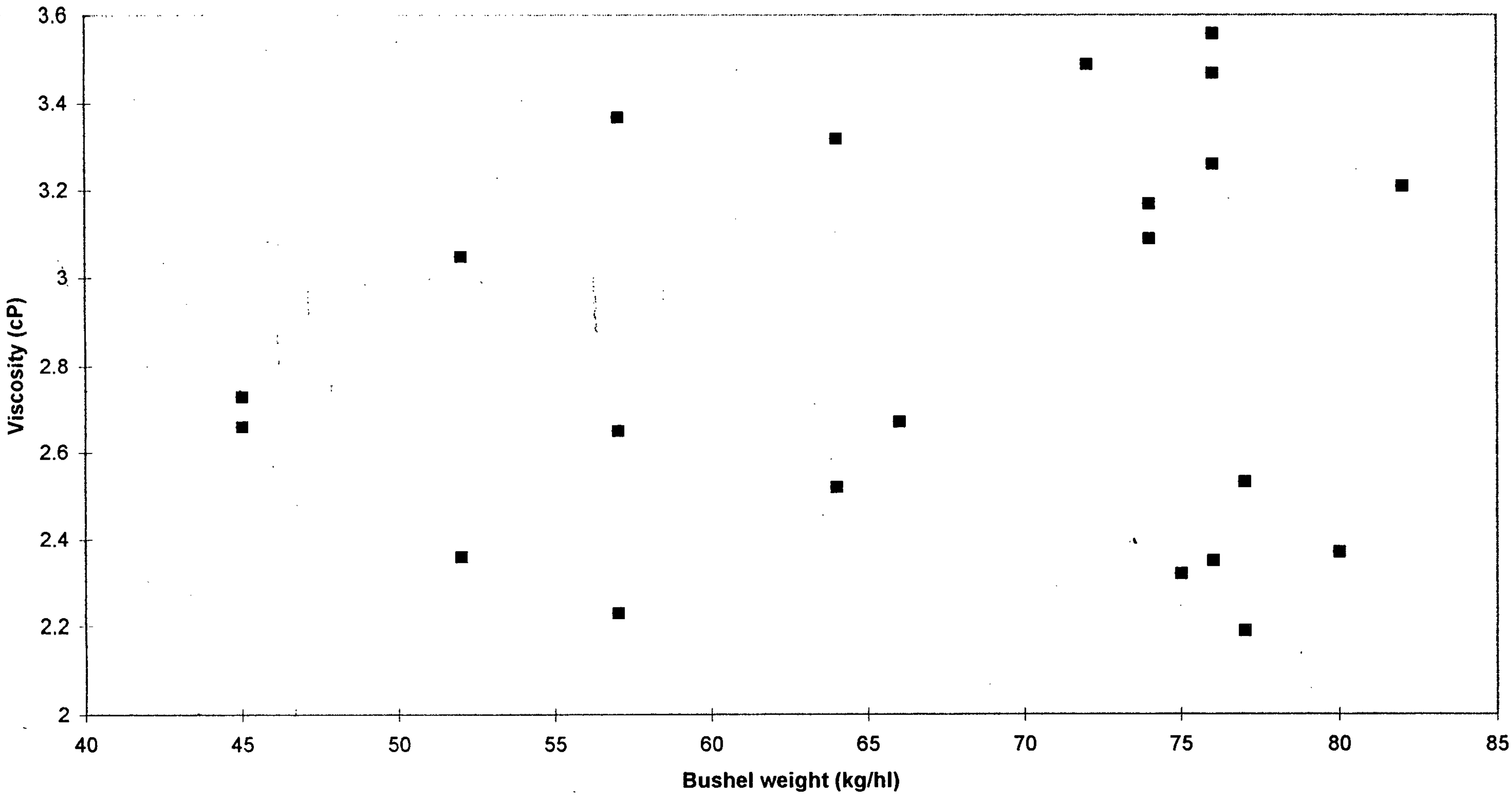
From Hickling (1994)

Figure 7 Relationship between bushel weight and soluble non-starch polysaccharides (NSPs) in wheat



From Hickling 1994

Figure 8 Relationship between bushel weight and viscosity in wheat



From Hickling 1994

Figure 9 Relationship between bushel weight and TMEn of wheat for poultry from Salmon and O'Neil 1977

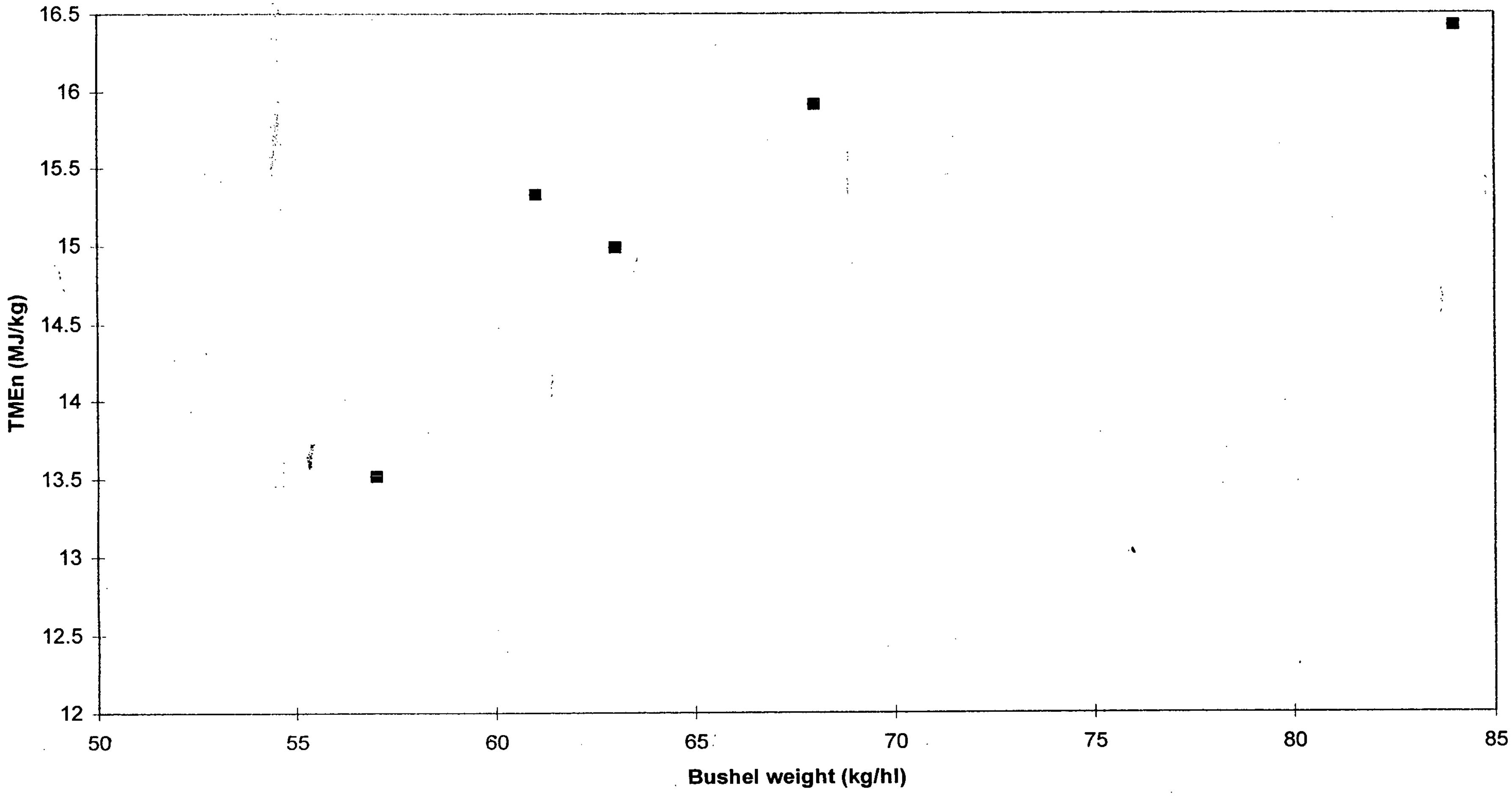


**Figure 10 Relationship between bushel weight and DE of wheat for pigs from Batterham et al. 1980**

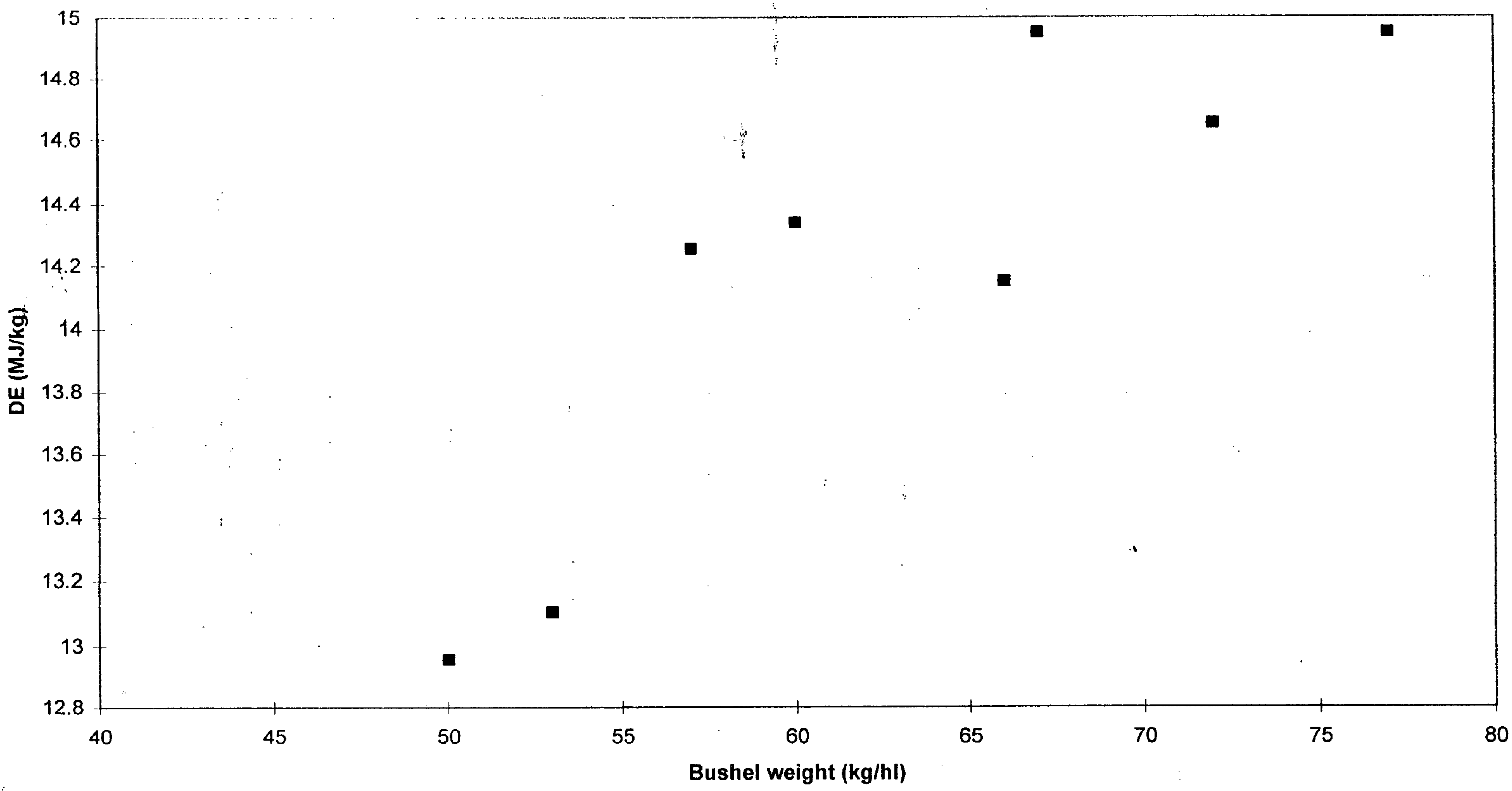


**Figure 11 Relationship between bushel weight and digestible energy for pigs from de Lange et al. 1993**

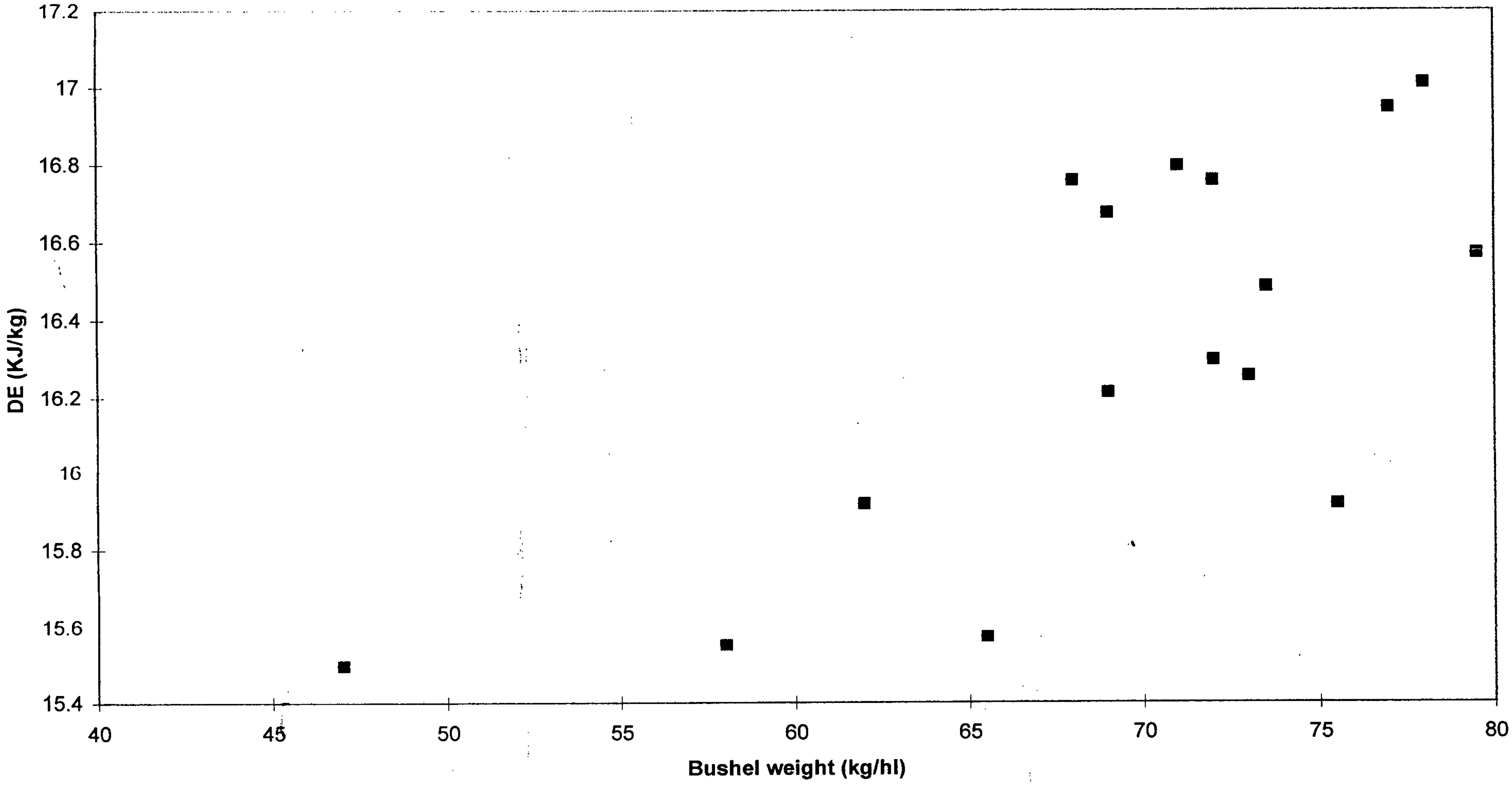


Figure 12 Relationship between bushel weight and TMEn for poultry from McNab 1991

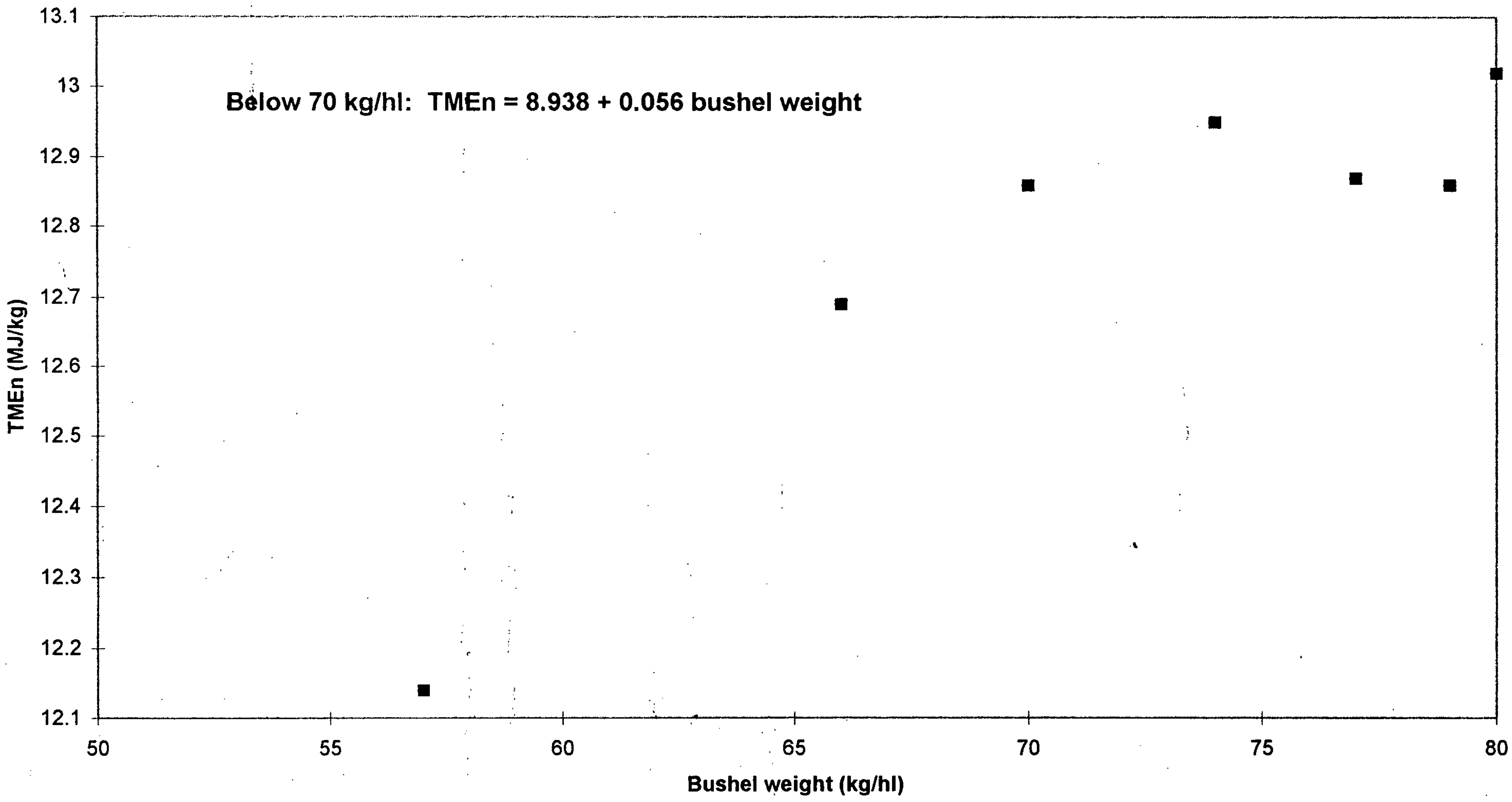
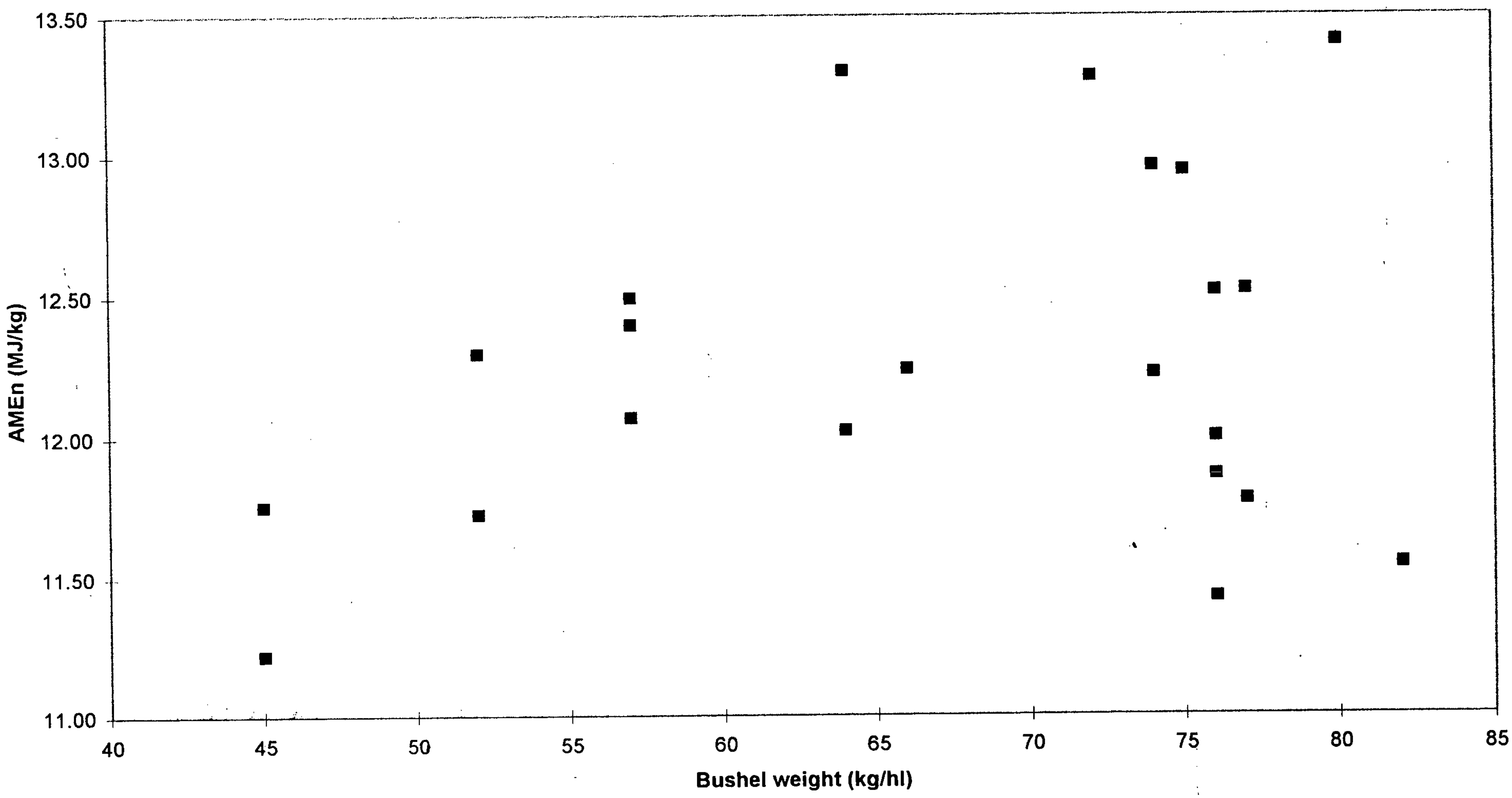
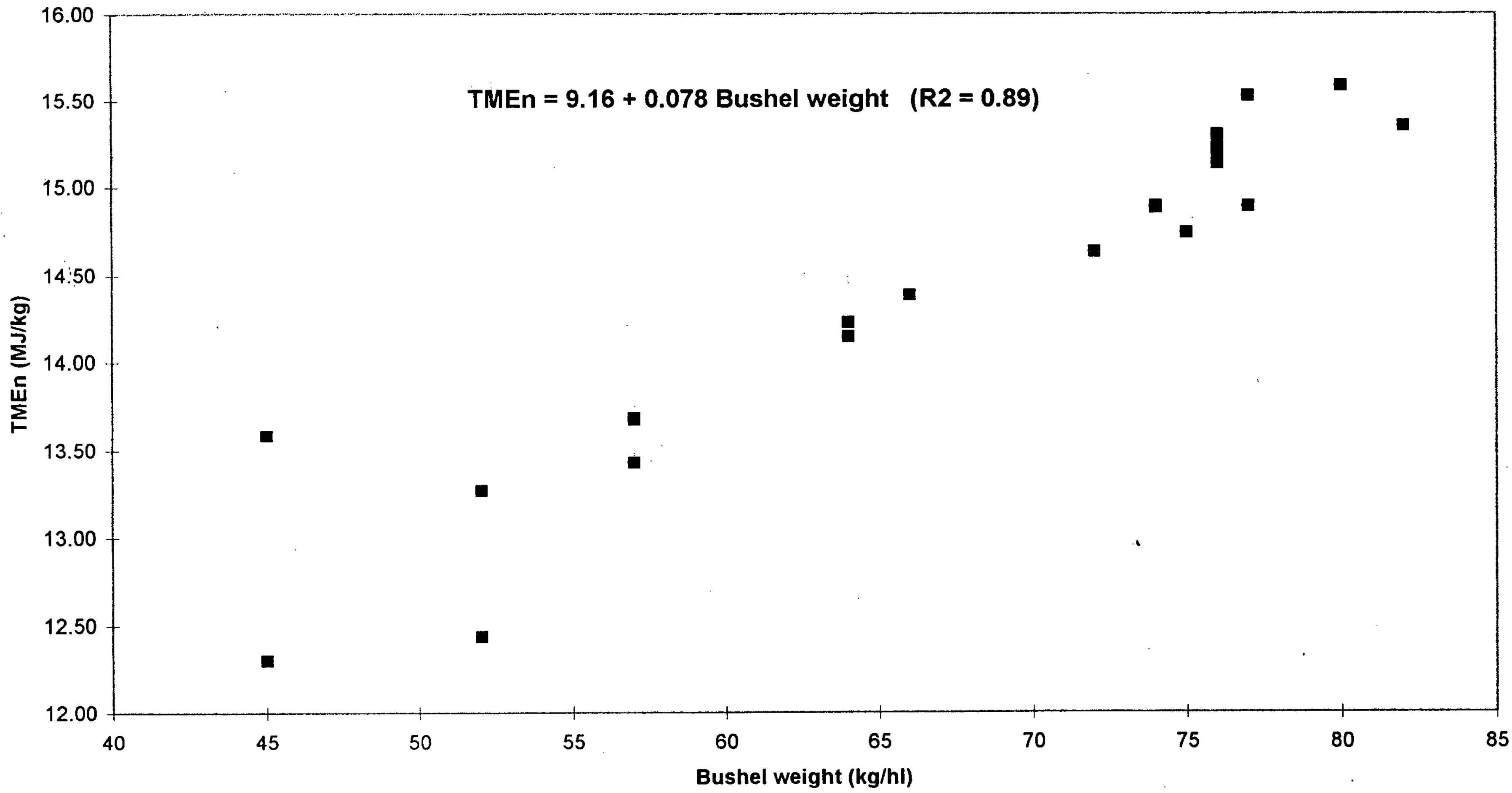


Figure 13  Relationship between bushel weight and AME in wheat



From Hickling (1994)

Figure 14 Relationship between bushel weight and TMEn in wheat



From Hickling (1994)