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Gaining from Improved Dairy Cow Nutrition: Economic, environmental and animal health benefits.

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A majority of UK dairy herds have the potential to increase profitability by improving the ration of their cows. This paper reports that gains averaging around £100 per cow have been made within one year of adopting the Keenan Hi-Fibre ration by 239 UK herds in 2006 and 2007. Larger gains have been made by herds in France. The key performance indicator underlying these gains is Feed Conversion Efficiency, whereby the same, or even a smaller amount of Dry Matter Intake generates higher yields per cow. Importantly, the gains are associated with large improvements in animal health and reductions in greenhouse gases per litre of milk produced.

Key words: *Feed conversion efficiency, cattle nutrition, greenhouse gas emissions, animal health.*

1. Introduction.

The dairy and beef sectors of UK agriculture are under scrutiny as never before. Concerns about global warming have highlighted cattle's estimated contribution to the generation of greenhouse gases, particularly methane and nitrous oxide. According to the Cabinet Office (2008) UK agriculture contributes only 0.7% of Gross Domestic Product but 7% of UK greenhouse gas emissions; cattle play a disproportionate role in this. Consequently, concerns about meeting national targets to reduce greenhouse gas emissions identify dairy and beef cattle as sectors which could make a significant contribution. The Vegan Society suggests that universal vegetarianism is the correct response to help tackle global warming, and certainly there appears to be little public, or policy support for the UK dairy and beef sectors. Nevertheless, based on the research reported in this paper, our contention is that through improved nutrition there is the potential of both sectors to at least mitigate their output of greenhouse gases, and to do so in a way which is commercially profitable.

There are also widespread public concerns about animal welfare and health; concerns currently directed much more at the poultry sector, but pressure exists across the board on animal production. Currently in the UK there are many cows capable, if adequately fed and managed, of producing over 10,000 litres milk per 305 day lactation. But with increased use of the Holstein, other issues have started to appear, thought to be related in part to limited trait selection. Poorer fertility, poor post-calving appetites, excessive body condition loss after calving, increased lameness, poor milk solids, compromised animal health and reduced longevity have all been attributed in some way to the breed change. It is interesting to consider how many of these problems are related to the way that cows are being nutritionally managed. Cunningham, (2005) highlighted this issue, stating, 'Genetics has created the potential, nutrition has failed to deliver it'. Farmers themselves have profound concerns about animal health, no more so than in the dairy sector, where infertility (difficulty in achieving repeat calvings), laminitis of cows' feet, and general poor condition, all impact adversely on profitability. A central hypothesis is that better nutrition improves all these dimensions of cow health.

The economic scope for improving dairy cow management and nutrition is presented in the next section of the paper. The third section of the paper explains the key elements of good cattle nutrition and the fourth describes a programme for delivering that nutrition. The fifth section examines empirical evidence that this programme can be successfully delivered, with economic benefits to producers, major improvements in animal health, and external benefits in the form of reduced greenhouse gas emissions.

2. **The Scope for Improving Cattle Nutrition and Management.**

It is accepted that there is a large spread in all dimensions of efficiency in farming. Some farms are at the leading edge of efficiency, and have little scope for improving certain things, while others are operating well below the highest levels of economically justified technical efficiency. For the England and Wales dairy industry an illustration of this was published in this Journal (Colman and Zhuang 2006), and is reproduced in Figure 1. The Figure shows the estimated proportions of England and Wales milk produced at below certain values of total cost of production in both 1996/7 and 2002/3. What is striking is the substantial variation in total cost per litre within the distinct years. In 2002/3 around 60% of milk was produced at below 18.02 pence per litre[1], as against an average producer milk price including bonuses of 18.02 in 2003 (MDC Datum). The price was even lower in 2002 than in 2003, so the implication is that over 40% of milk may have been produced during 2002 at a loss. In 1996 (1997) the average producer price was 24.97 (21.95), suggesting that the proportion of milk which was produced at a loss was then around 20 to 30%.

Since feed costs in 2002/3 accounted for just over 70% of average variable costs per litre (Colman et al. 2004, Table A1.1) more efficient nutrition management has a large potential for raising herd profit and overall efficiency. The same data set reveals that the best 25% of herds, by net margin, in England and Wales had variable feed (concentrate and forage) costs of 4.81 pence per litre (ppl), whereas for the bottom 25% the cost was 6.34 ppl, 32% higher. There was a clear association of higher yields by the top 25% of herds; they averaged 7090 litres per cow, as against only 4840 litres for the 25% with lowest net margin per litre. The better herds also performed significantly better in terms of fixed and overhead costs per litre.

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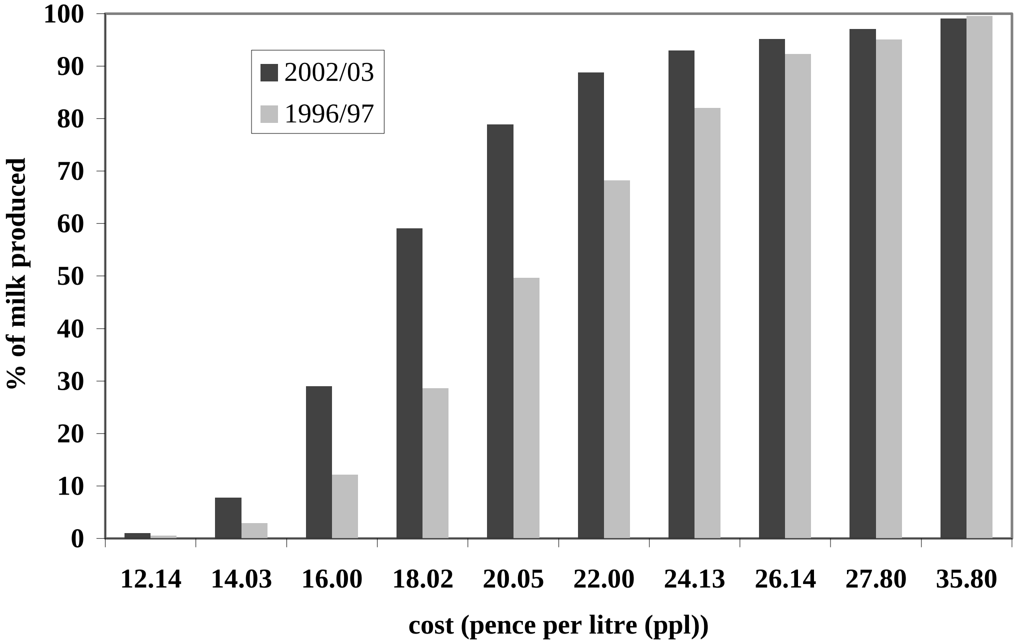
[1] The exactitude of the amount 18.02 is because, as with the other values on the X-axis, it is based on a specific group of representative farms.

Figure 1. Implied Cumulative Percentage of E&W Milk Production by Total Costs per Litre in 1996/7 and 2002/3



The difference in feed costs between the two groups, of 1.53 ppl, was worth £107 per cow per year for a herd yielding 7000 litres. It is not that the top quartile of herds by net margin spent a great deal more on variable feed costs than the bottom 25%, only £341/cow as against £307. The real message was that they operated a much more efficient cow nutrition regime and extracted a great deal more milk from the feed they used, by dint of better feed preparation and management of forages.

That leads to a central hypothesis for study, namely that raising Feed Conversion Efficiency is a key to raising herd profitability. As a secondary consequence, it also entails a reduction of the amount of greenhouse gases, and manure output per litre of milk. In a quota constrained situation that means total GHG and manure production from the dairy herd would be reduced.

Feed Conversion Efficiency (FCE) is defined as kilograms of energy corrected milk produced per kilogram of Dry Matter Intake (DMI).

3. The principles and practices of ruminant nutrition and cattle feeding.

Ruminant animals evolved to digest fibre and the rumen is the principal site of fibre digestion (Beever, 1993); only when significant amounts of finely ground fibrous feeds are fed does the large intestine make any significant contribution to overall fibre digestion (Thomson and Beever, 1979). The ruminal digestion of fibre is effected by the resident microbial population, including cellulolytic bacteria and specific rumen fungi (Lowe et al, 1987).

After ingestion, both simple and complex carbohydrates are degraded to simple sugars by extracellular microbial enzymes. Rate and extent of degradation are inversely related to molecular structure, fibre being slower and less extensively digested than starches whilst simple sugars are both rapidly and extensively digested (Beever, 1993). Subsequently, a significant proportion of the released mono-saccharides undergo fermentation and release energy (Adenosine Triphosphate; ATP) which is the principal energy source for rumen microbes to maintain cellular function and grow. The main end products of fermentation are short chain (volatile) fatty acids of which acetate, propionate and butyrate are the most important. These are subsequently absorbed through the rumen wall and transported to the liver via the ruminal vein (Reynolds et al, 1995).

Two other end products of ruminal carbohydrate digestion are carbon dioxide and hydrogen. Some may be lost directly by eructation but the majority is metabolised to methane by rumen methanogenic microbes and then eructated. Methane accounts for as much as 8-10% of total digested energy on some rations; a lactating dairy cow will produce between 500 and 700 litres per day according to feed intake and composition (Sutton et al, 1991).

Growth of microbes is essential to maintain overall population density in the rumen, and the synthesis of microbial biomass, of which protein is the largest single component, requires a synchronised supply of degraded nitrogen (amino acids and ammonia) and carbohydrate (principally hexose) moieties (Baldwin et al, 1987a).

Hydrolysis of dietary lipids also occurs in the rumen, followed by extensive hydrogenation of the released fatty acids due to the highly reducing environment of the rumen. This results in a major increase in the degree of saturation of the fatty acids leaving the rumen, compared with those ingested, unless ruminally protected fats are fed.

The small intestine is the major site of digestion and absorption of microbial biomass (principally protein), dietary lipid and any dietary starch and protein that has escaped rumen digestion (Beever & Siddons, 1986)

After absorption most nutrients enter the liver where some are metabolised and others transferred to peripheral circulation (Reynolds, 1995). The liver is the main site of glucose production and lactating dairy cows require an estimated 70 g glucose/litre milk (MacRae et al, 1988). On most diets, only limited amounts of glucose are absorbed across the small intestine and ruminally derived propionate is converted to glucose in the liver. When glucose demand outstrips propionate supply, certain amino acids are converted to glucose in the liver, which in turn reduces total amino acid supply (Reynolds et al, 2003).

Post-hepatic use of nutrients is affected by the physiological state of the animal and especially the endocrinological balance between tissue deposition and milk constituent synthesis, after taking due account of maintenance energy and protein demands (Baldwin et al, 1987b). Milk lactose, the key determinant of milk volume through known osmotic effects, is synthesised exclusively in the mammary gland from blood glucose. Milk proteins are synthesised primarily from blood sourced amino acids whilst milk fat synthesis relies either on ruminally derived acetate and butyrate or preformed fatty acids, derived either from the diet or during early lactation from body tissue loss, which comprises principally of fat (Gibb et al, 1992).

It follows that rumen function can have a major bearing on overall animal performance. It affects not only the amount of feed consumed but the extent of digestion that occurs there, especially of the fibre fraction. In turn this affects the final yield and composition of milk and meat. Fibrolytic bacteria operate most efficiently when pH remains above pH 6 (Mould et al, 1983). When rumen pH falls below this level, the functionality of rumen fibre degrading bacteria is impaired. At this stage they don’t necessarily die, but if the fall in pH due to increasing acidity is not quickly reversed, their reduced growth rates allow other micro-organisms to dominate. This is particularly important when high levels of starch are being fed, especially in discrete meals (Krause & Oetzel, 2005). In the first instance, as pH falls, streptococcus bacteria proliferate and rumen pH falls further until a point when lactate acid producing bacteria take over. As lactic acid is a stronger acid than the volatile fatty acids, this further reduces rumen pH. At the same time, numbers of lactate utilising bacteria start to increase but these are slower growing than lactate producers and unless substrate (carbohydrate) availability becomes limiting, such drops in rumen pH are difficult to arrest. This describes the onset of sub-clincial acidosis followed by clinical lactic acidosis (Bramley et al, 2006).

A similar situation can occur when excess amounts of sugar are fed although clinical lactic acidosis will not occur. A recent study by Williams and Doyle (2005) in cattle grazing lush fresh pasture noted sub optimal rumen pH values (<6.0) for significant periods of the day (circa 17 hrs). This would undoubtedly affect overall fibre digestion in the rumen and whilst non-lactic acidosis is easier to reverse, it is best avoided.

During the early stages of growth, both grazed forages as well as those intended for silage often contain low levels of physically effective fibre which could possibly compromise total time spent ruminating. It is suggested that efficient rumination requires between 25 and 30 minutes per kg of feed DM consumed. Reynolds and Humphries, (2008 not yet published) determined an average daily rumination time of 9.5hrs for lactating dairy cows consuming in excess of 23 kg DM/day as mixed rations, equivalent to between 22 and 25minutes per kg feed DM consumed. In contrast, cows grazing irrigated pasture without supplement, (Wales and Doyle, 2003) had a much shorter mean rumination time (5.89hrs) although with a lower level of feed intake (13.8kg DM per day) this equated to 25.6 minutes spent ruminating per kg feed DM consumed. Interestingly, when cows received 5kg supplementary feed, total rumination time was only marginally increased (6.31hrs) whilst time spent per kg feed DM intake declined to 20.8mins. In contrast, when free choice ryegrass straw was provided after milking, total rumination time per kg feed DM consumed was restored to 24 minutes per kg DM. At the same time, Wales & Doyle, (2003) reported a grazing time of 7.56hrs for pasture only fed cows with a DM intake rate of 30.4g/min, compared with a mean value of 87.0g DM/min when cows were fed mixed rations (Reynolds and Humphries, 2008 not yet published). From this data it is possible to conclude that as pasture-fed cows are managed in order to optimise grass intake, there exists a distinct possibility of rumination time being compromised, with associated negative effects on overall grass utilisation.

The immediate impact of compromised rumination is reduced saliva production. The reduced production of salivary buffers leads to lower rumen pH and in many instances sub-clincial rumen acidosis. Under such conditions, both the rate and extent of fibre digestion are reduced, which immediately impacts total feed intake as well as the extent to which consumed feed is digested. Whilst grazed or ensiled forages can be submitted for chemical analysis and shown to contain high levels of metabolisable energy, this is no guarantee that the cows will acquire this energy during the processes of digestion. Just a 6% impairment in overall digestion due to compromised rumen function is sufficient to cause milk and milk solids yields to be reduced by 10%.

This leads to the concept of feed conversion efficiency (FCE) as discussed by Beever and Doyle (2007). Whilst the pig and poultry industries, and to some extent the beef industry, have become aware of the importance of FCE as a major determinant of profitability, the dairy industry have been much slower to accept the concept. Average FCE on UK dairy farms is probably little over 1.2 kg milk/kg DMI yet levels of 1.4 to 1.5 kg/kg are achievable and some herds are at values of 1.6 kg/kg or above. Even a modest increase of 0.2 kg/kg equates to an extra 4 litres milk/cow/day and could result in an extra 800 litres per lactation without any notable increases in total feed use (see section 5 below). One major reason for poor herd FCEs is the provision of poor nutrition.

Helping avoid cows getting health problems, and as a consequence poor levels of FCE, requires careful feed management. The addition of cereal straw as a source of structural fibre has been proposed and some encouraging results have been reported when the straw of suitable length (30-80mm) is incorporated into the ration. But adding (ryegrass) straw either as a pellet (ground) or cube (coarse chopped) to cows grazing irrigated pasture showed no positive effects on milk production, milk composition, rumen pH or time spent ruminating per kg feed DM consumed (Wales et al, 2001), suggesting that method of straw inclusion in the ration could be important and the desired effects are unlikely to be achieved if free choice straw is provided from a ring feeder. The straw (minimum, 0.5 kg/day for a milking cow), needs to be provided along with other forages and supplements in a well mixed ration, and this applies equally to cattle at pasture fed a grazing mixed ration as a supplementary feed. When the straw is chopped during mixing to between 4 to 6 cm length, the results are almost instantaneous. The cattle will eat rather than reject the straw provided, manures become firmer, cows become more contented and milk and milk solids production increase.

There are other aspects of nutritional management which if adopted can bring sizeable gains. Early season grass can have protein levels which are between 25-35% higher than the cow’s requirements. This is a conundrum that many scientists are grappling with; needing lots of plant protein to optimise pasture growth but needing less to meet the cow’s needs. Feeding excessive amounts of protein promotes body condition loss as cows try to respond to produce more milk. Extra body condition loss occurring when attempting to rebreed cows doesn’t help with fertility and is one of the reasons why pasture-fed cows have lower than expected conception rates given their relatively modest levels of milk production. Strategic use of grazing mixed rations in such situations to avoid overfeeding of protein has been shown to deliver major financial benefits.

Finally the issues that too many cows face during the calving period need to be considered. Calving represents one of the biggest insults for cows and is a time when things can go seriously wrong. A recent survey to determine when dairy cows were culled from the herd, showed that from over 600,000 cows leaving nearly 6,000 herds during a 5 year period, 25% were culled during the first 60 days after calving (Minnesota DHIA). Clearly none of these could be considered to be voluntary cullings and it makes no business sense to have the costs and efforts of breeding cows, drying them off and then calving them, only to have to cull them before achieving their potential in the next lactation.

Current feeding strategies for dry cows are largely based on the perceived need to steam up prior to calving if good peak milk yields are to be achieved (Boutflour, 1928). This may have been appropriate for other breeds before the Holstein started to dominate but extra feeding, especially during the last three weeks of the dry period is now being seriously questioned (Drackley & Dann, 2008). There is no nutritional evidence to suggest cows should be fed ad libitum high energy rations at this time, especially when the likely outcome is storage of excess consumed energy as fat around specific organs including the uterus and the kidneys. This undoubtedly predisposes the cow to calving and post-calving issues, including dystocia, fatty liver and ketosis.

Part of the problem has been that it is perceived that appetites naturally decline towards calving date. Equally there was a widely held notion that dry cows do not over consume in respect to their total nutrient requirements if allowed ad libitum access to feed. But recent studies by Drackley et al (2005), have seriously challenged such views and led to the adoption of a feeding strategy to control feed intake during the dry period and most especially, minimise any decline in feed intake prior to calving. The impact of this new approach in terms of easier calvings and a much reduced incidence of peri-parturient health issues has been quite remarkable.

4. A system for Delivering Improved Dairy Cow Nutrition.

The Hi-Fibre Dairy system, recently launched by Keenans, is a direct result of on-farm experience and specifically reflects the nutritional science detailed above. It provides a series of unique nutritional solutions to optimise productivity and minimise health issues in all classes of dairy livestock, from growing heifers to dry cows and milking cows. It also applies to finishing beef cattle. Central to the system is the use of well-mixed rations containing adequate levels of all nutrients and most especially physically effective fibre to promote rumen function. Extensive use of home-grown forages is advocated, using both high quality silages and pasture as valuable sources of energy and protein, with strategic use of cereal straw, as an important source of physically effective fibre to promote good rumen and metabolic health. The system has six major components and is available to all farmers who own a Keenan mixer wagon. It is free of charge for 12 months after purchase of a new machine and then at an annual chargeable fee. Dedicated Keenan Rumans nutritionists operating in several countries deliver this service on-farm. It should be emphasised that they do not sell feedstuffs, but solely advise on optimal nutrition.

An important element in the delivery of the system is the Keenan Klassik mixer wagon, its functionality as well as the way in which it is used. Based on slowly revolving paddles with fixed knives in the base plus a top knife, the machine provides a gentle chopping and mixing action specifically designed to achieve well-mixed rations of optimal forage length. This compares with other machines, including vertical augers where the action of the central rotor with fixed knives is deemed to be more aggressive. Of equal importance is the loading order of the machine with respect to individual ingredients, overall load size in respect to total machine volume, speed of the tractor during mixing and time allowed for mixing. Many involved in the feeding of livestock believe that ration structure is unaffected by machine type or the way in which it is used. A recent study (Reynolds & Humphries 2008, not yet published) compared the same ration based on maize and grass silage, limited cereal straw plus energy- and protein-rich feeds for milking cows and showed statistically significant improvements in milk yield, milk protein content and milk protein yield when the ration was prepared with a Keenan Klassik compared with a vertical auger.

High importance is placed on rearing heifer replacements, with rations based on high levels of cereal straw recommended for housed animals. When at pasture, strategic supplementation to complement grazed pasture is advised, again with cereal straw incorporated to ensure adequate levels of physically effective fibre are consumed. Cereal straw also dilutes the nutrient density of the ration and provided it is well mixed and consumed without selection, will ensure more even intakes of nutrients across all animals. This significantly reduces the variation which often occurs in the growth and development within a cohort of heifers, reduces the spread in age at first calving and avoids some heifers becoming over-conditioned prior to calving (Hoffmann, 2007).

Issues relating to the nutritional management of dry cows have been briefly referred to in a previous section. For many years, it consisted of minimal attention being given after drying off until 3 weeks prior to calving, when additional energy was provided as part of the ‘steaming-up’ process. But the concept of ‘Far-off’ and ‘Close up’ dry cow management has not reduced the incidence of peri-parturient problems, of which assisted calvings, retained membranes, milk fever, ketosis, fatty liver and displaced abomasums all impact on cow health and subsequent lactational performance. It is not surprising that all of these problems have now been related to inappropriate nutrition during the dry period, and most interestingly during the early dry period, hitherto considered to be less important (Dann et al 2006).

The Keenan Controlled Energy:Hi Fibre strategy for dry cows provides a well mixed ration of low energy density but high in physically effective fibre by the inclusion of high levels of cereal straw (circa 50% DM basis). When fed throughout the whole dry period it impacts significantly on calving issues, with compelling on-farm evidence showing its value (see below). Additional to obvious improved ruminal effects, feeding a Low Energy:Hi Fibre ration throughout the dry period brings major metabolic benefits (Beever, 2006). This is principally due to an improved balance between growth hormone and insulin, two highly important but counter-acting hormones associated with milk production and maintenance of body integrity respectively (Drackley & Dann, 2008).

The next two elements of the Keenan Hi Fibre strategy relate to the nutritional management of the milking cow, dealing with housed and pasture fed cows respectively. In both situations, the practice of in-parlour feeding is positively discouraged for sound nutritional reasons. Instead, housed cows are fed a single mixed ration at all times, irrespective of days in milk or yield. No grouping of cows according to current yield is required. When combined with the Keenan Low Energy:Hi Fibre system for dry cows, Single group: Single ration feeding brings major gains in terms of improved FCE, with more milk for the same or less feed, better milk compositions and fewer health issues, especially sub-clinical rumen acidosis. Cows may approach peak production more slowly, but display improved persistency post-peak that results in at least the same amount of milk per lactation. Together with the improved post-calving intakes noted in cows fed Low Energy:Hi fibre rations during the dry period, body condition loss is markedly reduced, with important knock on benefits in cow fertility.

For pasture-fed cows, the major focus must remain on optimising the utilisation of all grass grown. Achieving optimal pasture utilisation requires good pasture management skills. Of equal importance however is optimal utilisation of consumed grass by the cow. Strategic supplementation with a suitably balanced grazing mixed ration can bring sizeable benefits. Not only does it allow possible shortfalls in grass supply to be filled, but more importantly, aims to correct inadequacies in grass composition. Chopped straw in a grazing mixed ration will fill any structural fibre shortage, always seen in early spring grass, whilst cereal energy, maize silage or high digestible fibre feeds will fill any energy supply issues. Provided the grazing mixed rations are well formulated such that they complement rather than replace grazed pasture, the benefits in terms of milk yield and lower total feed costs per litre can add significantly to overall farm profits. Grazing mixed rations are best offered prior to milking, ensuring adequate feed space to accommodate all cows.

The fifth element of the system requires the consistent delivery of well-mixed rations to all stock, containing the correct amount of physically effective fibre and homogenous throughout the whole feed-out. With the increased use of long forages, and especially significant amounts of cereal straw in some rations, the processes of chopping and mixing are crucial and need to be understood and correctly carried out by the farm operator. He/she must first receive suitable training in the general operation of the machine and the real purpose of producing quality mixed rations; namely consistent rations that limit diet selection while allowing animals to perform to their potential and remain healthy. Machine speed, as governed by tractor speed, feed loading order, load weight and mixing time are crucial to the outcome of the final mix. On too many occasions, rations that appear ideal on paper, under-perform due to one or more simple issue such as incorrect loading order or an overfilled machine.

The final element of the system is measurement of animal performance. Ration performance monitoring (RPM) is undertaken when Keenan nutritionists visit the farm and includes measurements of number of cows, average days in milk, total milk yield and milk composition as well as amount, composition and cost of the ration being fed. The acquired on-farm data allows herd FCE to be determined, along with the proportion of home-grown feed being used and total feed costs per litre milk produced. We contend that this measure is much more relevant than others such as margin over purchased feeds (MOPF) which do not reflect total feed usage and costs. The first RPM is taken when the farm enrols onto the system, with subsequent measurements approximately 90 and 365 days later although measurements can be undertaken more frequently according to the farmer's wishes. Whilst annual herd measurements of FCE allow gross performance and progress to be determined, shorter-term measures can be valuable in diagnosing problems and allowing timely intervention strategies to be implemented. These could include ration formulation changes, especially when different ration ingredients have to be introduced (eg changing silage clamps from first cut to second cut) or simply alterations to cow management, where aspects such as feeding infrastructure (to minimize feed wastage) or cow housing (easier access to feed bunk for all cows) could be important in respect to overall herd performance.

5. Empirical Analysis of the Impacts of Applying the System.

The objective of the nutritional advice offered to dairy farmers with new machines is to assist them to use their recent acquisition to the best effect and to enable them to increase nutritional efficiency in terms of FCE. These farmers are visited regularly and requested to return detailed statistics which enable any changes in FCE and margin per cow per day to be measured over the 12 months after they begin to receive the advice. Not all farmers accept the advice; they either make their own independent decisions or accept advice from different commercial sources. However, evidence of consistent significant improvement has been displayed in both France and the UK in both 2006 and 2007.

5.1 Impacts on FCE and margins per cow.

The logic of the economics is very simple. If DMI per cow averages 20 kg per day an FCE of 1.2 kg milk/kg DMI delivers 24 kg (litres) of energy corrected milk. If by improved ration management FCE can be raised to 1.3 kg/kg the average daily yield at the same DMI will be raised to 26 litres. The value of that will depend on the producer price of milk. In the UK in 2006 the average producer price of milk was just below 18 ppl and in 2007 just below 21 ppl. At these prices the extra 2 litres would be worth 36 and 42 pence per day per cow on the gross and net margins, assuming that the nutritional advice did not entail additional costs per kilo of DMI. Given that the herds we are studying have already invested in a feed mixer wagon, there is no additional machinery or labour cost to adopting the nutritional programme. Given also that the system aims to use home-grown feeds to the maximum extent there is every likelihood that cost per kilo of DMI will be lower than an alternative ration of the same size. It is also significant, as will be seen from the data below, that many enterprises actually reduce the quantity of DMI while raising yields and FCE.

Table 1 indicates the average FCE improvements in both 2006 and 2007 for French and UK herds receiving nutritional advice after buying a feed-mixer wagon. It also shows the change in average 'adjusted' margin per cow per day associated with the FCE changes. Because the comparisons involve the position at the end of 12 months with that at the beginning[2], it would be quite inappropriate to credit the nutrition with gains (losses) which occur due to increases (decreases) in the producer's price of milk or any changes in the price of particular feed ingredients. For that reason the 'adjusted' margin change is measured by holding prices of milk and feed ingredients at their beginning of year levels, and allows only for milk yield and DMI changes.

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[2] Because most herds do not return records exactly 12 months apart, the data are actually for gaps of 12 months plus or minus 30 days.

Table 1. The Response of Cohorts French and UK Dairy Farms to Nutritional Advice, 2006 and 2007.

	France		**UK**	
	2006	2007	2006	2007
Number of herds.	149	143	108	131
Av. FCE increase *(standard deviation)*	0.18 *(0.10)*	0.18 *(0.18)*	0.10 *(0.12)*	0.09 *(0.12)*
Av. adjusted margin increase/cow/day *(std devn.)*	89.8 cents *(84.0)*	85.0 cents *(91.0)*	33.0 pence *(42.4)*	24.5 pence *(44.36)*
Change in average yield (litres/day)	2.49	2.53	1.61	0.95
Change in DMI (kg/cow/day)	-1.02	-0.98	-0.30	-0.55
Change in margin per 0.1 change in FCE.	49.9 cents	47.2 cents	33.0 pence	27.2 pence

The groups of producers in 2007 were completely different from those in 2006, but the reactions to the nutritional advice were consistent between years. French producers had little opportunity to increase the amount of milk quota, or therefore milk output and strove to improve efficiency through increasing FCE by reducing DMI and cow numbers. In both years the French samples averaged FCE increases of 0.18 kg/kg, which is substantial from an average base level of 1.17 kg/kg in 2006 and 1.13 kg/kg in 2007. This enabled them to increase yields by an average of 2.5 litres per cow per day, while at the same time reducing DMI by approximately 1 kg/cow/day.

In the UK the pattern of response to the nutritional advice was similar to that in France, but was muted. The FCE increase of the two cohorts in 2006 and 2007 was about 0.1 kg/kg; the yield increase was 1.61 litres per cow per day in 2006, but only 0.95 litres/day in 2007, a year when forage conditions were poor. Nevertheless in the UK also there were reductions in DMI in both years.

It is striking to observe how close the margin changes per 0.1 kg/kg increase in FCE are to the theoretical argument set out above. For the UK the increases were 33 pence/cow/day in 2006 and 27.2 p/cow/day in 2007. With an exchange rate of around € 1.47:£1 in both years the adjusted margin gains for the French cohorts were approximately equivalent to 33.9 and 32.1 pence per cow per day /0.1 kg/kg increase in FCE. Given higher producer milk prices in France than the UK, these are slightly lower than might have been expected but in line with the theory.

The averages do hide considerable variation in performance within the four producer cohorts, which is not entirely surprising given the range of specific factors which affect individual herds. This is revealed by the standard deviations for FCE and adjusted margin change as recorded in Table 1, and by Figures 2 and 3 showing the distribution of adjusted margin changes for France and the UK in 2006.

Figure 2. Distribution of Adjusted Margin Changes, France 2006 *(cents/cow/day)*

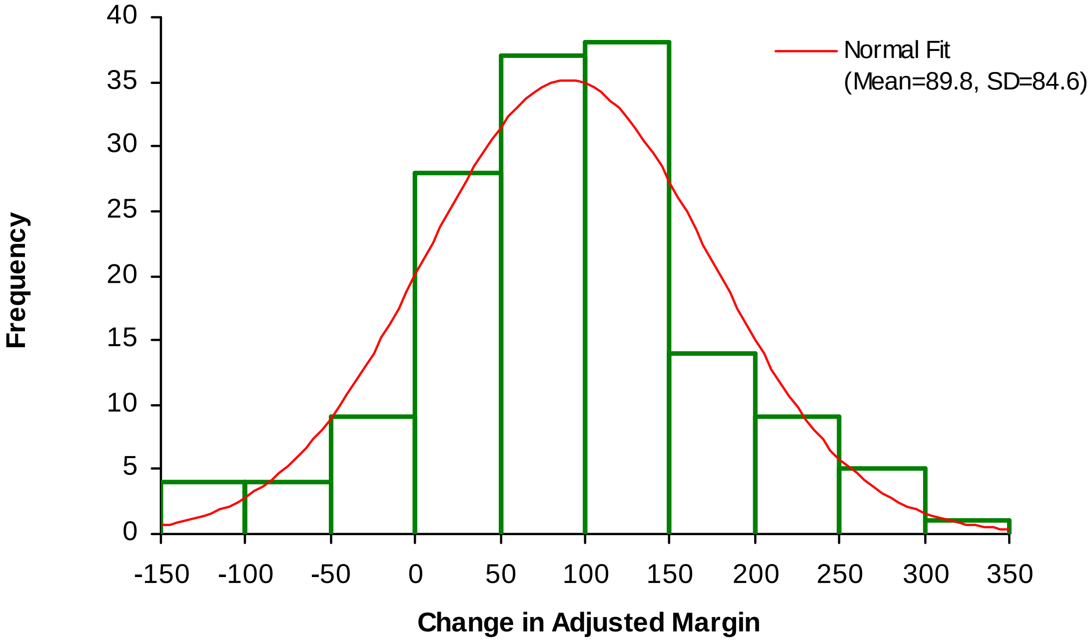
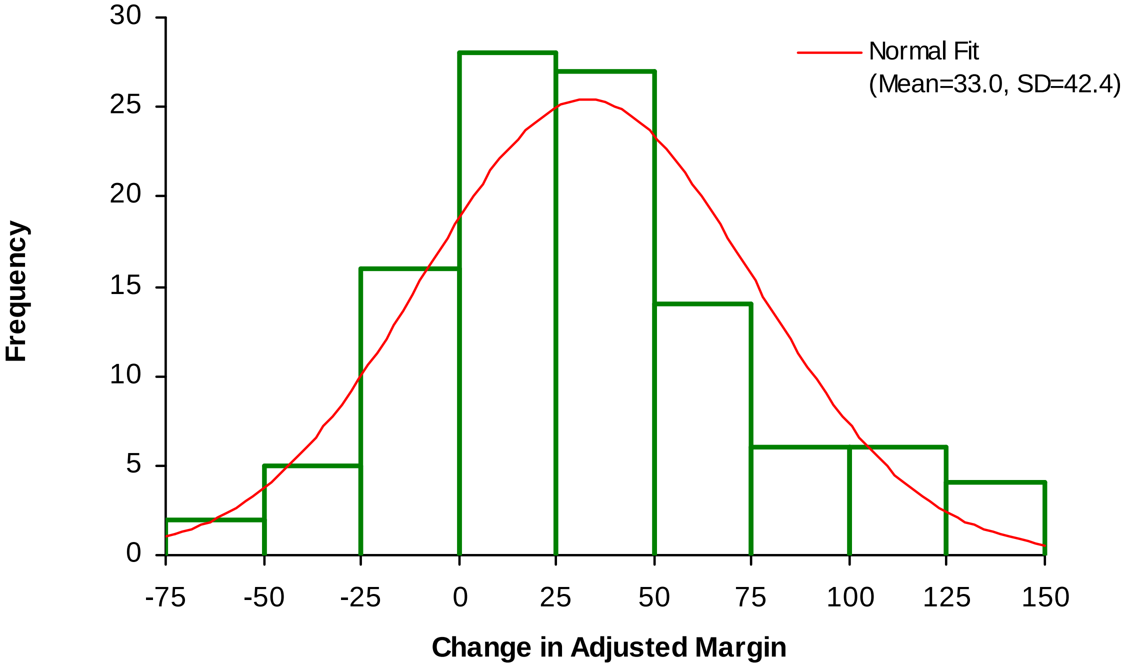


Figure 3. Distribution of Adjusted Margin Changes, United Kingdom 2006 *(pence/cow/day)*



The strength of the relationship between increases in FCE and margins is shown in regression results presented in Table 2. The parameter attaching to FCE change shows the linear increase in adjusted margin per unit change in FCE. Thus for the UK in 2006 an increase in FCE of a whole unit was estimated to raise adjusted margin by 300.6 pence/cow/day or 30 pence/0.10 kg/kg increase in FCE, almost exactly in line with expectations from the simple theoretical model. The UK result in 2007 and results for France in both years also support the theory.

Table 2. Regression Coefficients of Adjusted Margin/cow/day Change on FCE Change, France (cents) and UK (pence), 2006 and 2007.

	Intercept	**FCE change**	**R^2**	**F statistic**
France 2006	**11.3** *(1.47)*	**441.3** *(12.97)*	**0.53**	**168.1**
France 2007	**-17.7** *(6.60)*	**572.7** *(29.40)*	**0.73**	**379.4**
UK 2006	**2.76** *(0.97)*	**300.6** *(18.25)*	**0.72**	**271.4**
UK 2007	**-5.58** *(2.45)*	**341.4** *(15.76)*	**0.78**	**469.0**

Figures in parentheses are "t" values.

From the perspective of the possibilities of reducing the dairy sector's greenhouse emissions it is apparent from the above results that there is scope for quite rapid improvements in nutrition which enable the same quantity of milk to be produced with less cows than at present and with somewhat less feed. By increasing milk yields, the methane, nitrous oxide and manure burden per unit of milk output is reduced. FCE levels in the UK and France are still modest with respect to the highest achievable levels.

5.2. The environmental impact of improved Feed Conversion Efficiency.

All systems of dairying can be considered to be high polluting in terms of carbon and nitrogen emissions. This occurs irrespective of whether the cows are housed and fed for higher milk yields, or grazed at pasture, where milk yields are generally lower. Collective losses of carbon, in faeces and urine, and as carbon dioxide and methane in expired air, can account for 70% of total carbon inputs in feed whilst nitrogen losses in faeces and urine can be of a similar magnitude (Castillo et al, 2001). This translates into overall maximum efficiencies of transfer of dietary carbon and nitrogen into milk of between 25 and 30%, but in many instances, the achieved levels of efficiency can be much lower.

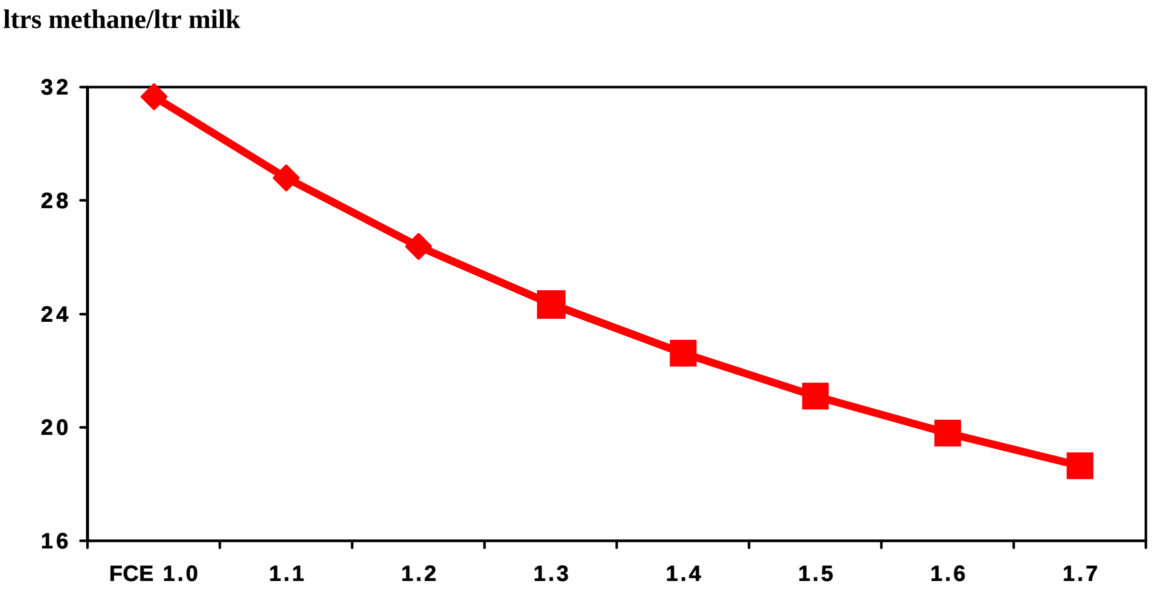
Further to these losses, the costs of rearing replacement heifers add to the total carbon and nitrogen burdens associated with milk production, and when compared with the animal's lifetime production of milk, increase the burden per cow. Against such costs, all animals that are culled from the herd and subsequently enter the food chain can be considered as a small potential credit in terms of overall emissions, but this will not apply to animals that die on the farm, those costs having to be borne by any milk produced during their lifetime.

Several strategies to improve the overall efficiency of conversion of dietary carbon and nitrogen into milk carbon and nitrogen can be advanced. Improving cow longevity, by increasing the number of successful lactations completed prior to removal from the herd, inevitably reduces the number of replacement heifers required each year, with a consequent reduction in the total carbon and nitrogen burdens associated with heifer rearing needing to be covered by the annual levels of milk production. Equally ensuring a higher percentage of heifer calves intended as herd replacements actually achieve a successful calving at or around two years of age will reduce the carbon and nitrogen burden. Further to these effects, improving lifetime milk production from cows will have a positive impact, allowing the summated carbon and nitrogen costs, especially with respect to daily maintenance costs to be shared across extra litres of milk. But undoubtedly the most significant and possibly most immediate impact on reducing carbon and nitrogen burdens can be gained by improving feed conversion efficiency, particularly when cows are milking.

To illustrate this point, the impact of improving FCE on methane emissions has been considered in more detail, although it is likely that changes of similar magnitude could be achieved with respect to other carbon as well as nitrogen excretions. The daily quantity of methane produced by a dairy cow depends upon the amount of ration DM consumed as well as ration composition in terms of overall digestibility and the relative proportions of starch and fibre. The most comprehensive data-set of quantitative measurements of methane emissions by dairy cows in the UK was obtained by The Centre for Dairy Research at The University of Reading. This formed the basis of an extensive analysis of energy metabolism undertaken by Cammell et al, (2000) and Kebreab et al (2003), from which a number of important revisions of energy feeding standards were proposed. Using a subset of this data, comprising 204 individual cow measurements, methane production was found to average 31.7 litres per kg feed DM consumed, with most values ranging between 27 and 34 litres/kg DM. Using this mean value, the impact of improving FCE on methane production per litre milk produced has been determined and is illustrated in figure 4.

As expected, at an average FCE of 1.0 kg milk/kg feed DM, methane output per litre of milk, without taking account of non-milk production costs such as heifer rearing, amounted to 31.7 litres/litre milk. With increasing FCE, which as indicated earlier results in more milk for the same amount of feed intake, methane load fell progressively to 24.4 litres/litre milk at an FCE of 1.3 kg/kg, equivalent to a 23% reduction, and by a further 24% to 18.6 litres/litre at an FCE of 1.7 kg/kg. Given it is possible in most farm situations to improve FCE by 0.3 kg/kg over a relatively short period of time when adopting the Keenan Hi-Fibre Dairy system, it follows it is possible to claim that this new approach to feeding dairy cows could potentially reduce methane emissions per litre milk produced by as much as 20%. In contrast, increasing feed intake increases the total amount of methane produced and whilst some expected gain in milk production will occur as a consequence of feeding more nutrients, the overall reduction in methane output per litre was estimated to be much less than that achieved by improving FCE. Feeding an additional 3 kg feed DM/day would increase daily methane production by over 90 litres/cow/day yet only reduce predicted methane emissions (litre/litre milk) by approximately 12%.

Figure 4. Impact of improved FCE on methane production (ltrs/ltr milk).



5.3. Impacts on Animal Health.

An on-farm study was conducted in France, Ireland, Sweden and UK during 2006/07 to examine the impact of the Keenan Low Energy:Hi Fibre strategy for dry cows on animal health issues. A total of 277 farms were involved and according to estimated average annual herd size for each farm, it was estimated that a total of 27,470 cows were included. Average herd size ranged from 53 (France) to 189 (UK) cows, with average herd yields ranging from 7191 (Ireland) to 9452 (Sweden) litres/cow/year. Herds in the study were above national average in both herd size and yield. That is significant insofar as intensively managed herds may have a different, and often increased pattern of health problems relative to the norm.

A condition of enrolment to the study was that herds had adopted the Keenan Low Energy:Hi Fibre system for dry cows for a minimum of 6 months. It was also essential that suitable records were available in respect to the incidence of metabolic disorders during respective peri-parturient periods before and after adoption of the new system. The results of the study are summarised in table 3.

Table 3. The incidence of metabolic issues recorded on 277 farms in 4 countries.

	France	**Ireland**	**Sweden**	**UK**	**Total**	**Incidence per 100 cows**
Herds	100	111	21	45	277	
Cows per herd	53	97	138	189		
Total cows	5300	10767	2898	8434	27470	
Cows affected;						
Assisted calvings;						
Before	2120	861	206	1096	4283	15.6
After	848	431	131	589	1999	7.3
Milk fever;						
Before	583	646	128	1349	2706	9.9
After	133	215	67	270	685	2.5
Retained membranes;						
Before	875	969	188	902	2934	10.7
After	477	431	128	228	1264	4.6
Ketosis;						
Before	477	215	171	953	1791	6.6
After	106	0	70	211	387	1.4
Displaced abomasums;						
Before	239	107	49	337	732	2.7
After	53	0	20	31	104	0.4

For the five diseases monitored in each of the four countries, adoption of the Keenan Low Energy:Hi Fibre system resulted in a significant reduction in the incidence of metabolic disorders. Retrospective data from the peri-parturient period prior to adoption of the system showed a combined incidence rate of assisted calvings of 15.6 cows per 100 calved, with 9.9 per 100 cases of milk fever, 10.7 cases of retained membranes, 6.6 cases of ketosis and 2.7 displaced abomasums per 100 cows. Collectively these amounted to 45.4 metabolic cases per 100 cows although this does not infer that 45 cows in every 100 were affected as some cows may have suffered more than one metabolic insult. Such a high figure is alarming for two reasons. First it is a measure of the size of the problem in the dairy industry generally and of how such issues may be having serious ‘knock-on’ effects in respect to the next lactation, as well as the ability of cows to rebreed. Secondly, it illustrates a major gulf between opinion and fact. Most farmers are of the opinion that their herds don't have many of those issues; but the facts seem to tell a quite different story.

As a result of adopting the new feeding strategy, the overall incidence of metabolic insults fell to just 16.2 cases per 100 cows calved. Most notable were the reductions in displaced abomasums (85.6% fewer cases), ketosis (78.7%) and milk fever (74.8%). In respect to individual countries, France had the highest incidence of assisted calvings and retained membranes, which interestingly are known to be inter-related. After adoption of the new system, incidence rates fell by 60 and 45% respectively. The UK had the highest incidence of milk fevers (16%), but this was reduced to just 3.2% after adoption of the system, an 80% reduction. Along with France, the UK also had the highest incidence of ketosis, but both countries showed an average reduction of 78%. Again France and UK had the highest incidence of displaced abomasums (circa 5 for every 100 cows calved), with the number declining by over 80% after adoption of the new system.

The estimated costs of such problems are difficult to rationalise, but include losses in terms of compromised milk production, poorer fertility and accelerated culling. The savings made in these made by adopting the Controlled Energy:Hi Fibre diet can be assumed to be significant.

6. Concluding Remarks.

A majority of dairy farmers have the opportunity to raise profitability by adopting the nutritional practice embodied in the Keenan Controlled Energy:Hi Fibre ration. The data presented shows that on average producers in the UK and France adopting this diet increase Feed Conversion Efficiency significantly in the first year on the system. In France the improvement in FCE in both 2006 and 2007 was 0.18 kg/kg, while in the UK it was nearly 0.10 kg/kg in both years. The value of these gains depends on the producer milk price, which has become more volatile, but in the UK was around 30 pence per cow per day, while in France it was around 85 cents/cow/day. Over a full lactation averaging 305 days, gains in FCE were worth over £90 per cow in the UK and around €260 per cow in France. These gains were made while actually reducing DMI on average in the study groups for both countries. When the producer price of milk and/or feed price is higher than in the surveyed period the gains will be higher as at the time of writing.

The full economic gains from adopting the Controlled Energy:Hi Fibre ration exceed those arising simply from increases in FCE. The animal health benefits recorded in France, Ireland, Sweden and the UK have been substantial, with savings in veterinary costs, reduced involuntary culling and improved fertility. Many herds experience substantial problems in these areas, and it is striking what improvements are shown to be possible. No specific average additional economic value has been computed for the improvements observed, but they are clearly significant.

In addition scientific evidence shows that improving FCE is associated with reductions in methane emissions per litre of milk produced. This is an extra external benefit from the nutritional improvement, although the levels of emission will always be significant.

Feed Conversion Efficiency emerges as a most important measure of dairy farming efficiency, and is one that extends to beef finishing and rearing as well. Raising FCE is an indicator of improved performance in several important dimensions simultaneously; profitability, animal health and greenhouse gas emissions. It is a valuable benchmark indicator to apply to different production systems. In 2006 the UK average FCE for the 108 dairy herds in the study was only 1.19 kg/kg. At the beginning of the year 6 producers were achieving over 1.4 kg/kg, but by the end of the year 23 were meeting that standard, with highest on 1.57 kg/kg.

In France only 9 out of 149 herds started the year with FCEs above 1.4 kg/kg, but at the end 54 achieved this level and above. This shows that substantial improvement is rapidly possible in the performance of dairy herds by more widely adopting the Hi-Fibre nutrition system.

Most dairy herds currently operating with an FCE of less than 1.25 could make significant improvements in profitability by focusing on supplying the hi-fibre ration that nutritional science has determined is best for the efficient feeding of healthy cows and cattle generally. A particularly important aspect of this which emerges is the desirability of a Controlled Energy:Hi Fibre diet for dry cows preparing for calving. This has particularly beneficial effects on cow health after calving as revealed by the animal health study.

Given the prospects of more international competition for European milk and dairy product markets, it is important that the dairy sector improves its technical and economic efficiency, and that more herds move closer to the frontier of what can be best achieved. Improved animal cow nutrition, as revealed in this paper, is a critical step for many producers if they are to achieve sustainable levels of competition and efficiency and move closer to those operating at the highest levels, whatever system of production they are on.

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