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Organic growing pigs in pasture systems – effect of feeding strategy and cropping system on foraging activity, nutrient intake from the range area and pig performance

Økologiske slagtesvin på friland – effekt af foderstrategi og afgrødesystem på fourageringsaktivitet, næringsstofindtag fra udearealet samt tilvækst og foderudnyttelse

Master of Science Thesis by
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Summary

Production of organic growing pigs is characterized by indoor housing with access to outdoor concrete yards and feeding high amounts of supplementary feed based on grain and imported protein feed. However, this is not in accordence with the organic principles, which insist on optimization of nutrient recirculation, use of local renewable resources and animals being able to perform normal behaviour.

The overall aim of the project was to contribute to development of an eco-efficent and trustworthy organic production system based on free-range growing pigs in pasture systems. The point of departure was to integrate the unique innate ability of pigs to forage above and below ground as a resource in the farming system. It was hypothesised that foraging in the range area could pose an important contribution to nutrient supply of growing pigs.

Foraging activity, nutrient intake from the range area and pig performance were investigated in 36 growing pigs foraging on alfalfa or grass and fed either a standard organic feed mixture (HP: high protein) or a grain mixture with 52% of crude protein recommendations (LP: low protein) from an average live weight of 58 kg to 90 kg in three replicates. Pigs were fed 80% of energy recommendations and had access to a total of 154 m^2 pig^{-1} during the 40-days experimental period from September to October 2013.

Rooting activity was significantly affected by feed and forage crop interactions but the effect of protein level was more pronounced in grass paddocks with LP pigs rooting 44% of all observations and HP pigs 19% compared to 28 vs. 16% for pigs foraging on alfalfa. Protein level did not have a significant effect on grazing activity but pigs on alfalfa grazed significantly more than pigs on grass (10 vs. 4% of all observations).

Based on crop samples alfalfa intake tended to be significantly affected by protein level with a daily dry matter intake in LP and HP pigs of 470 and 330 g pig^{-1}, corresponding to an energy intake of 0.35 vs. 0.32 Danish Feed Units. Alfalfa crude protein and lysine intake was higher in LP pigs compared to HP pigs but the difference was not significant. Compared to grass paddocks available earthworm crude protein was higher in alfalfa paddocks (84 vs. 55 g pig^{-1} day^{-1}) indicating the potential of contributing to protein requirements of organic growing pigs.

Daily weight gain and feed conversion ratio were significantly affected by feed and forage crop interactions. LP treated pigs had 33% lower daily weight gain compared to HP pigs (589 vs. 878 g) and 31% poorer feed conversion ratio (3.75 vs. 2.59 kg feed kg^{-1} weight gain) in grass paddocks, whereas in alfalfa paddocks LP pigs only had 18% lower daily weight gain compared to HP pigs (741 vs. 900 g) and 14% lower feed conversion ratio (2.95 vs. 2.54 kg feed kg^{-1} weight gain). LP pigs foraging on alfalfa used 169 g less feed crude protein compared to HP pigs, whereas in grass paddocks it was 109 g less, indicating the nitrogen efficiency of the systems.

Regarding development of eco-efficient forage based system for organic growing pigs, further investigations are needed, in particular on suitable forage crops, energy requirements for activity and social interactions and effect of group size on foraging behaviour.

Preface

The present thesis constitutes the completion of my master in Agrobiology - Animal health and welfare at the Faculty of Science and Technology, Aarhus University. The thesis work was prepared in connection with the department of Agricultural Systems and Sustainability at the Institute of Agroecology, Research Centre Foulum, Aarhus University. The experimental work was conducted from September to October 2013 at the research station Foulumgaard.

The thesis was developed within the framework of the ICOPP project (Improved Contribution of local feed to support 100% Organic feed supply to Pigs and Poultry). ICOPP is a CORE Organic II research project, which includes 15 partner countries across Europe. The project is supported by the European Union and is coordinated by ICROFS (International Centre for Research in Organic Food Systems).

With the thesis I hope to stimulate interest in people who are keen on developing eco-efficient free-range pasture systems for organic growing pigs - key words are nutrient recirculation, local renewable resources and natural pig behaviour. Clearly, there is an untapped potential of using the innate ability of the pig to explore and forage and to integrate this into the organic farming system.

It is of great importance for me to thank those who have been involved and helped me along the way:

The 36 growing pigs that constituted the foundation for the preparation of this master thesis. It has been of great value to work with them and to observe and notice the details of their multifaceted behaviour.

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1. Introduction

According to IFOAM (International Federation of Organic Agriculture Movements) organic agriculture is: *"A production system that sustains the health of soils, ecosystems and people. It relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects. Organic Agriculture combines tradition, innovation and science to benefit the shared environment and promote fair relationships and a good quality of life for all involved"* (IFOAM 2013a). Organic agriculture is based on the principles of Health, Ecology, Fairness and Care (IFOAM 2013b). Among others, these basic principles focus strongly on recirculation of nutrients in the farming system and use of local renewable resources. In addition, emphasis is on providing animals with opportunities to perform natural behaviour, getting feed adapted to their physiology and live in a natural environment (IFOAM 2013b; Lund 2006). In Denmark organic pig production is regulated by the EU legislation (Council regulation, EC 2007) as well as the Danish trade agreements (Organic Denmark 2013).

Organic pig production in Denmark represents 0.5% of the total pig production (Agriculture and Food 2013). In 2012 approximately 88,000 organic finishing pigs were slaughtered (Friland 2012) and the vast majority of these pigs were born in pasture systems. However, at weaning after 7-8 weeks (Organic Denmark 2013) organic growers are typically housed in stables with access to outdoor concrete yards (Hermansen *et al.* 2005). The main factor underlying this practise is environmental concern, which is related to high nutrient input from supplemental feed, in particular nitrogen, contributing to increased risk of nutrient losses (Eriksen & Kristensen 2001; Sommer *et al.* 2001; Hermansen *et al.* 2004; Quintern & Sundrum 2006). Hence, systems with growing pigs on pasture carry a high risk of nutrient losses since only 30% of feed N input is retained in pigs until slaughter (Eriksen *et al.* 2006). N-surpluses per hectare have been found to range between 270 kg N with 71 pigs ha^{-1} (Salomon *et al.* 2007) and 388 and 507 kg N for restrictive and *ad libitum* fed pigs respectively with 91 pigs ha^{-1} (Eriksen *et al.* 2006).

Thus, in practise organic pig production, like conventional, is based on feeding high amounts of supplementary feed containing cereals and oilseed products (Edwards 2003; Kongsted *et al.* 2013). Typically, the majority of the protein part of the feed, e.g. organic soy bean meal, is imported from Italy or China where the transport in terms of carbon footprint (394 g CO_2 kg^{-1} feed) is approximately the same as the carbon footprint for cultivation and processing (326 g CO_2 kg^{-1} feed) (Mogensen *et al.* 2011). In addition, this leads to occupation of land resources, competing with resources for human food production (Hermansen *et al.* 2013).

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Organic pig production clearly has an inherent dilemma between environmental concern on one hand and animal welfare on the other. The high import of protein feed as well as keeping pigs indoors on concrete floors is far from in accordance with the organic principles, which insist on a high level of self-sufficiency and animals being able to perform natural behaviour.

The currently typical system used for production of organic finishers seems to be neglecting the potential of pigs´ natural foraging behaviour. Andresen (2000) points to a shift of perspective by thinking of pigs in terms of their capabilities rather than being passive receivers. Bearing in mind that pigs have evolved as opportunistic omnivores with a unique capacity to forage above as well as below ground (Andresen 2000; Beattie & O´Connell 2002), it seems obvious to try and increase forage uptake from the areas they occupy. In wild boar, feral pigs and domestic pigs kept in semi-natural environments, foraging consist of a mixture of grazing and rooting, whereby a large variety of feed items, such as grasses, fruits, roots and invertebrates, are ingested (Edwards 2003).

From studies on direct foraging of ringed sows it has been documented that they are able to take up around 40-65% of energy requirements from clover-grass (Sehested *et al.* 2004; Fernández *et al.* 2006) and 50-60% of maintenance requirements (Rivera Ferre *et al.* 2001). Regarding direct foraging of growing pigs the literature is sparse. Mowat *et al.* (2001) reported a low intake from direct foraging of clover-grass for 50-60 kg pigs fed *ad libitum* with concentrate, corresponding to 4% of daily organic matter intake. Iberian fattening pigs in the Dehesa had a higher intake of grass corresponding to 11% of daily dry matter intake, but without any supplemental feed (Rodrígez-Estévez *et al.* 2009). There are more studies on the effect of allocated roughage. Intake of fresh clover-grass, clover-grass silage, barley-pea silage and fodder beet has been found to range between 2-19% of dry matter intake in 30 kg pigs (Carlson *et al.* 1999; Kelly *et al.* 2007; Jørgensen *et al.* 2012). Furthermore, Danielsen *et al.* (2000a) reported an intake of fresh grass or silage by 25 kg pigs amounting to 4-6% of total energy intake depending on *ad libitum* versus restricted feeding regimes.

Altogether, literature on direct foraging of growing pigs is limited and in particular knowledge of food intake below ground is almost non-existing. However, a large potential of nutrient contribution from the soil flora and fauna is expected (Edwards 2003). Under Northern European conditions clover grass fields have been found to contain between 200-359 earthworms per m^2 (depth of 20-30 cm) (Eekeren *et al.* 2010; Holmstrup *et al.* 2011). In addition, Bassler *et al.* (2000) reported earthworms (mainly *Eisenia foetida*) containing approximately 610 g crude protein per kg dry matter and Pokarzhevskii *et al.* (1997) found different earth worm species to contain a mean of 43.8 and 9.2 mg lysine and methionine respectively per g dry matter.

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In order to increase voluntary forage intake, pigs´ motivation for foraging is crucial. This is influenced by a number of factors of internal and extern origin (Kyriazakis 2003). Examples are: age (Edwards 2003), supplemental feed (Day *et al.* 1995; Danielsen *et al.* 2000a; Beattie & O`Connell 2002), forage crop preference (Rachuonyo *et al.* 2005) and management (Stern & Andresen 2003). Furthermore, to increase ingestion and utilization of forage crops, factors such as forage availability and nutritional value including fibre composition are important together with pig characteristics (Edwards 2003). In terms of supplemental feed, experiments have shown that pigs are able to select a diet balanced in protein when given a choice (Kyriazakis & Emmans 1991). There are indications that when limiting protein or amino acid content of an otherwise balanced ration, pigs respond by increasing food intake in order to compensate (Kyriazakis 1994). Regarding forage crop preference, pigs have been reported to prefer grazing alfalfa compared to grasses (Rachuonyo *et al.* 2005), which has also been confirmed from previous experiences (Kongsted 2013). In addition, alfalfa produces high yields (DLF Trifolium 2013) and has received considerable attention as a source of roughage for pigs (Blair 2007). The challenge is that growing pigs are less able to deal with bulky fibre-rich feed compared to adult pigs, due to the former having a reduced capacity of the intestinal tract (Kyriazakis & Emmans 1991).

Forage based systems might also be able to benefit organic farmers economically, as they are likely to reduce feed costs (Rachuonyo *et al.* 2005), which is important since feed can account for 50-60% of total production costs (Zollitsch *et al.* 2004). Hence, the farmer is not depending on fluctuating food prizes on the world marked. Furthermore, forage based systems are beneficial in terms of reduced costs of buildings and equipment compared to indoor housing. However, outdoor systems are also labour demanding and require a larger part of the crop rotation compared to indoor systems (Tvedegaard 2005).

In terms of energy as well as protein forage crops are significant potential sources (Andersson & Lindberg 1997). Hence, foraging above and below ground may be able to some extent to mitigate one of the primary challenges when feeding organic monogastric animals, which is to fulfill amino acid requirements. According to the EC organic regulation, from the 31st of December 2014, feedstuffs for organic pigs must be 100% organic (The Danish Agrifish Agency 2012).

In relation to marketing, systems with direct foraging are likely to be in accordance with consumer expectations, which among others, are related to secondary product qualities such as animal welfare and environmental protection (Hermansen 2003; Edwards 2005). Accordingly, the pork produced is suggested to be a high value product capable of justifying premium prizes.

1. Introduction

Overall societal aim

The overall societal aim of the project is to contribute to development of an eco-efficient and trustworthy organic production system based on free-range growing pigs. Hence, there is a potential in terms of pigs becoming an integrated and functional part of the whole farming system, providing not only food for humans but also ecosystem services (e.g. optimized nutrient recycling, diverse crop rotations, weed control, energy crops for biogas). The focus is on gaining knowledge of the potential of using pigs` innate ability to forage above and below ground as a resource in the farming system.

Overall scientific aim

The overall scientific aim of the project is to identify factors important for nutrient availability as well as nutrient intake and utilization in growing pigs foraging in pasture systems.

Specific objectives

The specific objectives are to examine effects of cropping system (alfalfa or grass-clover) and feeding strategy (protein allowance) on foraging behaviour, forage intake, growth and feed conversion rate.

Working hypotheses

The working hypotheses in the project are as follows:

- Pigs restricted in protein will exhibit increased foraging behaviour in the range area compared to pigs receiving a protein level according to recommendations.
- Pigs restricted in protein are expected to have a higher intake from direct foraging in the range area and by that to some extent compensate as reflected in growth and feed conversion ratio compared to pigs fed a protein level according to recommendations.
- Pigs foraging on alfalfa are expected to have a higher forage intake and a performance, which is less affected by protein restriction compared to pigs foraging on grass.

Outline of thesis

The objectives of the thesis are investigated by a literature review identifying factors important for foraging behaviour, forage availability as well as forage intake and utilization. In addition, methods to estimate forage intake are presented. The literature review is followed by a description of the performed experiment scrutinizing the hypotheses and a presentation of the results. Finally, knowledge from the literature review and additional information from other studies are combined in a discussion of the obtained results.

2. Literature review

2.1 Natural habitat and diet of wild boar and feral pigs

The domestic pig evolved from the wild boar (*Sus scrofa)*, an opportunistic omnivorous animal capable of adapting to various conditions (Edwards 2003; Wilcox & Van Vuren 2009). Although domestic pigs has been bred for many generations and the modern commercial breeds are housed indoors and fed concentrate feeds, they have retained many of the behavioural patterns related to natural foraging (Edwards 2003). Today, wild boar and feral pigs are present in many parts of the world and can provide us with unique knowledge of pigs` natural foraging behaviour and feed preferences as well as their adaptation abilities.

The European wild boar show migratory behaviour and also feral pigs are excellent colonizers as they are spread out over large parts of the world (Wood-Gush *et al.* 1990; Andresen 2000). The ability to thrive in a large number of habitats may be ascribed to the wild pigs´ dietary flexibility (Andresen 2000; Schley & Roper 2003). Under natural conditions, habitats preferred by wild boars and feral pigs are forest and scrub bush areas surrounding water holes, forests nearby rivers and streams or swamps and marshes. Open areas adjacent to forest or dense bush are preferred for activity, in particular if these areas are partly grassland (Graves 1984). Pigs have home ranges as opposed to territories and variations in size are a function of food availability (Graves 1984; Edwards 2003). A typical home range for a feral sow is 10 km^2 but with variations according to locality (Barett 1978).

Under natural conditions wild boar and feral pigs live on a very diverse diet, which is largely determined by the availability of different feed items. This is again depending on season, year and geographical region (Schley & Roper 2003; Wilcox & Van Vuren 2009). Vegetable feed is preferred to animal food, the former constituting the bulk of feed ingested. In wild boars inhabiting Western Europe vegetable feed has been found to comprise more than 90% of the diet (Schley & Roper 2003).

Energy rich plant sources such as mast crops (e.g. acorn, beechnuts, chestnuts) are the preferred food and the availability to a large extent determine amount and type of other plants in the diet during fall and winter (Graves 1984; Schley & Roper 2003). Of other food items ingested are fruits, (e.g. berries, wild apples, figs, grapes) sedges, common reed, olives, fungi and seeds of e.g. pine. During summer when preferred food becomes less available, pigs are feeding primarily on various grasses and other green plant material, roots, tubers and seeds of different plants (Hanson & Karstad 1959; Everitt & Alaniz 1980; Graves 1984; Dardaillon 1986; Schley & Roper 2003; Adkins & Harveson 2006; Bueno *et al.* 2009; Wilcox & Van Vuren 2009). Agricultural crops are reported to represent an important component of the wild boar diet in some regions of Western Europe, with maize as the preferred crop (Schley & Roper 2003).

Regarding food of animal origin invertebrates as well as vertebrates are ingested by pigs. Invertebrates include insects (e.g. grasshoppers), soil living invertebrates (e.g. earthworms and beetles) and snails and leeches (Hanson & Karstad 1959; Graves 1984; Welander 2000; Schley & Roper 2003; Bueno *et al.* 2009; Wilcox & Van Vuren 2009). Investigating stomach content Hanson & Karstad (1959) found 300 earthworms in a single pig, whereas Rose & William (1983) recorded an intake of earthworms by village pigs weighing 20-40 kg ranging from 414 to 1224 worms per day. Small vertebrates include frogs, snakes, reptiles and turtles (Graves 1984; Schley & Roper 2003). Furthermore, wild pigs are predating on small mammals (e.g. voles and rodents) as well as eggs and young of ground-nesting birds (Hanson & Karstad 1959; Wilcox & Van Vuren 2009). Larger mammals are eaten as carrion (Graves 1984; Schley & Roper 2003; Wilcox & Van Vuren 2009) and in general pigs will readily eat carrion including pig carcasses, but also fish and crab (Hanson & Karstad 1959; Everitt & Alaniz 1980; Wilcox & Van Vuren 2009).

2.2 Pig foraging behaviour

A pig that experiences hunger will search for food until this is found and consumed in sufficient amounts (Studnitz *et al.* 2007). Under natural conditions food resources are found sporadically within the home range and pigs spent the majority of their active time searching for food by exploring their surroundings (Studnitz *et al.* 2007). Domestic pigs kept in semi-natural conditions have been found to show similar behaviour to feral and wild pigs (Stolba and Wood-Gush 1989; Petersen 1994). Exploration is important for survival, since it informs the pig about availability of resources, which are exhaustible and seasonal (Studnitz *et al.* 2007). Thus, foraging is an integrated part of explorative behaviour and consists of appetitive behaviour, where the pig searches for and finds food and a consummatory behaviour where the food is ingested (Studnitz *et al.* 2007). Another type of explorative behaviour is motivated by the pig´s curiosity where a change in the environment or novelty is searched for (inquisitive exploration) (Wood-Gush & Vestergaard 1989). It might be related to informing the pig about potential food resources in the environment, as described above. Curiosity may also be stimulated by external stimuli e.g. by novelty (inspective exploration) in the environment (Wood-Gush & Vestergaard 1989; Studnitz *et al.* 2007). Irrespective of the type of exploration, the pig will root, sniff, nudge, bite and chew at edible as well as indigestible items (Studnitz *et al.* 2007). For rooting, the level is suggested to be related to the extent of hunger as found in domesticated sows (Edwards *et al.* 1993). Large populations of earthworms have shown to stimulate intense rooting activity in soil in village pigs (Rose & Williams 1983). In addition, wild boar showed preferences for rooting in soils rich in nutrients in the study by Welander (2000). Since foraging has a nutritional as well as an explorative component it is almost impossible to distinguish between the two (Wood-Gush & Vestergaard 1989; Andresen 2000), although experimentally they can be separated (Day *et al.* 1995). However, it can explain the pig´s various motivations for performing certain behaviours at specific objects in the environment. Thus, it might be possible to introduce management strategies into pasture systems, which are able to integrate motivation for exploration, aiming at increasing forage intake as well as fulfilling behavioural needs.

2.3 Activity level

Observing domestic pigs living in semi-natural conditions during a two year period, Petersen (1994) found that already within a few days postpartum piglets started to root, bite, chew and sniff at objects. Rooting increased to week five constituting 18% of the observation time and then decreased. Grazing showed the opposite pattern. Four weeks postpartum piglets started grazing and from week four to week eight grazing increased from 7 to 42% of the observation time. In other studies of pigs in semi-natural environments foraging related activities have been reported to make up approximately 52% and 54% of total observations (Stolba & Wood-Gush 1989; Rodríguez-Estévez *et al.* 2009) or 61-71% of the observation period in the latter study. In more confined paddock systems foraging activity have been found to represent from 19-42% of observational time depending on concentrate feed treatment (Andresen & Redbo 1999; Stern & Andresen 2003; Rivero *et al.* 2013; Horsted *et al.* 2013; Kongsted *et al.* 2013). In terms of travel distances Kurz and Marchinton (1972) used radio telemetry of feral hogs and reported mean distances of 2.5 km per day with 2.9 km as the longest distance. However, Barett (1978) found feral hogs travelling up to 10 km a day. In the study on Iberian pigs foraging acorns on 111 ha, pigs were observed to walk a mean distance of 3.9 km day^{-1} while foraging (Rodríguez-Estévez *et al.* 2009). Activity level, including travel distances is depending on distribution of feed resources in the environment and climate as well as nutritional status and age (Edwards 2003).

2.4 Nutritional contribution from direct foraging

Nutritional contribution from foraging in the range area depends on forage availability, foraging motivation, voluntary intake, forage nutritional value and the ability of the pig to ingest and utilize forage. These areas will be addressed in the following sections. Since the literature is sparse regarding pigs foraging in the range area, investigations on allocated forage or fibre-rich feed as well as concentrate feed will be included if they are assessed to have direct application value or give indications as to the effect on pigs foraging in range areas.

2.4.1 Factors affecting foraging behaviour

As referred to in the introduction, a pig`s motivation for direct foraging is influenced by various factors. Some of these factors are internal such as genotype, age and social interactions. Others are of external origin such as climate. In addition, there are factors such as management, which the farmer can use as a tool to affect foraging behaviour. In order to stimulate pigs´ motivation for foraging, these factors and their level of importance are investigated.

2.4.1.1 Genotype

The process of genetic selection for lean meat and increased feed efficiency has led to a selection for reduced appetite. Thus, in terms of breed or genotype and intake of fibre-rich feed, modern genotypes may have a lower intake compared to traditional breeds (Kelly *et al.* 2007). Edwards (2005) suggested that traditional breeds are subjected to less metabolic stress when feed is insufficient and of poor quality. This may result in traditional breeds being more able to cope with less nutritional feed compared to modern hybrids and as a consequence they may exhibit reduced foraging behaviour. Opposite, modern genotypes, which have high nutritional needs due to their improved growth potential, may show increased foraging behaviour. Kelly *et al.* (2007) investigated three genotypes (Camborough 12 = Landrace x Large white x Duroc; Saddleback; Saddleback x Duroc) on pasture or on pasture with additional *ad libitum* clover-grass silage but did not find any differences in proportion of forage intake between genotypes in the two systems. However, in a study by Edwards *et al.* (1991) a modern British hybrid had a higher voluntary feed intake of a fibre-rich diet consisting of unmolassed sugar-beet pulp compared to the Meishan breed, which evolved in China on high-fibre diets. Regarding concentrate feed intake, Quiniou *et al.* (1999) found that composition of body weight gain differed between genotypes, which were associated with differences in voluntary feed intake as well as feeding behaviour. The modern genotypes (the lean Pietrain and Large White) showed the highest voluntary feed intake compared to the traditional Chinese Meishan breed with more fat. Furthermore, daily number of meals was higher for the modern breeds, whereas meal size was higher for the Meishan breed. Hence, in terms of genotype and effect on foraging behaviour results are not conclusive.

2.4.1.2 Age

Age are reported to affect activity levels with subadult pigs spending more time on exploring the environment and searching for feed items compared to adult pigs (Stolba & Wood-Gush 1989). For the young pig the function may be to familiarize itself with the home range. Another suggestion is that it represents appetitive foraging behaviour and is motivated by nutritional needs (Stolba & Wood-Gush 1989). In feral pigs subadults have been reported to select a larger diversity of feed items compared to adult pigs, leading to increased foraging activity (Dardaillon 1989). On one hand it may be explained by the young pigs´ inexperience with the environment. On the other hand it may be caused by the higher protein requirements of young growing pigs (Dardaillon 1989).

2.4.1.3 Social interactions

According to experiments performed indoors with concentrates fed *ad libitum*, social or hierarchical interactions between pigs in a group affect feeding pattern, which may lead to a change in overall feed intake (Nyachoti *et al.* 2004). De Haer & de Vries (1993) found that pigs housed in groups of eight had fever daily meals but eating time per meal and meal size were higher compared to individual housed pigs. However, group housed pigs had a lower daily feed intake and spent less time eating during the day compared to individual housed pigs. The hypothesis behind is that a pig in a group must eat fast to get enough feed due to competition from pen mates (de Haer & Merkst 1992). Similar results were obtained in a system with deep litter and 200 growing pigs per pen compared to a conventional system with 20 pigs per group (Morrison *et al.* 2003). In both systems concentrate feed was fed *ad libitum*. Number of feeding events was significantly lower in the deep litter system compared to the conventional system, but the duration of feeding events was higher in the deep-litter system. This pattern has not been observed consistently throughout investigations, which is suggested to be caused by interacting external factors such as space allowance when accessing feed, stocking rate (Nyachoti *et al.* 2004) and access to straw (Morrison *et al.* 2003). According to Nyachoti *et al.* (2004) voluntary concentrate feed intake decreases in growing pigs kept in groups of up to 100 pigs per pen, whereas finishing pigs are able to maintain their feed intake, which is suggested to be due to the ability of finishing pigs to manipulate their feeding behaviour.

The literature on social and hierarchical interactions in pigs foraging in range areas is sparse. Extrapolating knowledge from indoor experiments, space allowance or stocking rate is suggested also to be important for the ability to perform foraging behaviour in pasture systems. However, provided that forage crop is not a limiting factor, competition between pigs regarding access to forage is suggested to be reduced. In order to increase foraging behaviour experiments indicate that foraging in the range must be combined with restricted supplemental feed allowance (section 2.4.1.7). Hence, this is suggested to affect feeding behaviour in terms of access to concentrate feed between dominant and subdominant pigs. Group size may also affect hierarchical interactions and thereby feeding behaviour in pigs on pasture, since it has been estimated that an individual pig is able to recognise 20-30 group members (Morrison *et al.* 2003).

2.4.1.4 Diurnal pattern

Typically, for wild boar and feral pigs foraging activity shows a diurnal pattern with activity peaks at dawn and dusk (Edwards 2003; Sandom *et al.* 2013). However, in areas where hunting is predominant, pigs are feeding and travelling during night time and resting during daytime (Stegeman 1938; Hanson & Karstad 1959). Activity patterns of wild pigs are to a large extent dependent on external factors such as location, season, weather, hunting pressure

(Graves 1984) and availability of food (Kurz and Marchinton 1972; Graves 1984). In farmed wild boars, which were on pasture from 8:30 to 16:30, Rivero *et al.* (2013) reported a peak grazing activity three hours after being led out to pastures. The pigs spent 62% of their time on grazing in these three hours compared to 42.4% during the entire grazing period. From observations of free-range sows in pasture systems, there are indications that the foraging activity pattern of wild boar and feral pigs, with peaks at sunrise and sunset, has been retained in the domesticated pig (Buckner *et al.* 1998).

2.4.1.5 Climate

External factors such as season and weather seem to play an important part of feral pigs´ activity pattern. During summer feral pigs are relatively inactive during midday, from 11 a.m. to 3 p.m. and on warm days they prefer to be active during early morning and late afternoon (Graves 1984). Furthermore, feral pigs have been found to be night active during summer and day active during winter (Hanson & Karstad 1959; Kurz & Marchinton 1972; Barrett 1978). This pattern was partly confirmed in an observation study of domesticated pigs living in a 4 ha natural area (Jakobsen 2013, *pilot study*). During the month of July, where the temperature was 25-28˚C at midday, the pigs had an inactive period from around 11 a.m. to 2 p.m. The pigs clearly chose to rest at the highest place below pine trees, which gave way to wind as well as shadow.

For growing pigs the thermo neutral zone ranges between 18-21˚C (Nyachoti *et al.* 2004). It is well-known that with increasing ambient temperatures, voluntary feed intake decreases (Edwards 2003). In addition, feeding pattern changes in relation to increasing temperatures with more feed consumed during night in hot periods. As temperature decreases below the thermo neutral zone voluntary feed intake increases (Quiniou 2000). Under north European conditions thermal heat stress is mainly a challenge during midsummer. However, with ingestion of fibre-rich feed, which increases metabolic heat production, heat stress may be exacerbated (Edwards 2003). For growing pigs on pasture Andresen & Redbo (1999) also reported a decrease in grazing behaviour with increasing temperature. However, in a temperature range of 12-25˚C rooting level was unaffected but with an obvious increase in the drinking/wallowing area from a temperature of approximately 20˚C. Thus, motivation for rooting was changed towards being based on thermoregulation. Furthermore, wind was observed to affect rooting behaviour in the study by Kongsted *et al.* (2013) with decreasing levels going from light, medium to strong wind. Under north European conditions, wild boars have been found to prefer rooting during autumn and winter and grazing during spring and summer (Sandom *et al.* 2013). This is suggested to be ascribed mainly to the availability and distribution of feed sources during the various seasons and the soil being more loose and humid during autumn (and partly winter) making access easier (Welander 2000; Vittoz *et al.* 2002; Bueno *et al.* 2009). During summer the soil can be dry and hard thereby physically limiting rooting behaviour as found by Rivera Ferre *et al.* (2001) in domesticated sows on pasture.

2.4.1.6 Forage crop preference

Growing pigs´ preferences in terms of forage crops are of major importance for level of foraging and voluntary intake. Growing European wild boar in a semi-extensive system showed preference for larger leaves of plantain and ryegrass but a clear preference for plantain over ryegrass (Hodgkinson *et al.* 2011). Furthermore, in continuous and rotational grazing systems growing European wild boar showed selective grazing in clover-grass paddocks (Rivero *et al.* 2013) and Carlson *et al.* (1999) found that growing pigs (30 kg) selected the leaves of cut clover-grass containing high levels of sugars components. According to a preference trial with gilts, grazing alfalfa and white clover as well as rooting white clover, were clearly preferred compared to tall fescue or buffalograss. This was ascribed to the palatability and ease of grazing legumes compared to grasses, which are more fibrous and difficult to graze for pigs (Rachuonyo *et al.* 2005). In addition, the experiment performed by Gustafson & Stern (2003) indicated that growing pigs are selective grazers, whereby consumed forage quality differs from the overall quality of the pasture. As opposed to this only one pig, out of five, showed a clear preference for the clover component of the grass-clover sward in the study by Mowat *et al.* (2001). Thus, the selective grazing behaviour indicates that pigs prefer easily digestible protein rich crops. On one hand crop preference is an intrinsic characteristic of the pig. On the other hand, a farmer can choose to grow forage types preferred by pigs and partly influence the quantity and quality of these crops by management incentives.

2.4.1.7 Paddock management

Due to the explorative behaviour of pigs as described in section 2.2 experiments indicate that it is possible to implement management incentives in order to stimulate foraging behaviour in pigs. According to Andresen & Redbo (1999) weekly access to new pasture (50 m^2 or 100 m^2 $week^{-1}$ with 5 pigs $paddock^{-1}$) clearly stimulated foraging and explorative behaviour in growing pigs. In addition, foraging activity was higher in 100 m^2 paddocks compared to 50 m^2, which was caused by a higher supply of forage in the 100 m^2 paddocks. In the same study, passive behaviour increased with time in experimental paddocks, which was explained by forage depletion as well as the paddocks getting barren, providing no stimuli for activity. Hence, this indicates that continuous allocation of new land can be a relevant management tool in order to increase levels of foraging behaviour. This was also confirmed in the study by Stern & Andresen (2003), which reported a clear preference of growing pigs for newly allotted areas compared to well-known areas. On the contrary, Rivero *et al.* (2013) did not find any difference in levels of grazing behaviour in European wild boar managed in continuous and rotational grazing systems. However, it must be noted that the experiment only lasted five days. Stocking density may also have an impact on rooting depth as found by Andresen *et al.* (2001) with high stocking rate leading to an increased rooting depth compared to low stocking rate (10 vs. 20 m^2 pig^{-1} $week^{-}1$). Hence, this may be a way to access higher availability of feed below ground. Andresen (2000) suggested that moving huts, feeding and drinking facilities regularly may increase direct foraging, since pigs will situate themselves around these. In more extensive systems availability of water in near proximity of foraging areas is important for maintaining foraging behaviour. Rodríguez-Estévez *et al.* (2010) reported a decrease in foraging behaviour of Iberian pigs due to lack of water, since pigs had to walk a long distance to get access.

2.4.1.8 Supplemental feed allowance

Table 2.1 and 2.2 present the results of studies investigating the effect of reduced energy and protein in supplemental feed respectively on rooting and or grazing behaviour in growing pigs housed indoors and in pasture systems.

As the study by Beattie & O´Connell *et al.* (2002) indicates, the relation between feed restriction and rooting behaviour tends to be linear. Four levels of feed (1.05, 1.20, 1.35 and 1.50 kg feed per pig^{-1} day^{-1}) were included. In peak rooting periods significantly more pigs receiving 1.20 and 1.35 kg feed rooted compared to pigs receiving 1.50 kg. However, during a twenty-four hour period feed restriction had no effect on the number of pigs rooting. The same was found in the study by Day *et al.* (1995) (same weight class and indoors) where pigs receiving 80% of *ad libitum* feed were observed to root significantly more in substrates compared to *ad libitum* fed pigs. Stern & Andresen (2003) introduced a dietary energy level representing 80% of recommendations, which significantly affected 50 kg pigs´ rooting activity, but not grazing, compared to pigs receiving 100% dietary energy. In an experiment where growing pigs had *ad libitum* access to Jerusalem artichokes tubers in the soil, the dietary energy level was even further decreased to 25% of recommendations for indoor growing pigs. This resulted in restricted fed pigs foraging significantly more for tubers (7.9% of total observations) compared to pigs on 100% dietary energy with 1.1% of total observations. In terms of rooting, the level observed in restricted pigs was slightly higher compared to non-restricted pigs but the difference was not statistically significant. Furthermore, only pigs on 100% dietary level showed grazing behaviour. The study by Rodríguez-Estévez *et al.* (2009) did not compare dietary levels. Rather, foraging behaviour was studied in Iberian pigs in a system of clear forest of evergreen oaks with no supplemental feed at all. Thus, the majority of the feed ration consisted of acorns and grass. Foraging behaviour was observed with up to 71% of the observation period, indicating that levels of restriction must be relatively high in order to increase foraging behaviour considerably.

Regarding protein restriction, a crude protein level of 122 g kg^{-1} feed significantly increased rooting activity in straw compared to levels of 206 and 240 g in growing pigs (30-40 kg) housed indoors (Jensen *et al.* 1993). However, in terms of rooting activity in the environment no significant effects of crude protein level were found. In pasture systems, the reported differences between protein regimes did not affect pigs´ rooting or grazing behaviour significantly. Subjecting growing pigs (approx. 37 kg) on a second year clover grass paddock, to either 137 g crude protein kg^{-1} dry matter (50% of lysine recommendations) or 191 g (85% of lysine recommendations) turned out not to give any significant differences in foraging behaviour in the study by Andresen & Redbo (1999). Thus, as might be expected, there was no difference in either rooting or activity in general, when subjecting growing and finishing pigs in grass pastures to 86%, 93% or 100% amino acid levels according to recommendations in the study by Høøk Presto *et al.* (2008).

2.4.2 Conclusions on factors affecting foraging behaviour

In conclusion, foraging behaviour is influenced by several factors such as age, with subadult pigs spending more time on appetitive foraging and exploration behaviour compared to adults. Regarding genotype different hypothesis exists but results from various studies are divergent. Results from studies on indoor housed pigs show that social or hierarchical interactions clearly affect feeding behaviour, although external factors related to management also have impact. To some extent this is also suggested to apply for pigs on pasture. However, literature on the area is lacking. The external factor climate clearly influences foraging behaviour. Voluntary feed intake decreases above the thermo neutral zone of the pig. Under Northern European conditions thermal heat stress is primarily a problem during summer and may be exacerbated by ingestion of fibre-rich feed, which increases metabolic heat. Pig forage crop preference is of paramount importance and studies indicate that pigs prefer easily digestible protein-rich crops. The literature is limited regarding paddock management and effect on foraging behaviour. However, studies indicate that continuous access to new pasture increases foraging behaviour, partly by stimulating inspective exploration. The relatively sparse literature on restricted concentrate feeding regimes suggest that restricting growing pigs in terms of energy below 80% of recommendations increases foraging behaviour. In terms of protein there are indications that the level must be reduced considerably to increase foraging behaviour, since a comparison of 50% and 85% of recommended lysine allowance was found not to give any significant differences in foraging behaviour.

Table 2.1. Studies investigating effect of reduced energy in supplemental feed on rooting and grazing in growing pigs. Abbreviations: Ref. = reference; Exp. = experimental; CP: crude protein; ME: metabolizable energy; obs.: observations; recom: recommendations; JA = Jerusalem artichokes. Breed: LW= Large White; L = Landrace; Y = Yorkshire; H = Hampshire; D = Duroc.
[*]Res.:16 days = 79 m^2 pig^{-1}, next 10 days = 147 m^2 pig^{-1}, next 14 days = 215 m^2 pig^{-1}. Ad lib.: 16 days = 79 m^2 pig^{-1}, next 24 days = 147 m^2 pig^{-1}.
Figures with different superscript letters indicate significance.

Ref.	Indoors/ outdoors	Stocking density	No. of pigs	Breed	Weight/ age of pigs	Exp. period	Supplemental feed regime	Results
1	Indoor		16	LW x L	39.9 kg 12 weeks		1: 80% of *ad libitum* 2: *ad libitum*	Rooting substrate, proportion of time: 1: 0.08[a] 2: 0.05[b]
2	Indoor		192	LW x L	11 weeks		1: 70% appetite: 1.05 2: 80% appetite: 1.20 3: 90% appetite: 1.35 4:100% appetite:1.50 kg feed pig^{-1} day^{-1}	Rooting at peak periods, % of total no. of pigs: 1: 10.7[a] 2: 11.4[a] 3: 6.6[b] 4: 8.3[b] Rooting behaviour over a 24 hour period, % of total no. of pigs: 1: 3.9[a] 2: 3.4[a] 3: 2.3[a] 4: 2.7[a]
3	1st year clover grass ley	200 m^2 $group^{-1}$ 50 m^2 $group^{-1}$ day^{-1}	44	LW x L	50.3 kg 14 weeks	43 days	1: 80% 2:100% of dietary energy allowance according to recom	Rooting, % of all obs.: 1: 8.5[a] 2: 5.8[b] Grazing, % of all obs.: 1: 33.6[a] 2: 30[a]
4	"Dehesa" acorns, grass	111 ha	84	Iberian **nose-ringed**	1: 113.4 kg 2: 110.2 kg	1: 2 months 2: 2 months 08.30-18.30	÷ suppl. feed	Foraging activity, % of observation period: 1: 71 2: 61 % of light hours: >54% of daylight hours

5	*Ad libitum* JA in soil + grass	Stocking density*	36	L, Y x D	62.6 kg 18 weeks	40 days	1: Restricted ME: 10.6 MJ CP: 315 g Lysine: 18.9 g kg^{-1} feed 2: *Ad libitum* ME: 12.2 MJ CP: 169 g Lysine: 8.6 g kg^{-1} feed	Rooting for tubers, % of all obs.: 1: 1.1^{a} 2: 7.9^{b} Rooting, % of all obs.: 1: 4.5 2: 3.9

References: 1: (Day *et al*. 1995); 2: (Beattie & O`Connell 2002); 3: (Stern & Andresen 2003); 4: (Rodríguez-Estévez *et al.* 2009); 5: (Kongsted *et al*. 2013).

Table 2.2. Studies investigating effect of reduced protein level in supplemental feed on rooting and grazing in growing pigs. Abbreviations: Ref. = reference: Exp. = experimental; CP: crude protein; ME: metabolizable energy; obs.: observations. Breed: LW = Large White; L = Landrace; Y = Yorkshire; H = Hampshire. Figures with different superscript letters indicate significance.

Ref.	Indoors/ outdoors	Stocking density	No. of pigs	Breed	Weight/ age of pigs	Exp. period	Supplemental Feed regime	Results
1	Indoor		20	LW x L	1: 36.5 kg 11 weeks. 2: 31.6 kg 9 weeks	3 weeks	1: 122 g CP 2: 206 g CP 3: 240 g CP kg^{-1} fresh food	Rooting in straw, % of all obs.: 1: 7.8^{a} 2: 5.2^{b} 3: 4.9^{b} Rooting in environment, % of all obs. 1: 2.6 2: 1.7 3: 1.4
2	2nd year clover grass lay	5 pigs 50 m^2 $week^{-1}$ 5 pigs 100 m^2 $week^{-1}$	20	La, Y x H	37 kg 13-17 weeks	35 days	1: 137 g CP 2: 191 g CP kg^{-1} dry matter feed	Rooting, % of all obs.: 1: 14.7^{a} 2: 13^{a} Grazing, % of all obs.: 1: 48.4^{a} 2: 47.8^{a}
3	Grasses and weeds	375 m^2 pig^{-1}	48	L, Y x H	19.1 kg	-	1: 0.6 2: 0.55 3: 0.52 g lysine/MJ ME:	Activity level (including rooting), % of total no. of pigs: NS

References: 1: (Jensen *et al.* 1993); 2: (Andresen & Redbo 1999); 3: (Høøk Presto *et al.* 2008).

2.4.3 Biomass availability and forage type

The literature is sparse regarding crops suitable for growing pigs foraging in the range area. However, as Edwards (2003) describes availability and nutritional value of forage are important prerequisites in terms of the extent to which forage can accommodate nutrient requirements of pigs on pasture.

Initially, forage crops may be present in the range area. However, as pigs are introduced to the paddock foraging activity in particular rooting as well as the mere trampling of pigs may quickly exert damage to the sward leaving it overturned and bare (Edwards 2003). In free-range sows, also organic, this is partly solved by ringing sows. However, in practise the workload of providing all growing pigs produced on a farm with nose-rings would be too high and more important, ringing is not in accordance with the organic principle of *Fairness*. Furthermore, if forage crops are available below ground, as e.g. with Jerusalem Artichokes, rooting is favourable. In addition, access to biomass below ground, in the form of earthworms, beetles roots etc., presupposes rooting behaviour.

In terms of developing eco-efficient systems for direct foraging pigs, forage crop yield is of major importance. If yields are low, more land is needed to supply the appropriate amount of nutrients and as a consequence resource efficiency is reduced. A related aspect of equal importance is forage type and chemical composition. Alfalfa has been found to contain between 15.4 -24% crude protein and clover-grass between 20-24% (dry matter basis) (Møller *et al.* 2005). In addition, Cupic *et al.* (2001) reported alfalfa leaves and stems to contain 36 and 15% crude protein and 12 and 40% fiber respectively (dry matter basis). However, during a growth season the chemical composition of forages changes according to the various crop development stages (Andresen 2000). In the experiments performed by Andresen *et al.* (2001) and Stern & Andresen (2003) crude fibre and neutral detergent fibre content of clover-grass increased gradually during the experimental weeks. For crude protein, the content decreased gradually during weeks in both experiments. Furthermore, in the study by Cupic *et al.* (2001) year and cut significantly affected crude protein content in alfalfa with decreasing levels going from first to fourth cut. In addition, variation in chemical composition of a forage crop within a field may be large (Andresen *et al.* 2001).

In terms of quantification of biomass available below ground earthworms are well studied. Under north European conditions Holmstrup *et al.* (2011) found total densities of earthworms in clover grass fields ranging from 200-350 individuals per m^2 within a depth of 30 cm corresponding to a biomass weight of 50-160 g fresh weight. Eekeren *et al.* (2010) reported higher densities with 322-480 individuals per m^2 within a depth of 20 cm, however, corresponding to a lower total biomass availability of 82-135 g. The highest biomass level was found in clover fields compared to clover-grass and grass fields, the latter containing the lowest level. A relevant aspect is earthworms` sensibility to soil tillage and earthworm abundance has been found to decrease by 2-9 times, in particular when comparing pastures with conventional tillage systems (Chan 2001). In terms of nutritional value, as described in the introduction, Bassler *et al.* (2000) reported 610 g crude protein per kg dry matter earthworms. For lysine and methionine Pokarzhevskii *et al.* (1997) reported a mean of 43.8 and 9.2 mg respectively per g dry matter depending on earthworm species.

In conclusion, knowledge of crops suitable for growing pigs foraging in the range area is limited. Forage availability including yield are important for pigs to be able to ingest a considerable amount of forage on a given area. Furthermore, changing nutritional value of forage crops over the season needs to be taken into consideration. Earthworm biomass is promising in terms of protein and essential amino acids contents, although biomass density seems to depend on forage crop and cropping system.

2.4.4 Ability of the pig to ingest and utilize forage crops

Besides nutritional composition of forage crops pigs must be able to ingest and utilize forage in order to benefit nutritionally. The ability of pigs to digest bulky and fibre-rich feed, increases with age and/or live weight (Noblet & Le Goff 2001). Thus, the largest difference in digestibility is seen between young pigs and adult pigs (Fernández and Jørgensen 1986; Edwards 2003). This can be explained by the hindgut size as a proportion of live weight, or relative to feed intake, which increases significantly with live weight. Subsequently, there is a lower rate of passage in the intestines and a prolonged time for fermentation in the hindgut (Noblet & Le Goff 2001). Hence, when pigs are subjected to a reduced nutrition regime, the ability to response by an increased feed intake is suggested to be limited by the capacity of the gastrointestinal tract (Edwards 2003). It is generally recognized that weight and volume of stomach, caecum and colon increase in pigs receiving bulky diets. This is a direct effect of the gastrointestinal tract adapting to the increasing fill of the gut or the caecum and colon (Kyriazakis & Emmans 1995; Jørgensen *et al.* 1996). In addition, colon length increases as a consequence of adaptation to fibre-rich feeds (Jørgensen *et al.* 1996). Thus, pigs which receive high-fibre diets from an early age on are suggested to show an increased intake capacity compared to pigs at the same age/weight, which have not been subjected to the same adaptation process.

Forage crops contain high proportions of fibre compared to e.g. cereals (Andersson & Lindberg 1997) and fibre is predominantly digested in the caecum and colon by fermentation processes, producing volatile fatty acids with a utilization efficiency equivalent to approximately 0.70 of enzymatically digested carbohydrates (Noblet & Le Goff 2001). Hence, the energy available for the pig is reduced with high-fibre diets compared to feeding high levels of cereals and oil-seed feed. However, this is also influenced by factors such as fibre source properties (e.g. cellulose, lignin, pectin) weight of the pig and adaptation (Noblet

& Le Goff 2001). Furthermore, digestion of nutrients in the small intestine is reduced by increasing fibre content in the diet, though digestion is also influenced by fibre properties (Dierick *et al.* 1989; Andersson & Lindberg 1997).

There is limited evidence of digestibility of forage crops. In the study by Mowat *et al.* (2001) organic matter digestibility of a diet, including concentrates *ad libitum and* clover-grass in the range area amounted to 84% in pigs weighing 50-60 kg. However, it must be noted that forage intake amounted to only 4% of daily organic matter intake. For growing European wild boars (24 kg) grazing tall fescue, white clover, perennial ryegrass and plantain, total tract energy digestibility coefficients ranged from 29-65% (Quijada *et al.* 2012). In comparison, total tract organic matter digestibility of a basal concentrate diet fed to 30 kg pigs was considerably higher with approximately 78% (Jørgensen *et al.* 2012). The majority of studies related to digestibility is focusing on allocated and in some cases also processed forages. Anderson & Lindberg (1997) estimated a total tract organic matter digestibility of 40 and 50% for allocated alfalfa and white clover meal respectively in pigs weighing 41 to 74 kg. In terms of total tract crude protein digestibility the figures were 49 and 53% respectively. In comparison, Vestergaard *et al.* (1995 cf. Blair 2007) recorded a mean apparent crude protein digestibility of 14% in growing pigs supplied with cut grass, which seems rather low. According to in vitro estimates, Carlson *et al.* (1999) found total tract organic matter digestibility coefficients of 64, 56 and 51% for fresh clover-grass, clover-grass silage and whole crop barley-pea silage respectively. In addition, in vitro total tract organic matter digestibility of leaves and stems of clover-grass was 67 and 56% respectively. Hence, this shows the higher nutritional value of leaves over stems. For 30 kg pigs offered the same types of forages, Jørgensen *et al.* (2012) reported total tract energy digestibility of 60 and 48% for fresh clover-grass and silage (clover-grass and whole crop barley-pea) respectively. Inclusion of forage in a diet reduces digestibility of the total ration as found by Jørgensen *et al.* (2012). Adding 10% gross energy from clover-grass silage or whole crop barley-pea silage to a basal diet reduced total tract energy digestibility of the whole ration with 3.4 and 5% respectively.

In conclusion the ability of the pig to ingest and utilize forage crops depends on factors such as size of the pig, fibre content and fibre composition of forage crops as well as adaptation to fibre-rich feed. Data on digestibility coefficients for forage crops are lacking but a study of European wild boar reported total tract energy digestibility coefficients ranging from 29-65% in 29 kg pigs.

2.4.5 Forage intake and pig performance

Table 2.3 and 2.4 present studies investigating supplemental feeding regimes and effect on forage intake and performance of modern hybrid growing pigs and growing European wild boar, including Iberian pigs, respectively foraging in range areas.

2. Literature review

Studies indicate that when growing pigs on pasture are offered *ad libitum* access to concentrate feed forage intake is negligible (Mowat *et al.* 2001; Kelly *et al.* 2007). Supplemental feed must be restricted in order to increase forage intake. In modern hybrid pigs 80% dietary energy allowance was estimated to increase forage intake by 5% in the study by Stern & Andresen (2003) and resulted in a 15% decrease in daily weight gain compared to 100% dietary energy allowance. Feed conversion rate did not differ between treatments and amounted to 42 and 44 MJ ME kg^{-1} weight gain for restricted and non-restricted pigs respectively. In a similar feeding regime with growing pigs on pasture and additional clover-grass silage, total forage intake was estimated to be 460 and 390 g kg^{-1} weight gain for restricted and non-restricted pigs respectively (Strudsholm & Hermansen 2005). Thus, a restriction in terms of 80% of *ad libitum* allowance did not significantly affect forage intake. Feed conversion rate was improved compared to the study by Stern & Andresen (2003) with 36 and 42.3 MJ ME kg^{-1} weight gain for restricted and non-restricted pigs respectively. In the study by Kongsted *et al.* (2013) a heavy restriction in concentrate feed allowance for growing pigs (25% of recommended daily energy allowance) resulted in an estimated intake of 7 kg Jerusalem artichokes pig^{-1} day^{-1}, which is a considerably amount. However, the pigs also had an average weight of 62 kg. In this study foraging in the range area was estimated to accommodate approximately 60% of energy requirements. As a result concentrate feed intake was low while a relatively high daily weight gain was maintained with 560 g pig^{-1} day^{-1}. In a study by Riart (2002) pigs grazing pastures with alfalfa, tall fescue and *Cebadilla criolla* were fed *ad libitum* with a concentrate feed containing suboptimal protein levels. Pigs weighing 30-70 kg responded by consuming 150 and 40 g dry matter pig^{-1} day^{-1} during spring and summer respectively, whereas heavier pigs (70-100) ingested considerably higher levels with 510 and 320 g dry matter pig^{-1} day^{-1} respectively.

One of the most extreme example of concentrate feed restriction is represented by the Dehesa system where Iberian pigs are foraging on acorns and grass and receive no supplemental feed at all (Rodríguez-Estévez *et al.* 2009; Rodríguez-Estévez *et al.* 2010). Though, it must be noted that pigs are moved to the system at a weight of approximately 110 kg and are slaughtered at 160 kg live weight. Feed intake was reported to range from 4.9-6.4 kg acorns and 2-3.1 kg grass pig^{-1} day^{-1} (fresh weight) and daily weight gain was approximately 790 g pig^{-1} day^{-1}. These pigs were nose-ringed, which affects feeding behavior and feed intake below ground. Restricting growing European wild boar foraging clover-grass, ryegrass or plantain in terms of free access to a concentrate feed for 45-60 minutes a day, led to an average forage intake ranging from 210-550 g dry matter pig^{-1} day^{-1} depending on forage type and season (Hodgkinson *et al.* 2009; Rivero *et al.* 2013). In the study by Hodgkinson *et al.* (2009) it was estimated that grass intake supplied the pigs with 90 and 45% of maintenance requirements during spring and summer respectively. In the study by Rivero *et al.* (2013) clover-grass intake constituted 27% of total dry matter intake. In comparison, Quijada *et al.*

(2012) reported grazing of different forage species to supply growing European wild boars with 52-142% of maintenance requirements. As in the study by Hodgkinson *et al.* (2009), the energy consumed from pasture was higher during spring compared to summer, probably reflecting the changing quality of forage during the growth season.

In studies on allocated roughage to growing pigs, intake also seems to depend on concentrate feed allowance. Carlson *et al.* (1999) showed how 30 kg growing pigs, restricted to 1 kg concentrate feed pig^{-1} day^{-1} were capable of consuming between 444-1137 g roughage pig^{-1} day^{-1} (fresh weight) with higher levels for fresh forage compared to ensiled forage. On average this corresponded to 18-19% of total dry matter intake. In a similar experiment by Jørgensen *et al.* (2012), also with 30 kg pigs, dry matter intake constituted only 10-12% of total dry matter intake. However, a large variation between pigs was recorded and concentrate feed allowance was higher with 1.5 kg pig^{-1} day^{-1} compared to the study by Carlson *et al.* (1999).

In conclusion, studies indicate that forage intake increases if pigs are restricted in energy. Levels of forage intake in outdoor areas have been found to range between 0.8-2.7 kg pig^{-1} day^{-1} (fresh weight) and for dry matter the levels are 201-550 g pig^{-1} day^{-1} depending on restriction level, pig weight and season. For allocated roughage intake values range from 0.4-1.1 kg fresh weight pig^{-1} day^{-1}. However, in order to increase forage intake considerably, energy and nutrient restriction must be heavy as found in the study by Kongsted *et al.* (2013). Effect on performance remains uncertain though few investigations showed that daily weight gain and feed conversion rate are not seriously deteriorated. Studies on effect of protein restriction is limited but there are indications that a reduced level increases forage intake. However, more information on levels to accommodate a considerable forage intake is lacking.

Table 2.3. Studies investigating forage intake and performance in growing pigs foraging in range areas. Abbreviations: Ref. = reference; Exp. = experimental; suppl. = supplementary feed; JA = Jerusalem Artichokes; DEA = dietary energy allowance; EC = energy concentration; DM = dry matter; Ad lib. = *ad libitum*; Res. = restricted; OM = organic matter; recom. = recommended; DWG = daily weight gain; FCR = feed conversion rate; NS = non-significant; ME = metabolizable energy; Conc. = concentrate; DE = digestible energy; main. = maintenance; requirem. = requirement; WG = weight gain. Breed: Cam = Camborough 12, D = Duroc; L = Landrace; LW = Large White; Sad. = Saddleback; Y = Yorkshire.

Ref.	No. pigs	Nose-ring	Breed	Weight/ age	Exp. period	Forage	Area	Suppl. feed	Forage intake fresh weight	Forage intake DM	Performance
1	5	?	Cam x D	1: 61.7 2: 50.1	5 days adaptation 5 days Exp.	1st year clover-grass ley.	6 m^2 pig^{-1} day^{-1}	Ad lib.		Grass 60 g Clover 40 g Kg^{-1} OM pig^{-1} day^{-1}	
2	44	÷	LW x L	50.3 kg 14 weeks	43 days	1st year clover grass ley	18 m^2 + 4.5 m^2 pig^{-1} day^{-1}	1: 80% 2:100% of DEA	1: 5%↑ compared to 2:		DWG: 1: 15% reduction compared to 2: FCR: NS
3	54	÷	LW x L	10 weeks	49 days	3rd year clover-grass ley	30-40 kg: 3 m^2 >80 kg: 6 m^2 pig^{-1} day^{-1}	1: increase EC. 2: increase volume 15% ME above indoor recom.	1: 1.1 2: 0.8 kg pig^{-1} day^{-1}		DWG, g: 1: 882 2: 910
4	98	÷	LW x L, D	18.3 kg 52 days	1 year	Clover-grass	11 m^2 pig^{-1}	1: 80% (of ad lib.) 2: ad lib.	1: 0.46 2: 0.39 Kg roughage kg^{-1} WG		DWG, g 1: 634 2: 737 FCR, MJ ME kg^{-1} WG 1: 36 2: 42.3
5	72	÷	Cam.; Sad.; Sad. x D	30-90 kg	2 years.	Clover-grass+ clover-grass silage	50 m^2 pig^{-1}	Ad lib.	Silage: 30 g pig^{-1} day^{-1}		
6	36	÷	LY x D	62.6 kg 18 weeks	40 days:	Ad lib. access to JA tubers in soil	1: Res.[1] 2: Ad lib.[2]	**1: Res.:** Lysine: 18.9 g ME: 10.6 MJ **2: Ad lib.:** Lysine: 8.6 g ME: 12.2 MJ kg^{-1} feed	7 kg pig^{-1} day^{-1}	1.3 kg pig^{-1} day^{-1}	DWG, g 1: 560 2: 1224 FCR, Conc. 1: 17.9 2: 42.8 MJ ME kg^{-1} WG

References: 1: (Mowat *et al.* 2001); 2: (Stern & Andresen 2003); 3: (Gustafson & Stern 2003); 4: (Strudsholm & Hermansen 2005); 5: (Kelly *et al*. 2007); 6: (Kongsted *et al*. 2013).
[1]Restricted pigs and space allowance: 79 m^2 pig^{-1} day^1 the first 16 days, 147 m^2 pig^{-1} day^1 the next 10 days and the last 16 days 79 m^2 pig^{-1} day^1.
[2]*Ad libitum* pigs and space allowance: 79 m^2 pig^{-1} day^1 the first 16 days, the last 24 days 147 m^2 pig^{-1} day^1.

Table 2.4. Studies investigating forage intake and performance in European wild boar and Iberian pigs foraging in range areas. Abbreviations: Ref. = reference; EWB = European wild boar; Exp. = experimental; Suppl. = supplementary feed; DEA = dietary energy allowance; EC = energy concentration; DM = dry matter; DWG = daily weight gain; FCR = feed conversion rate; NS = non-significant; ME = metabolizable energy; DE = digestible energy; main. = maintenance; requirem. = requirement; WG = weight gain.

Ref.	No. pigs	Nose-ring	Breed	Weight/ age	Exp. period	Forage	Area	Suppl. feed	Forage intake fresh weight	Forage intake DM	Performance
1	12	+	EWB	18.8 kg	2 x19 days: 1:spring 2:summer	Ryegrass or plantain alternating between days 8.30-16.30:	4.4 m^2 pig^{-1} day^{-1}	45 min. free access		Ryegrass: 1: 418 2: 210 Plantain: 1: 550 2: 226 g pig^{-1} day^{-1}	Ryegrass: 1: < 4 MJ 2: < 2 MJ DE pig^{-1} day^{-1} → 1: < 90% 2: < 45% of main. requirem.
2	84	+	Iberian	1: 113.4 kg 2: 110.2 kg	1: 2 months 2: 2 months	"Dehesa" acorns, grass 8.30-18.30	1.13 ha pig^{-1}	÷	Acorn, 1: 6.4 2: 5.5 Grass, 1: 2 2: 2.6 kg pig^{-1} day^{-1}	Acorn, 1: 3.6 2: 3.1 Grass, 1: 0.38 2: 0.49 kg pig^{-1} day^{-1}	
3	84	+	Iberian	110.2 kg 12.1 months	2004 2005	"Dehesa" acorns, grass 8.30-18.30	1.13 ha pig^{-1}	÷	Acorn: 4.9 Grass: 2.7 kg pig^{-1} day^{-1}	Acorn: 2.9 Grass: 0.5 kg pig^{-1} day^{-1} Acorn: 51.3 Grass: 5.1 MJ ME pig^{-1} day^{-1}	DWG, g 790 FCR 10.5 kg acorns kg^{-1} WG
4	16	+	EWB	18.3 kg	2 x 5 days	1: Continuous 2: Rotational clover-grass 8.30- 16.30	1: 3.5 2: 3.5 m^2 pig^{-1} day^{-1}	60 min. Free access		1: 236 2: 248 g pig^{-1} day^{-1} 27% of total DM intake	DWG, g 1: 257 2: 245

References: 1: (Hodgkinson *et al.* 2009); 2: (Rodríguez-Estévez *et al.* 2009); 3: (Rodríguez-Estévez *et al.* 2010); 4: (Rivero *et al.* 2013).

2.5 Methods to estimate forage intake in pigs

The literature presents different methods to investigate forage intake in pigs (including wild boar and feral pigs). As methods described for sows may apply for growing pigs, they are also included.

2.5.1 Biomass above ground

As the name of the method **herbage cutting technique** implies, estimated forage intake is based on collection of forage crop samples. Sampling is performed prior to and after pigs` access to the grazing area. Regarding height of forage crop cutting, Andresen & Redbo (1999) cut to 1 cm above ground, Gustafson & Stern (2003) and Fernández *et al.* (2006) used a level of 2 cm above ground, whereas Rivera Ferre *et al.* 2001, Hodgkinsom *et al.* (2009) and Rivero *et al.* (2013) cut samples to soil level. In order to estimate apparent consumption, post-grazed forage availability is subtracted from pre-grazed forage availability and divided by the number of pigs. To estimate nutrient composition of forage crop samples, plant species are separated and analysed individually. Rivero *et al.* (2013) used hand clipping in undisturbed post-grazed areas to estimate nutritional composition. Clipping was performed above residual sward height. Fernández *et al.* (2006) used a somehow modified version where forage availability was based on forage height measurements combined with dry matter analysis through an equation (kg dry matter ha^{-1} = 199 * height (cm)). To estimate crop quality Fernández *et al.* (2006) collected samples by hand to mimic the selective grazing behaviour of sows.

The herbage cutting technique has minimal impact on animal grazing behaviour. However, if the time between forage crop sampling in pre- and post-grazed areas is too long, pasture growth will continue and as a consequence forage crop intake will be under-estimated (Hodgkinson *et al.* 2009). Compared to the cutting technique, the method of hand clipping above residual sward height in undisturbed post-grazed areas turned out to give a different nutrient composition of the forage crop in the study by Rivero *et al.* (2013). This was suggested to be due to the pigs´ selective foraging behaviour where primarily the upper leafy part of the forage crop is consumed. Compared to the method of hand-plucking pigs may be better at selecting high quality parts (Fernández *et al.* 2006). To increase accuracy of estimated forage intake cutting height must be determined in relation to the pigs foraging behaviour, which depends on factors such as sward height and density, botanical composition and stocking density (Rivera Ferre *et al.* 2001; Rivero *et al.* 2013).

The **n-alkane marker technique** is based on the content of natural n-alkanes in herbage combined with applying (dosing) an artificial n-alkane marker on concentrate feed pellets, which are fed to the pigs in known quantities (Rivera Ferre *et al.* 2001). Forage crop and faeces samples are collected throughout the trial and n-alkane concentrations in samples determined. This, together with the known artificial n-alkanes from concentrate feed, makes it possible to estimate the intake of each feed component (Mowat *et al.* 2001).

As is the case with the herbage cutting technique, the n-alkane marker technique is subjected to bias related to cutting height of forage crop samples. Furthermore, the method is not interfering with grazing behaviour or welfare of the pigs (Rivera Ferre *et al.* 2001). In order to increase accuracy of the method, it is important that the concentrate feed is ingested by the pigs. Hence, troughs and feeding situation must be designed as not to spill any feed (Rivera Ferre *et al.* 2001). To avoid this, Mowat *et al.* (2001) and co-workers accustomed the pigs to be fed by hand with concentrate feed in the form of cakes prior to the start of the trial.

The direct **in situ observation** method is sparsely described in the literature. It implies direct continuous observation of grazing and individual feeding behaviour (Rodríguez-Estévez *et al.* 2009). The authors applied the method to investigate feed intake of Iberian growing pigs in the Dehesa system with clear forest of evergreen oaks, where the primary source of feed is acorns. The observers followed focal pigs throughout the day, staying in close proximity (1-3 m) to the animals in order to see or hear (cracking of acorn) consumption of feed items. Grass intake per mouthful was estimated by hand-plucking grass samples imitating pig grazing behaviour. Grass quality was estimated by plucking grass in the areas where the pigs resided. Samples of acorns were collected throughout the area and individually weighed to quantify intake per bite. In addition, samples of acorns were collected from randomly selected oaks to estimate average nutritional composition. Prior to the start of the trial, observers were trained in observing the pigs and to identify feed items ingested and pigs were accustomed to observers.

The method can easily interfere with foraging behaviour. Hence, it is important for observers to be familiar with pig behaviour and to allow time for the pigs to be accustomed to the presence of the observers. Furthermore, the pigs must be observed throughout the day. If this is fulfilled and the observers are actually able to identify ingested feed items the method seems reliable. However, as Rodríguez-Estévez *et al.* (2009) describes the method is time-consuming and it does not provide information about the weight of the ingested food. It is a challenge if pigs choose to forage during night. However, in the described experiment pigs were held in a small enclosure with shelters during the evening and night to prevent foraging. In a similar experiment, in terms of observation method, conducted with young female pigs on a natural area (Jakobsen 2013, *pilot study*), pigs were readily accustomed to the presence of the observers. Furthermore, it was possible to identify the vast majority of feed items ingested by pigs through grazing behaviour.

Through the method of **"backwards calculations**" difference in nutrient intake from concentrate feed and nutrient requirements of pigs according to the weight gain they have had throughout an experiment is calculated. Hence, the difference represents the nutrient intake from foraging (Stern & Andresen 2003; Kongsted *et al.* 2013). The method provides a rough estimate of feed intake from foraging. It is less labour intensive and cheaper compared to the other methods. However, combining the method of backwards calculation with one of the above mentioned methods is suggested to provide a more accurate estimate.

A frequently used method to estimate food items ingested by wild boar and feral pigs is to **analyse stomach content**. As reported by Schley & Roper (2003) the majority of investigations they consulted used stomach content analysis. Stomachs must be collected right after slaughter and either investigated right away or frozen for later analysis (Baubet *et al.* 2004; Adkins & Harveson 2006). In the study of Everitt & Alaniz (1978) a random sample of approximately one litre was deduced from total stomach content and preserved in formalin for later analysis. Furthermore, plant samples were collected in foraging areas and plant species identified to help identifying species in stomach content. In order to help determine plant preferences, plant species composition was estimated in foraging areas. Adkins & Harveson (2006) used a method where stomachs were washed on top of a sieve in order to remove smaller unidentifiable contents. Sieved stomach content was then allowed to air dry, spread out across a pan, after which a pin frame was fitted. At each of the pin points, stomach content was identified in order to estimate frequency of occurrence of different feed items.

The procedure of identifying stomach contents differs between investigations, suggesting that it must be adapted to the actual circumstances and possibilities. An important drawback of the method is that the animal must be slaughtered, leaving out any further investigations on the live animal. This implies that the welfare of the animal at slaughter must not be compromised. The stomach must be removed right after the pig has been slaughtered and investigated or frozen for later analysis, which may have practical implications. It is relevant to slaughter animals after some hours of feeding due to the stomach being full, as done by Everitt and Alaniz (1978). Feed items which are digested quickly may be underestimated. In addition, feed items which are small and frequently consumed by the pig are subjected to overestimation if they are based on frequency of occurrence (Schley & Roper 2003)

2.5.2 Biomass below ground

As described in the introduction knowledge of food intake below ground in domesticated pigs is almost non-existing. Likewise, description of methods to estimate biomass intake from the soil is limited. However, a considerable work has been done in terms of identifying and estimating level of different feed items ingested by feral pigs and wild boar. It is suggested that these methods will be applicable for domesticated pigs with some modifications.

The method of **stomach content analysis** can also be applied for identifying biomass ingested below ground. In this context earthworm biomass is the most relevant. Overall, this has been done by identifying and counting earthworm setae, which primarily consist of chitin, on the basis of identification of mean numbers of setae on earthworms in the study area (Baubet *et al.* 2003). The authors used a method where the stomach content was washed through several sieves of different mesh size in order to end up with a fraction containing earthworm setae. They suggested that counting earthworm setae is a more reliable method compared to counting or weighing fragments of earthworms in stomach content, since the latter tends to underestimate the actual number of earthworms ingested.

In addition, **faeces samples** can be used for identifying number of earthworms ingested by using the same procedure as described above involving identification and counting of earthworm setae. Normally, the relatively high number of faeces samples collected requires conservation, either by preservation in formalin (Baubet *et al.* 2004) or by freezing.

For obvious reasons the **in situ observation** method is not applicable in wild boar and feral pigs, but may prove useful in domesticated pigs. In the study of Rodríguez-Estévez *et al.* (2009) the method was successfully used to identify feed items ingested above ground as described in section 2.5.1. However, the pigs were nosed-ringed, which prevented them from rooting and thereby liming consumption of feed items below ground. Rose & William (1983) were able to estimate earthworm intake by village pigs in Papua New Quinea by in situ observations. However, these pigs were tethered and each pig had access to an area of 3.6 m^2 freshly harvested mounds, which is suggested to have contributed to identification of earthworm ingestion. In the pilot study by Jakobsen (2013, *pilot study*), pigs quickly accustomed to the presence of the observers and accepted close proximity. Still, identification of feed items ingested through rooting behaviour proved difficult. Hence, the usefulness of the method remains to be investigated.

2.6 Conclusions from literature review

Forage nutrient availability is among other factors depending on crop type and yield as well as crop developmental stage, which is related to season. Furthermore, yields within paddocks or fields can vary considerably. Far more factors are important in terms of increasing yields and nutrient quality of forage crops, an area which is beyond the scope of this thesis. However, in relation to development of eco-efficient pasture systems for pigs, the subject is of major relevance.

In terms of factors affecting foraging behaviour, age is important with young pigs showing an increased level compared to adults. There is evidence that diurnal patterns of pigs have been retained from the wild boar with activity peaks at dawn and dusk. Studies on genotype and effect on forage behaviour are not conclusive and further information is needed to verify or reject hypotheses put forward in the literature. Investigations performed on indoor housed pigs clearly show that social interactions affect foraging behaviour. However, it remains to be investigated to what extent this also applies for growing pigs in forage based systems. Crop preference is of great importance in terms of increasing foraging behaviour as well as forage intake. Studies suggest that pigs prefer easily digestible protein-rich crops. However, more information on specific types of crops preferred by pigs is needed. Experiments indicate that management incentives by means of “strip grazing” and stocking density can be implemented in order to increase foraging behaviour, although more studies are needed to investigate this relevant aspect further. Protein and energy restriction seem promising in terms of increasing foraging behaviour and forage intake. Experiments indicate that energy levels must be reduced below at least 80% of recommendations to affect foraging behaviour and forage intake. However, more information is required to get a more profound knowledge on levels of restriction in particular for protein.

Regarding ingestion and utilization of forage crops intrinsic characteristics of the pig such as size and adaptation to bulky fibre-rich feed are important as well as forage crop characteristics such as fibre composition and fibre content. Clearly, more information on fresh forage digestibility of different crops is required to assess their nutrient quality for growing pigs.

The information provided from the literature review, including detection of important areas of limited knowledge, was an important incentive for conducting the present experiment, which included a comparison of two types of cropping systems and two supplemental feeds with different protein content.

3. Materials and methods

Below is a description of the experiment, which was performed from the 4th of September to the 14th of October 2013 at research station Foulumgaard, Aarhus University.

3.1 Animals, experimental design and treatments

A total of 36 growing pigs consisting of 19 females and 17 castrated males (Landrace, Yorkshire and Duroc crossbreds) were included in the 40-days experimental period with a mean live weight of 58 kg (51-68 kg) at the beginning of the experiment and a mean live weight of 90 kg (79-107 kg) at the end of the experiment. The pigs were recruited from a conventional farm with free-range sows where they were reared on pasture and fed *ad libitum* with a commercial diet for weaners and growers. The pigs were not nose-ringed.

The overall experimental design was a 2x2 treatment replicated in three blocks (Figure 3.1) with two allocated concentrate treatments (HP: high protein, LP: low protein) and two forage crop treatments (alfalfa, grass-clover). The pigs were grouped according to weight and gender into the three blocks with four paddocks in each block. Within blocks the pigs were allocated by gender to the four paddocks. In every paddock were three pigs (either one female pig and two male pigs or one male pig and two female pigs).

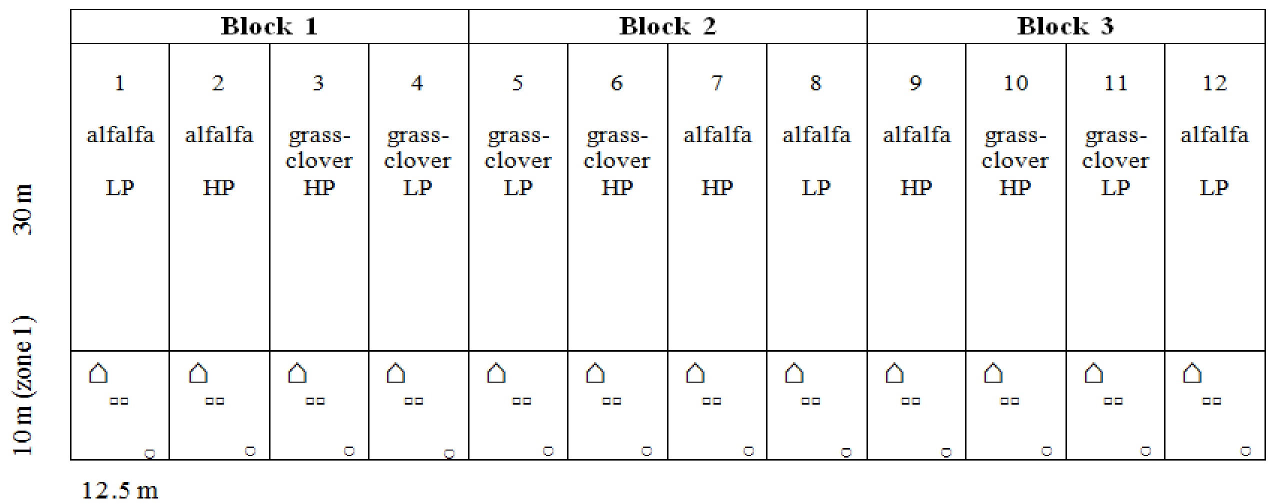

Figure 3.1. Illustration of experimental paddocks.
⌂ = hut, ○ = water tub, □□ = feed troughs. LP = low protein. HP = high protein.

Forage crop was randomized to paddocks within blocks. One forage crop treatment was a well-established alfalfa (*Medicago sativa*) and the other newly-established grass-clover with 85% rye grass (*Lolium perenne L)* and 15% white clover (*Trifolium repens*). Regarding the two concentrate feed treatments, pigs were fed a mean of 2.23 kg feed pig^{-1} day^{-1} or 2.25 and 2.17 FU for HP and LP treated pigs respectively (FU = Danish feed unit for growing-finishing pigs = 12.2 MJ ME) (Christiansen 2010). This corresponds to 80 and 78% respectively of energy requirements according to Danish indoor recommendations for growing pigs (Anonymous 2008). The HP feed consisted of 205 g crude protein and 10.55 g lysine kg^{-1} dry matter feed and the LP treatment of 107 g crude protein and 4.35 g lysine kg^{-1} dry matter feed. In terms of relative crude protein content, pigs on LP treatment received 52% of the HP treatment.

3.2 Experimental feed

The pigs were fed once a day at 7.30 am. Treatment HP consisted of an organic standard concentrate pelleted (3.5 mm) mixture for organic growing-finishing pigs. Treatment LP a mixture of coarsely grinded and granulated organic wheat (42%), barley (30%) and oats (25%) (Table 3.1) Both feeds were optimized in terms of vitamins and minerals. One random sample of each concentrate feed was collected and sent for nutrient content analysis (Eurofins Steins 2013) (Table 3.2) Dry matter content was determined by drying samples in the oven at 103˚C for 24 hours (EU regulation 152 2009). Crude fat was extracted with petroleum after hydrochloric acid hydrolysis (EU Regulation 152 2009). Crude protein (total nitrogen x 6.25) was analyzed by the Dumas method (combustion at 800-1000˚C) (Jung *et al.* 2003) and the essential amino acids according to the method described under section F in EU Regulation 152 (2009).

Table 3.1. Composition of concentrate feed treatments. HP = high protein; LP = low protein.

Composition (%)	HP feed (100% crude protein)*	LP feed (52% crude protein)*
Wheat	-	41.7
Barley	38.2	30.3
Oats	7.5	25
Triticale	10	-
Rye	5	-
Soy cake	17.2	-
Sunflower cake	5	-
Peas	5	-
Broad beans	5	-
Rape	2.6	-
Rape seeds	1.9	-
Chalk	1.1	1.2
Mono calcium phosphate	0.8	1.1
Salt	0.5	0.5
Vitamins + minerals	0.2	0.2

*based on relative crude protein allowance between the two treatments.

Table 3.2. Nutrient content in concentrate feed treatments HP and LP based on one random sample of each. HP= high protein; LP=low protein.

Nutrient content	HP Feed (100% crude protein)[a]	LP Feed (52% crude protein)[a]
Energy, FU[b], per kg feed	1.01	0.974
Dry matter, %	87.5	85.3
Crude protein, % (DM basis)	20.5	10.7
Crude fat, % (DM basis)	5.7	3.9
Crude ash, % (DM basis)	5.7	5.4
Amino acids, g 100 g^{-1} dry matter		
Lysine	1.055	0.435
Methionine	0.312	0.186

[a]based on relative crude protein allowance between the two treatments.
[b]FU: Danish Feed Unit for growing-finishing pigs, 1 FU = 12.2 MJ ME (Christiansen 2010).

3.3 Experimental paddocks

The twelve paddocks were situated right next to each other and separated by a two strand electrified wire fence. There were six paddocks with alfalfa and six with grass-clover (Figure 3.1). The alfalfa paddocks had been under-sown with barley/pea as a cover crop in 2010, which was harvested as whole crop on the 21st of July 2010. During 2013, before the pigs were introduced to the paddocks, the alfalfa was cut on the 10th of June. In addition, on the 9th of August approximately 50% of each paddock was cut. The grass-clover paddocks had been under-sown with barley as a cover crop in spring 2013. The barley was sown on the 24th of April and the grass-clover on the 7th of May. On the 1st of July the barley was harvested. Due to weevills (*Sitona*) the clover content in grass-clover paddocks was strongly reduced and was estimated to be around 1% in each paddock. Thus, grass-clover paddocks are referred to as grass paddocks and the forage treatment referred to as grass treatment. The field had not received any pesticides or artificial fertilizer since autumn 2009. The soil is characterized as fine loamy sand (Greve 2013).

Pigs in each paddock had access to an insulated hut with a floor area of 4 m^2 (1.3 m^2 per pig). The hut was placed directly on the pasture and supplied with straw. Water was offered from a water tub, beside which a wallowing area was available. In addition, each group of pigs had access to two feed troughs, which provided sufficient space for all pigs to eat simultaneously. Huts, feed troughs and water tubs were stationary throughout the experiment.

Initially, the paddock size was 12.5x10 m (125 m^2 ~ 42 m^2 per pig) representing zone 1 (Figure 3.1). However, the pigs were subjected to successive access to new pasture ("strip grazing"). Every Tuesday and Friday, all pigs got access to three meters of new pasture (Table 3.3). Accordingly, a paddock was divided into zones with each zone representing 37.5 m^2.

Every paddock was divided into a total of 11 zones. As the pigs got access to new zones, these were named zone 2, 3, 4 ect. (appendix 1).

Table 3.3. Pasture area available per pig in the 12 paddocks from the arrival of the pigs to the end of the experiment.

Week	Day	Pasture area available/pig, (m^2)
36	0-4	42*
37	5-11	54*
38	12-18	79*
39	19-25	104*
40	26-32	129*
41	33-39	154*
42	40	167**

*Area available per pig at the end of the week.
** Area available per pig at the start of the week.

The amount of concentrate feed allocated to pigs in each paddock was recorded on a daily basis (Figure 3.2 and appendix 2). Thus, it was possible to calculate feed intake for the group of pigs in each paddock. No feed was left over by the pigs. From day zero to day 7 pigs were fed a mixture of concentrate feeds HP and LP, after which they were fed entirely with the experimental feed treatment. Thus, they had one week to adapt to the experimental treatments and to be accustomed to the paddocks. Day zero specifies the day pigs were inserted into the experimental paddocks.

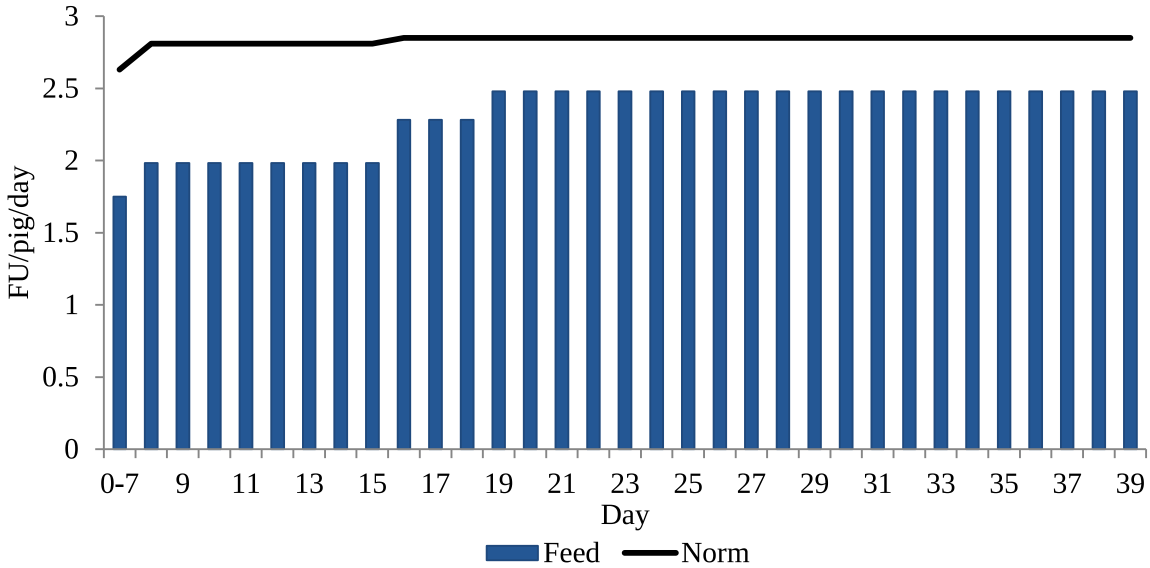

Figure 3.2. Concentrate feed allocation (FU pig^{-1} day^{-1}) as a mean of the two treatments during the 40-days experimental period. Norm designates recommended feed allowance for indoor growing pigs (60-90 kg) (Anonymous 2008). FU: Danish Feed Unit for growing-finishing pigs, 1 FU = 12.2 MJ ME (Christiansen 2010).

3.4 Recordings

3.4.1 Paddock appearance

To investigate effects of concentrate feed and forage crop treatments on paddock appearance, the following were recorded visually for each zone in every paddock five times during the experiment (day 12, 16, 26, 30 and 37) (Table 3.4). Percentage plant cover, which were divided between plants standing upright and plants trampled. Percentage area uprooted, divided between shallow rooted areas (≤10 cm) and deep rooted areas (>10 cm). Percentage plant cover and percentage uprooted were summed to 100%. If possible, plant height was measured with a ruler from the soil surface as a mean of five heights evenly distributed in a V-pattern. The recording sheet used can be found in appendix 3. The same two persons conducted the recordings at each assessment.

Table 3.4. Number of zones assessed in each paddock on day 12, 16, 26, 30 and 37 during the 40-days experimental period.

Day	Zones assessed								
	1	2	3	4	5	6	7	8	9
12	X	X							
16	X	X	X						
26	X	X	X	X	X	X			
30	X	X	X	X	X	X	X		
37	X	X	X	X	X	X	X	X	X

Effect of feed and forage crop treatments on paddock appearance were evaluated by presenting a status on the last day of assessment (day 37). A description of development in paddock appearance during the experimental period was represented by zone 3 on day 16, 26, 30 and 37 respectively. Zone 3 was chosen as it had been assessed four times. Hut, feed troughs and water tub were situated in zone 1 and 2 so the pigs resided there much of the time. Hence, these zones were assessed not to be representative for paddock development.

3.4.2 Pre-grazed forage crop samples

To assess temporal availability and nutrient composition of forage crops, two samples of alfalfa and grass were collected on day 12 (zone 3), 23 (zone 6), 30 (zone 8) and 37 (zone 10) in all 12 paddocks in the areas, which the pigs got access to right after sampling or the day after sampling (day 12). A 50x50 cm steel frame was placed on the ground and the forage crop cut to a height of 6 cm. Samples were collected one meter from the rear fence in a straight line from either the left or right side of the paddock (measured from the electric fence) according to a predetermined pattern (Figure 3.3). The two samples collected from each paddock were pooled. Prior to collecting samples forage crop height was measured from the soil surface with a ruler, as a mean of three measurements evenly distributed in every sample plot.

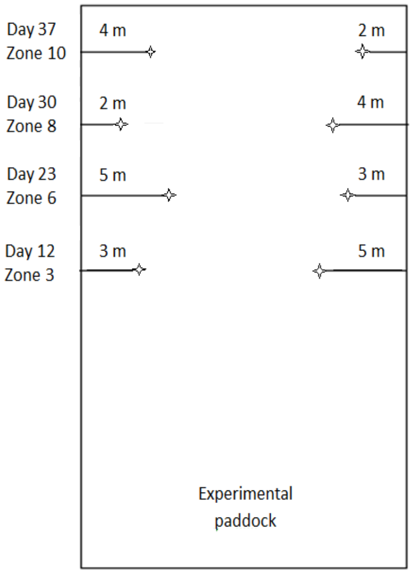

Figure 3.3. Day and pattern of cut forage crop sampling in each paddock during the trial. Four-pointed star indicates sampling position.

Analysis

If possible, samples were weighed (fresh weight) immediately after collection and dried individually in the oven at 60°C for 72 hours to estimate dry matter content at paddock level. Otherwise, samples were stored at 5°C. Afterwards, dried plant samples were grinded to one mm particles to prepare for chemical analysis (Eurofins Steins 2013) (Table 3.5). Nutrient content (crude protein, amino acids, crude fat and FU) was analyzed by the methods described in section 3.2. Samples from day 23, 30 and 37 were manually divided into alfalfa and dandelions (*Taraxacum officinale*) since they contained a large amount of dandelions. Due to the reduced clover content in grass paddocks, samples were not divided into clover and grass. From each grass sample a representative sample was deduced. All plant material from alfalfa and dandelion samples was used to estimate dry matter content, except for samples collected on day 23 where a representative sample was deduced from individual samples.

Pooled samples from alfalfa paddocks collected on day 12 were analyzed for FU, crude protein, crude fat, lysine and methionine. Pooled samples from alfalfa paddocks collected on day 23 and 37 respectively were analyzed for FU, crude protein, crude fat, lysine and methionine content separately with regard to alfalfa and dandelion. By mistake, samples from day 30 were not analyzed separately for alfalfa and dandelions. Thus, a mean of nutritional values of samples collected on day 23 and 37 were applied. Analyzing for FU, crude protein, crude fat, lysine and methionine for each sampling day made it possible to make a more precise estimate of forage crop nutritional value. Pooled samples collected from grass paddocks on day 12, 23, 30 and 37 respectively were analyzed for FU, crude protein and crude fat. Since grass paddocks were quickly uprooted by the pigs and grass intake suggested to be of minor importance, it was decided not to collect samples from grazed forage. Thus, grass intake could not be estimated and therefore all cut samples collected on day 12, 23, 30 and 37 were pooled prior to analysis for lysine and methionine.

Table 3.5. Nutrients in forage crop samples collected on day 12, 23, 30 and 37 during the 40-days experimental period.

Nutrients	Alfalfa			Dandelion	Grass
	Long	Short	Grazed		
Dry matter (DM) %					
Day 12	19.32				20.52
Day 23		18.15		14.36	19.15
Day 30		23.95	44.79	17.96	25.89
Day 37		22.36	40.04	16.53	23.47
Mean	19.32	21.49	41.99	16.28	22.26
Energy, FU kg^{-1} DM*					
Day 12	0.626				0.574
Day 23		0.773	0.223	0.73	0.521
Day 30			0.288		0.654
Day 37		0.71	0.165	0.752	0.554
Mean	0.626	0.742	0.229	0.741	0.576
Crude protein % (DM basis)					
Day 12	27.5				14.7
Day 23		31.4	13.6	25.3	13.8
Day 30			13.5		12.1
Day 37		28.7	9.7	25.6	13.3
Mean	27.5	30.1	12.3	25.5	13.5
Crude fat % (DM basis)					
Day 12	3.1				3.4
Day 23		4.0	1.3	5.3	3.2
Day 30			1.6		3.9
Day 37		3.7	1.1	5.0	3.5
Mean	3.1	3.9	1.3	5.2	3.5
Lysine, g 100 g^{-1} DM					
Day 12	1.392				
Day 23		1.742	0.657	1.383	0.714
Day 30					
Day 37		1.727	0.392	1.418	
Mean	1.392	1.735	0.525	1.401	0.714
Methionine, g 100 g^{-1} DM					
Day 12	0.362				
Day 23		0.449	0.153	0.446	0.219
Day 30					
Day 37		0.438	0.0885	0.466	
Mean	0.362	0.444	0.1208	0.456	0.219

*FU: Danish Feed Unit for growing-finishing pigs, 1 FU = 12.2 MJ ME (Christiansen, 2010).

Estimation of forage crop availability and nutrient content

Since the pigs were weighed on day 40 in the morning and each paddock comprised 462.5 m^2 at this point, estimations of crop availability and nutrient content were based on this figure. As described, forage crop sampling was conducted in zone 3, 6, 8 and 10 respectively in each paddock. Thus, it was possible to calculate estimates of crop availability and nutrient content in these areas. In the remaining zones estimates were based on estimates for zone 3, 6, 8 and 10 according to the shortest number of days between the day of access to an estimated zone and a non-estimated zone (Table 3.6). However, for alfalfa paddocks this procedure deviated slightly. Alfalfa plant height differed between sample day 12 and 23 since approximately 50% of each paddock had been cut on the 9th of August, which were expected to influence nutritional value. Alfalfa in zone 1 to 4 as well as 75% of zone 5 was high and 25% of alfalfa in zone 5 was low. Accordingly, for 75% of zone 5 estimates calculated for zone 3 were used and for 25% of zone 5 estimates from zone 6 were used. Due to dandelion only being present in the low alfalfa, estimates were only calculated for zone 5 (25% of availability in zone 6) to zone 10.

Table 3.6. Procedure when estimating availability and nutrient content of alfalfa, dandelion and grass in the 10 zones in each paddock during the 40-days experimental period. Bold zones indicate sampling. Non-bold zones indicate that estimates from sampled zones were applied.

		Estimates applied from zone:	
Zone	Access to zone, day	Alfalfa, Grass	Dandelion
1	0	3	-
2	5	3	-
3	13	3	-
4	16	3	-
5*	20	75% (zone 3), 25 % (zone 6)	25 % (zone 6)
6	23	6	6
7**	27	8	8
8**	30	8	8
9	34	10	9
10	37	10	10

*For grass in zone 5 estimates from zone 6 were applied.
**Nutritional value of alfalfa and dandelion in zone 7 and 8 were estimated by a mean of the nutritional value of alfalfa and dandelion respectively in zone 6 and zone 10.

3.4.3 Post-grazed forage crop samples

To estimate forage crop nutrient intake, two samples of grazed alfalfa were collected on day 23 (zone 3), 30 (zone 6) and 37 (zone 8) respectively in each paddock using a 50x50 cm steel frame. Thus, samples were collected in the zones where cut alfalfa crop samples previously had been collected. Sampling was performed one week after the pigs got access to the area. By using a rake it was possible to collect trampled alfalfa. The two samples collected from each zone were pooled. Samples were collected in a straight line from either the left or right side of the paddock (measured from the electric fence) according to a predetermined pattern and to avoid sampling in the same spots as pre-grazed sampling had been performed (Figure 3.4).

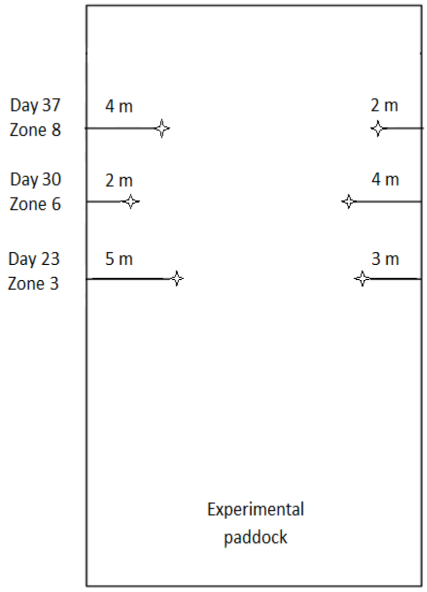

Figure 3.4. Day and pattern of grazed forage crop sampling in each paddock during the trial. Four-pointed star indicates sampling position.

Analysis

If possible, samples were weighed (fresh weight) immediately after collection and dried individually in the oven at 60°C for 72 hours to estimate dry matter content at paddock level. Otherwise, samples were stored at 5°C for later analysis. Afterwards, dried plant samples were grinded to one mm particles and sent for chemical analysis (Eurofins Steins 2013) (Table 3.5) Crude protein, amino acids, crude fat and FU were analyzed by the methods described in section 3.2. Fresh weight of samples collected on day 23 (zone 3) was very high compared to samples from day 30 and 37, which was suggested to be due to a relatively high amount of soil. Thus, it was decided to exclude dry matter analysis from samples collected on day 23 and apply dry matter estimates from day 30 (zone 6). In addition, results from the nutrient analysis were excluded and instead analysis results (FU, crude protein and crude fat) from a pooled sample of day 23 and day 30 were applied. A pooled sample from day 30 and day 37 respectively were analyzed for FU, crude protein and crude fat. Furthermore, a pooled sample collected on day 37 was analyzed for lysine and methionine. By mistake samples collected on day 23 (high alfalfa) and 30 (low alfalfa) were pooled and analyzed for lysine and methionine. Rather, samples collected on day 30 and 37 should have been pooled prior to analysis since the alfalfa was short on both days and therefore assumed to be of almost similar nutritional value. However, as effect of time on plant nutritional value was expected to be larger compared to effect of plant height, the analysis of the pooled samples of day 23 and 30 were used to estimate lysine and methionine of high alfalfa on day 23. For day 30 a mean of the analyses of lysine and methionine on day 30 and 37 were applied.

Estimation of nutrient content in alfalfa paddocks:
As described, post-grazed sampling was performed on day 23 (zone 3), 30 (zone 6) and 37 (zone 8). Estimates of energy and nutrient availability in these zones were applied to the remaining zones for each paddock. As described in section 3.4.2 on pre-grazed crop sampling, estimates were based on nutrient content in the 10 zones in each paddock in total comprising 462.5 m^2. Regarding method of applying estimates to the remaining zones, estimates of zone 1-4 were based on the estimated values of zone 3. For zone 5 and 7 estimates from zone 6 were applied. For zone 8, 9 and 10 estimates from zone 8 were applied.

3.4.4 Soil samples

To estimate earthworm availability soil samples were collected every Monday (day 12, 19, 26 and 33) in the pasture area, which the pigs would get access to on the following day. On day 12 a sample measuring 25x25x25 cm was collected from every paddock with a spade. On day 19, 26 and 33 the samples collected measured 20x20x20 cm. Soil samples were collected one meter from the rear fence in a straight line from either the left or right side of the paddock (measured from the electric fence) according to a predetermined pattern (Figure 3.5).

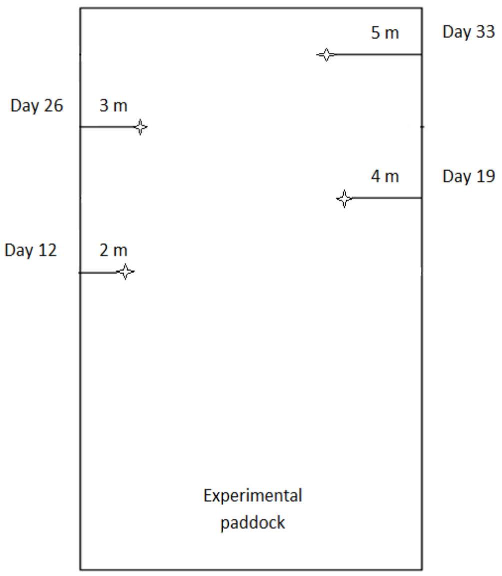

Figure 3.5. Pattern of soil sampling in each paddock during the trial.
Four-pointed star indicates sample location.

Analysis

A total of 48 soil samples were collected during the experimental period and stored at 5°C. Due to limitations on time, only the twenty-four samples from day 12 and 19 were sorted by hand for earthworms. They were collected in aluminum trays (paddock level) and stored at -19°C. Later, earthworms were defrosted, washed, weighed and sent frozen for chemical analysis (Eurofins Steins, 2013) (Table 3.7). Nutrient content was analyzed according to the methods described in section 3.2 except for dry matter, which was measured by freeze drying (lyophilized) (EU Regulation 152 2009).

Since alfalfa paddocks were well-established and grass paddocks newly-established earthworm contents from alfalfa and grass paddocks were analyzed separately regarding dry matter and crude protein. Dry matter and crude protein were analyzed on a pooled sample from alfalfa paddocks 2, 8 and 12, a pooled sample from grass paddocks 4, 6 and 11 (all collected on day 12), a pooled sample from alfalfa paddocks 1, 7 and 9 and a pooled sample from grass paddocks 3, 5 and 10 (all collected on day 19). Earthworm species contain different amounts of various amino-acids. This is a reflection of consumed bacterial populations, which are one of earthworms' main sources of essential amino acids as described by Pokarzhevskii *et al.* (1997). Since the paddocks were established on the same field with a similar soil type, earthworm species were expected not to differ between paddocks with alfalfa and grass. Hence, earthworms in soil samples from alfalfa and grass paddocks collected on day 12 and 19 were pooled prior to analysis for lysine and methionine. In addition, energy and crude fat content were analyzed on a pooled sample from alfalfa and grass paddocks collected on day 12 and 19. Earthworm samples were considered representative for the entire 40-days experimental period. Thus, mean estimates from the two sampling days were calculated.

Table 3.7. Earthworm nutrient content from soil samples collected in alfalfa and grass paddocks on day 12 and 19 during the 40-days experimental period. Analysis for FU, crude fat, lysine and methionine are from a pooled sample from alfalfa and grass paddocks on day 12 and 19.*

	Earthworm nutrient content	
	Alfalfa paddocks	Grass paddocks
Dry matter (DM) %		
Day 12	26.7	27.8
Day 19	27.3	27.0
Energy, FU kg^{-1} DM*		
Day 12 + 19	0.646	0.646
Crude fat % (DM basis)		
Day 12 +19	3.6	3.6
Crude protein % (DM basis)		
Day 12	43.8	42.0
Day 19	40.4	50.6
Lysine, g 100 g^{-1} DM		
Day 12 + 19	2.51	2.51
Methionine, g 100 g DM^{-1}		
Day 12 + 19	0.726	0.726

* FU: Danish Feed Unit for growing-finishing pigs, 1 FU = 12.2 MJ ME (Christiansen 2010).

3.4.5 Behavioural observations

Behavioural observations were performed to investigate effect of forage crops and concentrate feed treatments on pig behaviour. During the experimental period behavioural observations were conducted three days every week on Tuesdays, Wednesdays and Thursdays (day 13, 14, 15, 20, 21, 22, 27, 28, 29, 34, 35, 36). At each observation day pigs were observed from 8.30-10.00 am, 10.30-12.00 am, 1.30-3.00 pm, 3.30-5.00 pm and 5.30-7.00 pm. Behavioural elements were recorded as scan sampling at two minutes intervals (Martin & Bateson, 2007). See appendix 4 for the recording sheet used. Definitions of the recorded behaviours are given in Table 3.8.

Observation order of paddocks was randomized between blocks and within block. The paddocks were observed in pairs (1-2, 3-4, 5-6, 7-8, 9-10, 11-12). A dice was used to decide which block to observe first and the subsequent blocks were observed in numerical order. The same pattern was applied within blocks. Two neighbouring paddocks or the behaviour of six pigs were observed for fifteen minutes (seven scan samplings per pig five times during a day). Thus, in total each pig was scan sampled 420 times from day 13 to day 36. The behavioural elements were recorded by the same two observers throughout the entire experimental period. The observer was placed outside the paddocks approximately seven meters from the fence in a vehicle and did not intervene with the pigs. Three minutes were available to move to the subsequent paddocks and accustom the pigs to the arrival and presence of the vehicle.

Table 3.8. Definitions of pig behaviour recorded during observations.
(mod. a. Studnitz 2001; Stern & Andresen 2003; Horsted et al. 2012; Jakobsen 2013 pilot study).

Behaviour	Definition
Eating concentrates	The pig has its snout in the feed trough, either eating concentrates or searching (sniffing, licking) for left overs. The pig is lifting its head from the feed trough and is chewing. The pig is eating left overs right beside the feed trough.
Grazing*	The pig is pulling/biting of grass, alfalfa or other forage items with the mouth. The pig is chewing and or swallowing grass, alfalfa or other forage items.
Rooting*	The pig´s snout is in the soil with shovelling and forward headed movements along or into the soil. The back can be relaxed or arched.
Rooting and chewing*	The pig is rooting and right after the head is lifted and chewing is visible.
Resting	The pig is lying immobile either in ventral position or on the side with eyes open or closed. The pig is sitting with front legs stretched and hooves on the ground. Hindquarters and body are immobile. Head might be moving.
Hut	The whole body of the pig is inside the hut. The pig might be standing so the head is outside the hut.
Other activities	Drinking, walking, standing, social interaction (e.g. playing), grooming, wallowing.

*If a pig was grazing, rooting or rooting *and* chewing while performing other behaviours, grazing, rooting or rooting *and* chewing were recorded.

On all days of behaviour observation, climatic conditions including air temperature (Figure 3.6), wind (no wind, light wind, medium wind and strong wind) and weather (sunny, light clouds, heavy clouds, light rain, heavy rain), according to description by Kongsted *et al.* (2013), were recorded every fifteen minutes (*n* = 360). This made it possible to investigate pig behaviour in relation to climatic conditions.

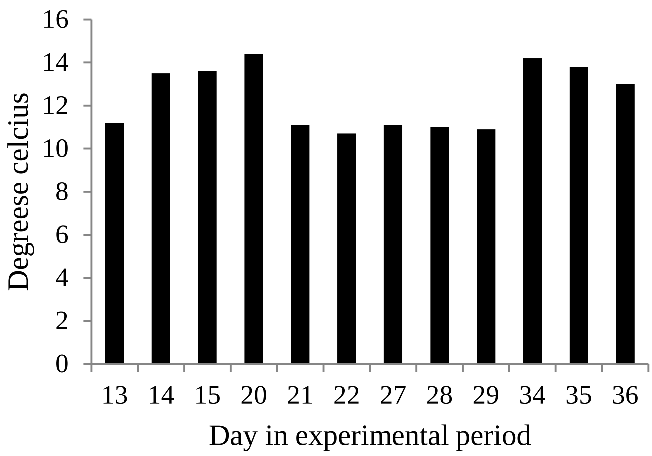

Figure 3.6. Mean daily temperature during the behavioral observations.

3.4.6 Live weight and back fat

In order to measure pig performance (daily weight gain and feed conversion ratio) pigs were weighed prior to insertion to the paddocks (day zero) and at the end of the experiment (day 40). Additionally, on day 37 a trained person scored body condition for each pig according to a five level scale where '1' was very lean and '5' was very fat as described by Bonde *et al.* (2004). During body condition scoring it was decided to implement half scores. Thus, a pig was scored according to a 10 level scale. As the majority of pigs across treatments received the same score, no statistical analysis of the data was performed. Back fat was measured on an individual basis (right above the last rib and seven cm from the backbone) with an ultrasound scanner (USM 32 Krautkramer®) (Madsen *et al.* 2008).

Table 3.9 summarizes the recordings conducted during the 40-days experimental period.

Table 3.9. Recordings obtained during the 40-days experimental period.

Week	Date	Weekday	Day	Weight	BCS*	Back fat	Stomachs	Soil	Pre-grazed	Post-grazed	Paddock expansion**	Paddock assessment	Behaviour
36	04-09-2013	Wedn	0	X									
	05-09-2013	Thurs	1										
	06-09-2013	Fri	2										
	07-09-2013	Sat	3										
	08-09-2013	Sun	4										
37	09-09-2013	Mon	5								X		
	10-09-2013	Tues	6										
	11-09-2013	Wedn	7										
	12-09-2013	Thurs	8										
	13-09-2013	Fri	9										
	14-09-2013	Sat	10										
	15-09-2013	Sun	11										
38	16-09-2013	Mon	12					X (1x12)	X (2x12)			X	
	17-09-2013	Tues	13								X		X
	18-09-2013	Wedn	14								X		X
	19-09-2013	Thurs	15								X		X
	20-09-2013	Fri	16								X	X	
	21-09-2013	Sat	17										
	22-09-2013	Sun	18										
39	23-09-2013	Mon	19					X (1x12)					
	24-09-2013	Tues	20								X		X
	25-09-2013	Wedn	21								X		X
	26-09-2013	Thurs	22								X		X
	27-09-2013	Fri	23						X (2x12)	X (2x6)	X		
	28-09-2013	Sat	24										
	29-09-2013	Sun	25										
40	30-09-2013	Mon	26					X (1x12)				X	
	01-10-2013	Tues	27								X		X
	02-10-2013	Wedn	28								X		X
	03-10-2013	Thurs	29								X		X
	04-10-2013	Fri	30						X (2x12)	X (2x6)	X	X	
	05-10-2013	Sat	31										
	06-10-2013	Sun	32										
41	07-10-2013	Mon	33					X (1x12)					
	08-10-2013	Tues	34								X		X
	09-10-2013	Wedn	35								X		X
	10-10-2013	Thurs	36								X		X
	11-10-2013	Fri	37		X	X			X (2x12)	X (2x6)	X	X	
	12-10-2013	Sat	38										
	13-10-2013	Sun	39										
42	14-10-2013	Mon	40	X							X		

*BCS = body condition score. **Paddock expansion: Alternating between weeks within blocks with either three meters on Tuesdays or one meter on Tuesdays, Wednesdays and Thursdays respectively (see Appendix 1)

3.5 Statistical analysis

The statistical analyses were performed in SAS (SAS Institute 2013a). All data underwent a check for normal distribution by using the Proc Univariate procedure in SAS (SAS Institute 2013b). Homogeneity of variance was examined by plotting residuals against predicted values. All interactions and main effects with significance level above (P>0.10) were removed one by one and the analysis repeated.

3.5.1 Alfalfa intake

Effect of concentrate feed treatments on estimated intake of alfalfa (group level, n = 12) was investigated by a linear mixed model (1) using the Proc Mixed procedure in SAS (SAS Institute 2013c).

$$Y_{il} = \mu + \alpha_i + \delta_l + \varepsilon_{il} \qquad (1)$$

Y_{il} is the response variable for each group of pigs (intake g pig^{-1} day^{-1}); μ is the general level of intake of the various nutrients (intercept); a_i is the fixed effect of concentrate feed (i = HP, LP); δ_l is the fixed effect of block (l = 1, 2, 3) and ε_{il} is experimental error.

3.5.2 Behaviour

Effect of concentrate feed and forage crop treatments on occurrence of behavioural elements was investigated by the following model (2) using the Proc Mixed procedure in SAS (SAS Institute 2013c) where Y_{ijlmno} is the behaviour in percentage of daily group sums, (n = 105).

$$Y_{ijlmno} = \mu + \alpha_i + \beta_j + \delta_l + D_m + W_n + P_o + (a\beta)_{ij} + (\alpha D)_{im} + (\beta D)_{jm} + (\alpha W)_{in} + (\beta W)_{jn} + (DW)_{mn} + (\alpha P)_{io} + (\beta P)_{jo} + (a\beta D)_{ijm} + (a\beta W)_{ijn} + (a\beta P)_{ijo} + \varepsilon_{ijlmno} \qquad (2)$$

Rooting and *rooting and chewing* were summed and named *rooting*, due to the latter activity constituting only a minor part of total rooting activity. Apart from analysing *rooting* and *grazing* as individual categories they were summed and analysed representing total foraging activity. Furthermore, *hut* and *resting* were analysed as individual categories as well as summed to analyse total resting behaviour since behaviour in *hut* was predominantly observed to be related to resting. *Rooting, foraging, eating concentrates, grazing* and *other activities* were square root transformed to obtain an approximately normal distribution. For each group of pigs, observations right next to each other in time (observation day) were assumed to be highly correlated - an effect which is reduced as observations get further apart. Thus, the observations have an autoregressive structure, which in SAS is specified by Type = AR (1) using the Repeat function (co-variance structure) (SAS 2013d).

The notation for α_i and δ_l, is similar to Equation 1. β_j is the fixed effect of forage crop (j = alfalfa, grass); μ is the general level of each behaviour in percentage of daily group sums; D_m is the effect of day (m = 1, 2, 3 in each week); W_n is the effect of week (n = 1, 2, 3, 4) and P_o is a covariate representing the effect of weather (o = sunny, light clouds, heavy clouds, light rain, heavy rain). Furthermore, the following two-way and three-way interactions were included in the mode: feed and forage crop ($a\beta_{ij}$), concentrate feed and day (αD_{im}), forage crop and day (βD_{jm}), concentrate feed and week (αW_{in}), forage crop and week (βW_{jn}), day and week (DW_{mn}), concentrate feed and weather (αP_{io}), forage crop and weather (βP_{jo}), concentrate feed, forage crop and day ($a\beta D_{ijm}$), concentrate feed, forage crop and week ($a\beta W_{ijn}$) and concentrate feed, forage crop and weather ($a\beta P_{ijo}$). ε_{ijlmno} is experimental error. Weather was included as this variable was assumed to be the most important regarding impact on behaviour. Temperature was not included as it was relatively constant throughout the twelve observation days (Figure 3.6). To investigate any effects of wind on behavior it was included in the final model.

3.5.3 Performance

The effect of concentrate feed and forage crop treatments on daily weight gain and back fat (animal level, n = 36) was investigated by the following linear mixed model (3) using the Proc Mixed procedure in SAS (SAS Institute 2013c).

$$Y_{ijkl} = \mu + \alpha_i + \beta_j + \gamma_k + \delta_l + (a\beta)_{ij} + (a\gamma)_{ik} + \beta\gamma_{jk} + \delta W_{ijkl} + A_{ijl} + \varepsilon_{ijkl} \quad (3)$$

Y_{ijkl} is the response variable for the individual pig (daily weight gain or back fat). The notation for α_i, β_j and δ_l, is similar to Equation (2). μ is the general level for daily weight gain and back fat respectively; γ_k is the fixed effect of gender (k = female, castrated male); $(a\beta)_{ij}$ is the two-way interaction between concentrate feed and forage crop; $(a\gamma)_{ik}$ is the two-way interaction between concentrate feed and gender; $\beta\gamma_{jk}$ is the two-way interaction between forage crop and gender. δW_{ijkl} is a covariate with W representing the start weight of the pigs and δ the corresponding regression parameter (i = HP, LP; j = alfalfa, grass; k = female, castrated male; l = block: 1, 2, 3); A_{ijl} is the random effect of group (i = HP, LP; j = alfalfa, grass; l = block: 1, 2, 3) and ε_{ijkl} is experimental error. One pig (no. 123, female) suffered from a chronic joint infection and was therefore excluded from the statistical analysis.

Effect of concentrate feed and forage crop treatments on feed conversion ratio was analysed at group level (n = 12) (Equation 4).

$$Y_{ijkl} = \mu + \alpha_i + \beta_j + \gamma_k + \delta_l + (a\beta)_{ij} + (a\gamma)_{ik} + \beta\gamma_{jk} + \delta W_{ijkl} + \varepsilon_{ijkl} \quad (4)$$

Y_{ijkl} is the response variable for each group of pigs (weight gain FU^{-1}); μ is the general level for weight gain per FU. The notation is the same as in Equation (3) but with W representing mean start weight of each group of pigs.

4. Results

4.1 Paddock appearance

Difference between paddocks in paddock appearance at the end of the 40-days experimental period, (day 37) is presented in Table 4.1. For all treatments the vast majority of the paddock area was uprooted with negligible differences within treatment. In grass paddocks with LP pigs the total area was uprooted. The largest difference was seen between grass paddocks with LP treated pigs and alfalfa paddocks with HP pigs.

Table 4.1. Paddock appearance on the last day of assessment (day 37). Percentage rooted and plant cover =100%. Presented as a mean of the nine zones in every paddock for each of the four treatments. HP = high protein, LP = low protein.

	Area rooted: (%)	Deep rooted[a] >10 cm (%)	Plant cover (%)	Plants trampled[b] (%)	Stems without leaves (%)[c]	Plant height (cm)
Alfalfa HP	81.4	0	18.8	11.8	83.3	17
Alfalfa LP	95.3	0.1	4.7	3.0	95.5	21
Grass HP	92.6	0.5	7.5	3.1	-	9
Grass LP	99.9	5.5	0.1	0.1	-	0

[a]In percentage of area rooted. [b]In percentage of plant cover. [c]In percentage of alfalfa plants standing.

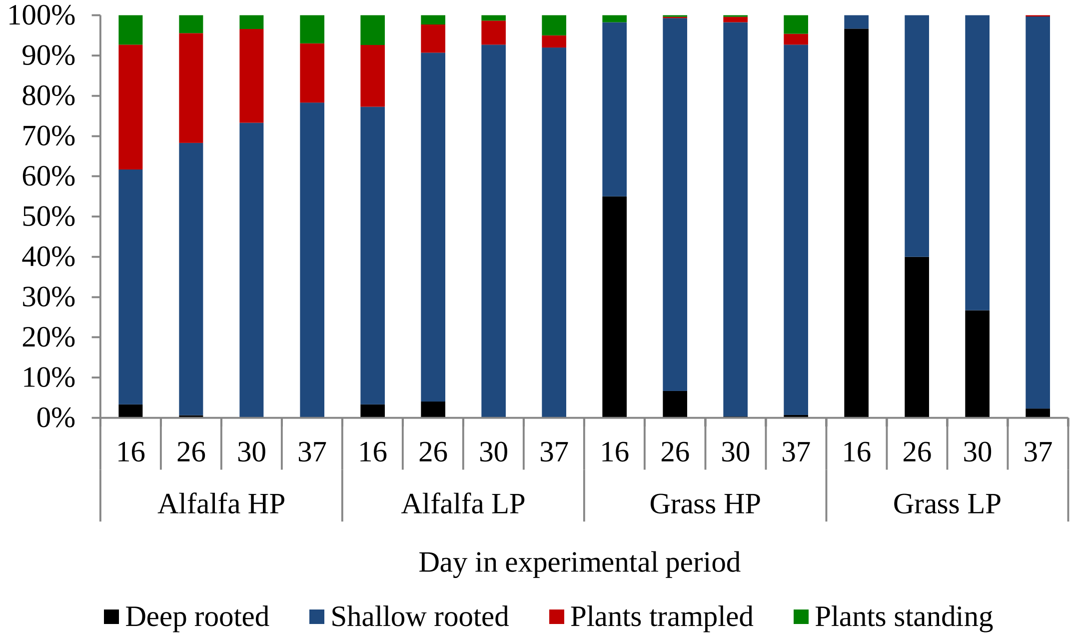

Figure 4.1. Development in paddock appearance of zone 3 during the 40-days experimental period, presented as a mean of each of the four different treatments; Alfalfa HP, alfalfa LP, grass HP, grass LP. HP = high protein, LP = low protein. Pigs were given access to zone 3 on day 13.

4. Results

The effect of treatments on paddock development during the experimental period represented by zone 3 is presented in Figure 4.1. Total rooted area increased in alfalfa paddocks for both feed treatments. Already from day 16, it was evident that in grass paddocks with LP treatment there were no plants standing. Pigs were given access to zone 3 on day 13. Hence, this shows how fast they were capable of disturbing plant cover.

Figure 4.2 shows the effect of treatments on plant height development during the trial, represented by zone 3. In zone 3, alfalfa mean height was 51 cm prior to pig access. Thus, for both feed treatments alfalfa plant height was reduced considerably already three days after access. Furthermore, the difference between treatments in terms of alfalfa plant height was considerable with a similar decrease from day 16 to day 30. However, from day 30 to day 37 the decrease was clearly larger in paddocks with LP pig compared to paddocks with HP pigs.

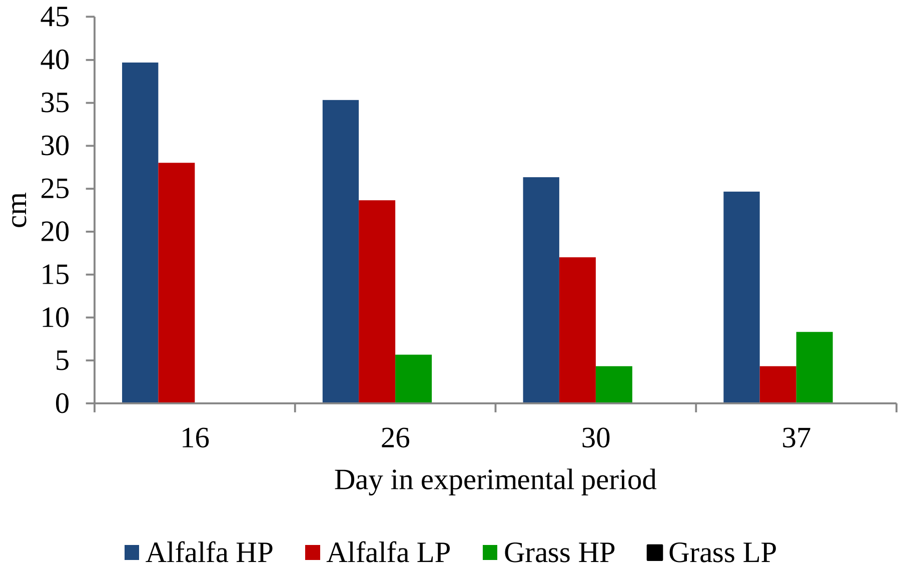

Figure 4.2. Plant height development in paddocks during the experimental period, represented by zone 3. HP = high protein, LP = low protein. Pigs were given access to zone 3 on day 13.

4.2 Biomass availability and estimated alfalfa intake

Estimated yields of alfalfa, dandelion and grass are presented in Table 4.2. Based on dry matter only a 5% higher yield was seen in grass paddocks compared to alfalfa paddocks (dandelion included). The differences in yields between paddocks were higher for grass (min. 1388; max. 1793 kg ha^{-1}) and dandelion (min. 174; max. 445 kg ha^{-1}) compared to alfalfa (min. 1212; max. 1374 kg ha^{-1}).

Table 4.2 also shows estimated nutrient availability of forage crop in alfalfa paddocks and grass paddocks. Regarding dry matter availability, pigs in alfalfa paddocks had 555 and pigs in grass paddocks 644 g pig^{-1} day^{-1} corresponding to 2.9 and 3 kg fresh weight pig^{-1} day^{-1}

respectively. Minimum and maximum values were 507 and 617 g dry matter in alfalfa paddocks and 592 and 709 g in grass paddocks. Thus, a 14% higher dry matter availability was found in grass paddocks compared to alfalfa paddocks. Energy content (FU pig^{-1} day^{-1}) was similar for grass paddocks and alfalfa paddocks, whereas crude protein availability was 42% higher in alfalfa paddocks compared to grass paddocks. Furthermore, lysine availability was 44 % higher in alfalfa paddocks compared to grass paddocks.

Table 4.2. Mean yield and mean nutrient availability (dry matter basis) of alfalfa, dandelion, grass and earthworms in paddocks during the 40-days experimental period. Estimates are based on pre-grazed forage crop samples and soil samples.

	Alfalfa paddocks		Grass paddocks
	Alfalfa	Dandelion	Grass
Yields, kg ha^{-1}			
Fresh weight	6538	1612	7586
Dry matter	1293	263	1630
Nutrients, g pig^{-1} day^{-1}			
Dry matter	511	44	644
FU* pig^{-1} day^{-1}	0.34	0.033	0.370
Crude fat	17	2.3	22
Crude protein	144	11	89
Lysine	7.547	0.622	4.598
Methionine	1.953	0.203	1.410
Earthworm nutrients, g pig^{-1} day^{-1}			
Dry matter	203		115
FU* pig^{-1} day^{-1}	0.131		0.075
Crude fat	7		4
Crude protein	84		55
Lysine	5.090		2.908
Methionine	1.472		0.841

*FU: Danish Feed Unit for growing-finishing pigs, 1 FU = 12.2 MJ ME (Christiansen, 2010).

Estimated availability of earthworm biomass and earthworm nutrient content is presented in Table 4.2. Earthworm dry matter availability was 43% higher in alfalfa paddocks compared to grass paddocks. However, dry matter availability differed considerably between grass paddocks (min. 64; max. 211 g pig^{-1} day^{-1}) and less between alfalfa paddocks (min. 153; max. 284 g pig^{-1} day^{-1}). The difference in earthworm dry matter availability between alfalfa and grass paddocks was reflected in a 34% higher crude protein and a 43% higher lysine availability in alfalfa paddocks compared to grass paddocks. Furthermore, the variation between alfalfa paddocks in terms of crude protein (min. 65; max. 118 g pig^{-1} day^{-1}) and lysine (min. 4.3; max. 7.1 g pig^{-1} day^{-1}) was considerable. A similar picture was seen for grass paddocks with a min. and max. crude protein level of 51 and 100 g pig^{-1} day^{-1} respectively and a lysine availability with a minimum of 1.6 and a maximum of 5.3 g pig^{-1} day^{-1}.

4. Results

Effect of concentrate feed treatment on estimated alfalfa intake is presented in Table 4.3. The analysis showed no significant effect of feed treatments on dry matter intake, although there was a tendency to a significantly higher intake in pigs receiving LP feed compared to pigs on HP feed treatment. On average, estimated dry matter intake amounted to 400 g pig^{-1} day^{-1} with a minimum of 311 and a maximum of 508 g pig^{-1} day^{-1} corresponding to 2.3 and 2.6 kg fresh weight pig^{-1} day^{-1}. Average daily intake of energy (min. 0.29; max. 0.37 FU pig^{-1}), crude protein (min. 118; max. 140 g pig^{-1}) and lysine (min. 6.5; max. 8.2 g pig^{-1}) was higher for LP treated pigs compared to HP treated pigs but the levels were not significantly different.

Table 4.3. Effect of treatments (HP = high protein, LP = low protein) on estimated nutrient intake from grazing alfalfa (g pig^{-1} day^{-1}) (dry matter basis). Least square-means, standard errors (SE) and P-values. Estimates are based on pre- and post-grazed alfalfa crop samples.

Feed:	**Dry matter**	(SE)	*P*-value	**FU***	(SE)	*P*-value	**Crude protein**	(SE)	*P*-value	**Lysine**	(SE)	*P*-value	**Methionine**	(SE)	*P*-value
HP	330	23.50		0.32	0.015		127.7	6.36		6.9			1.9	0.088	
LP	470	23.50		0.35	0.015		144.3	6.36		7.7			2.1	0.088	
			0.05			0.30			0.21			0.26			0.28

*FU: Danish Feed Unit for growing-finishing pigs, 1 FU = 12.2 MJ ME (Christiansen, 2010).

4.3 Pig behaviour

Effect of forage crop, concentrate feed and feed x crop interactions on pig behaviour were investigated by analysing daily proportions of individual behavioural categories in percentage of all observations (Table 4.4). Regarding feed and crop interactions, a significant effect was found for rooting behaviour but not grazing behaviour. For both crops, LP pigs rooted significantly more than HP pigs but the effect of feed was larger in grass (44 vs. 19% of total observations) compared to alfalfa (28 vs. 16%). In terms of main effects, grazing was not observed significantly more in pigs receiving LP treatment compared to HP treated pigs. However, it turned out to be significantly affected by forage crop treatment with grazing activity in grass paddocks constituting 41% of that observed in alfalfa paddocks. Week significantly affected grazing behaviour with slightly increasing levels throughout weeks (LS-means: week 1=4.7%, week 2=6.3%, week 3=6.7%, week 4=10.5%, P <0.0001) but no such effect was found for rooting behaviour (week 1=25.3%, week 2=25.4, week 3=23.5%, week 4=28.7%, P = 0.27). Weather and wind turned out not to have significant effects on rooting nor grazing.

For total resting behaviour (pigs resting and pigs in hut) there was a tendency (P = 0.05) to a significant effect of feed and forage crop interactions. Pigs receiving LP treatment in grass paddocks were observed resting less compared to the other feed and forage crop interactions. Regarding main effects, total resting behaviour was significantly affected by concentrate feed treatment, with resting behaviour for LP pigs constituting 67% of resting behaviour recorded in HP treated pigs. Total resting behaviour turned out not to be affected by forage crop treatment. In addition, week did not have a significant effect on total resting behaviour (LS-means: week 1=48.2%, week 2=47.7%, week 3=53.3%, week 4=45.1%, P = 0.12). The same was true for effect of weather and wind, although weather significantly affected pigs in hut (P <0.0001) as could be expected.

Figure 4.3 shows the diurnal pattern of foraging behaviour (rooting and grazing) for each of the four treatments. For all treatments foraging was decreasing from feeding at 8:00 until midday, except for HP treated pigs in alfalfa paddocks where a slight increase was seen from 10:00 to 12:00. During the afternoon there was a general trend of an increase in foraging behaviour for LP pigs, followed by a short period of decrease. In late afternoon these pigs again increased foraging, which then declined rapidly from 16:00 until the end of the observation period. In comparison HP pigs had a more slow increase in foraging behaviour during the afternoon. HP treated pigs in grass paddocks also decreased foraging behaviour from 16:00 until the end of the observations period but the decrease were more gradual compared to LP pigs. In alfalfa paddocks HP pigs increased their foraging behaviour until 17:00 after which there was a sharp decline until the end of the observation period.

Table 4.4. Effect of treatment (HP=high protein vs. LP=low protein; alfalfa vs. grass and feed crop interactions) on daily frequencies of behavior in percentage of all observations; Least square-means (back transformed for rooting and grazing), standard errors (SE) and P-values. Total resting behavior includes resting and in hut. Figures with different superscript letters indicate significance.

	Rooting	(SE)	*P*-value	**Grazing**	(SE)	*P*-value	**Total resting**	(SE)	*P*-value
Feed:									
HP	17.1[a]	1.28		6.7	1.56		58.0[a]	1.80	
LP	36.0[b]	1.28		7.0	1.56		39.1[b]	1.80	
			<0.0001			0.8			<0.0001
Crop:									
Alfalfa	21.5[a]	1.28		10.3[a]	1.56		50.4	1.65	
Grass	30.3[b]	1.28		4.2[b]	1.56		46.8	1.65	
			<0.0001			<0.0001			0.1
Feed x Crop:									
HP, Alfalfa	15.5[a]	1.80		10.6	2.17		57.6	2.31	
LP, Alfalfa	28.4[b]	1.80		9.7	2.17		43.1	2.31	
HP, Grass	18.8[a]	1.80		3.6	2.17		58.6	2.31	
LP, Grass	44.4[c]	1.80		4.7	2.17		34.9	2.31	
			<0.0001			0.4			0.05

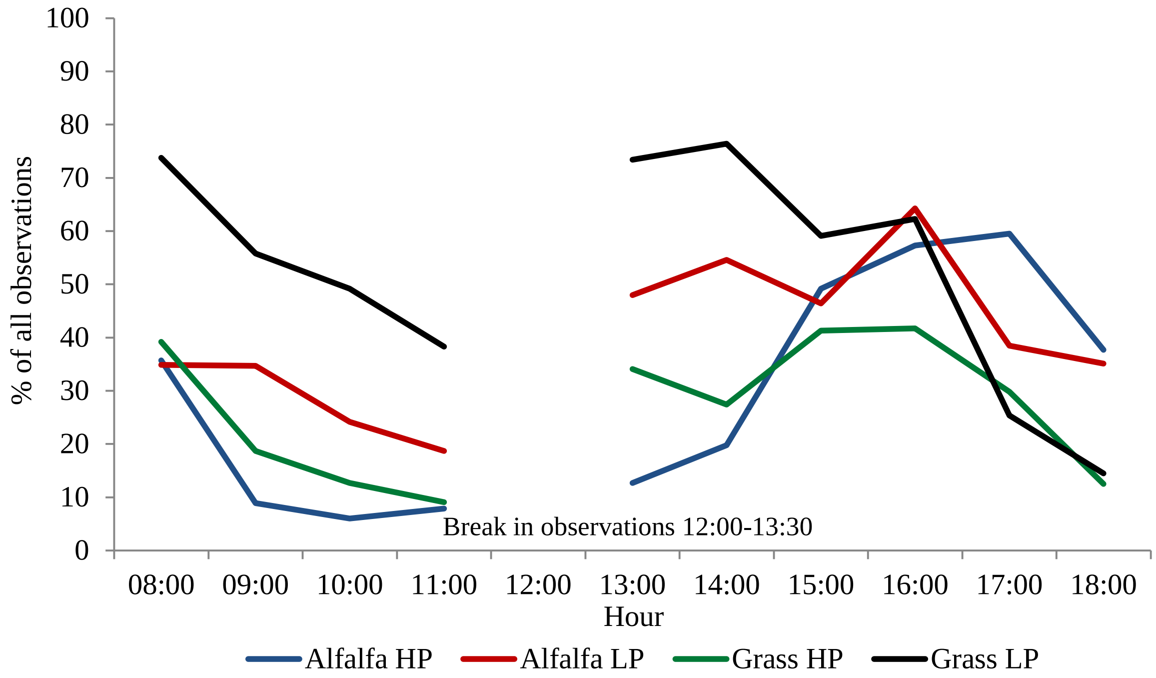

Figure 4.3. Diurnal pattern of pig foraging behaviour (rooting and grazing in percentage of all observations) presented as a mean of each of the four treatments. HP = high protein, LP = low protein.

4.4 Pig performance and body condition

Effects of concentrate feed, forage crop and feed x crop interactions on daily weight gain, feed conversion ratio and back fat are presented in Table 4.5. Significant interactions between feed and forage crop were observed on daily weight gain and feed conversion ratio. LP treated pigs in alfalfa paddocks turned out to have a significantly higher daily weight gain compared to LP treated pigs in grass paddocks as well as a significantly improved feed conversion ratio. Weight difference between HP and LP treated pigs was only 18% in alfalfa paddocks whereas it was 33% in grass paddocks. Regarding main effects of feed and forage crop, they significantly affected daily weight gain as well as feed conversion ratio. For back fat no significant effect of feed and crop interactions or main effect of feed was observed. However, back fat tended to be higher in pigs in alfalfa paddocks compared to pigs in grass paddocks. As expected in terms of gender, castrated male pigs tended to have significantly higher back fat depth compared to female pigs (LS-means 7.4 vs. 7 mm, P = 0.05). The vast majority of pigs (32) received body condition score 3. Only three pigs received score 2.5, which was the lowest score appointed. Thus, LP treated pigs had scores comparable with HP treated pigs, indicating that no pigs suffered ill effects due to the reduced protein treatment.

Table 4.5. Effect of treatments (HP=high protein vs. LP=low protein; alfalfa vs. grass and feed crop interactions) on pig performance. Least square-means, standard errors (SE) and P-values. Figures with different superscript letters indicate significance.

	Daily weight gain, g pig^{-1}	(SE)	*P*-value	**Feed conversion ratio**, FU* kg^{-1} weight gain	(SE)	*P*-value	**Back Fat**, mm pig^{-1}	(SE)	*P*-value
Feed:									
HP	889[a]	0.02		2.56[a]	0.04		7.1	0.16	
LP	665[b]	0.02		3.35[b]	0.04		7.4	0.17	
			<0.0001			<0.0001			NS
Crop:									
Alfalfa	820[a]	0.02		2.75[a]	0.05		7.4	0.17	
Grass	733[b]	0.02		3.17[b]	0.05		7.0	0.17	
			0.003			<0.0001			<0.1
Feed x Crop:									
HP, Alfalfa	900[a]	0.03		2.54[a]	0.07		7.2	0.23	
LP, Alfalfa	741[b]	0.03		2.95[b]	0.06		7.7	0.25	
HP, Grass	878[a]	0.03		2.59[a]	0.06		6.9	0.23	
LP, Grass	589[c]	0.03		3.75[c]	0.07		7.1	0.23	
			0.02			<0.0001			NS

*FU: Danish Feed Unit for growing-finishing pigs, 1 FU = 12.2 MJ ME (Christiansen, 2010).

5. Discussion

The point of departure in the discussion is the results of the measurements and analysis performed during the experiment, combined with knowledge from the literature review.

5.1 Pig performance

Feed and crop interactions were found to have a significant effect on daily weight gain and feed conversion ratio. For LP pigs in alfalfa paddocks a 20% reduction in energy and a 48% reduction in crude protein decreased daily weight gain with 18%, resulting in 14% poorer feed conversion ratio compared to HP pigs in alfalfa paddocks restricted 20% in energy. However, for LP pigs in grass paddocks the effect was a 33% decrease in daily weight gain and 31% poorer feed conversion rate compared to HP pigs in grass paddocks. LP pigs received 2.17 FU (26.5 MJ ME) and 203 g crude protein pig^{-1} day^{-1} and still pigs in alfalfa paddocks were able to maintain an average daily weight gain of 741 g, which was significantly higher compared to 589 g by LP pigs in grass paddocks. Thus, even though LP pigs were not able to fully compensate by foraging in the range area, the results suggest that in particular LP pigs in alfalfa paddocks benefitted considerably from the supply of energy and nutrients in the range area. Furthermore, pig performance must be viewed in the context of concentrates being fed *ad libitum* until the start of the experiment at a mean live weight of 58 kg. In addition, the digestive system had not been adapted to a high forage intake, underpinning the effect of direct foraging.

Hence, the hypothesis that pigs restricted in protein were expected to have a higher intake from the range area and by that to some extent compensate as reflected in performance compared to non-restricted pigs was verified in particular for LP pigs in alfalfa paddocks. In addition, the hypothesis that protein restricted pigs in alfalfa paddocks were expected to have a higher forage intake from the range area resulting in less affected performance compared to protein restricted pigs in grass paddocks was verified. However, the observed difference in performance between LP pigs in alfalfa paddocks and LP pigs in grass paddocks may have been less pronounced if the clover content in grass paddocks had been higher, thereby increasing supply of protein.

LP pigs in grass paddocks exhibited a considerably higher frequency of rooting behaviour compared to the other treatments, which was hypothesized to contribute to nutritional requirements. However, according to observed performance, nutrient contribution from foraging below ground is suggested to have been of minor importance. HP pigs received 2.25 FU (27.5 MJ ME) and 399 g crude protein pig^{-1} day^{-1} and maintained high daily weight gains with on average 900 and 878 g for pigs in alfalfa and grass paddocks respectively. This suggests that even though pigs were restricted 20% in energy they benefitted from foraging in the range area. It may also have been due to a considerably higher protein content in the organic feed mixture compared to requirements.

For HP pigs and LP pigs in alfalfa paddocks, average daily weight gain was relatively high compared to key figures for Danish organic pig herds with an average daily gain of 770 g pig^{-1} (Farming Info 2012). However, the basis for these figures is a rather large difference in daily weight gain with a min. and max of 594 and 969 g pig^{-1} day^{-1} respectively. Values for feed conversion ratio (HP alfalfa = 2.54; HP grass = 2.59; LP alfalfa = 2.95 FU kg^{-1} weight gain) were lower compared to key figures with an average of 3.09 FU kg^{-1} weight gain (min. 2.88; max. 3.31). However, it must be noted that key figures were based on 10 organic herds and 35,490 growing-finishing pigs of which the majority was housed indoors. In addition, key figures were based on an average start weight of 21.2 kg until slaughter, which is within a different weight range compared to the present study.

Compared with other studies on growing pigs in pasture systems, daily weight gain of pigs in alfalfa paddocks and HP pigs in grass paddocks was higher compared to the values observed in the study by Stern & Andresen (2003) with 811 and 686 g on 80 vs. 100% of recommended feed allowance and 634 and 737 g on 80 vs. 100% of recommended feed allowance in the study by Strudsholm & Hermansen (2005). Furthermore, feed conversion ratio, except for LP pigs in grass paddocks, were improved compared to the levels found in Strudsholm & Hermansen (2005) with 3 and 3.4 FU kg^{-1} weight gain for 80 vs. 100% of recommended feed allowance.

Regarding back fat no significant effect of feed and forage crop interactions was found, but a tendency to a significant effect of forage crop was observed with higher back fat in pigs in alfalfa paddocks compared to pigs in grass paddocks. This is suggested to be due to the higher forage intake observed for pigs in alfalfa paddocks, supplying the pigs with energy.

From a practical point of view, restricted feeding may have implications for the farmer in terms of quality supplemental payments for pig carcasses. Payments are set according to slaughtered weight, lean meat percentage and back fat (Friland 2013). For organic pigs, total lean meat percentage must be a minimum of 56% and back fat within a range of 10-22 mm (Friland 2013). Normally, outdoor pigs often have high lean meat content (Strudsholm 2004), although it was not possible to confirm in the present study. However, average back fat was only 7 mm with a mean live weight of 90 kg at the end of the experiment. Hence, according to quality supplemental payments, this would have resulted in a reduced payment to the farmer. In Denmark, it is normal procedure to slaughter finishers at approximately 110 kg live weight, due to the stipulated requirements on slaughtered weight, which must be within the range of 75-92.9 (Friland 2013). If the pigs had been allowed to grow until 110 kg live weight, back fat depth may have been within the prescribed range. However, quality supplemental payment is an economic factor to consider, unless alternative marketing is practiced.

5.2 Pig behaviour

A significant effect of feed and crop interactions was found on rooting behaviour. For alfalfa as well as grass a significant difference between HP and LP treated pigs was found. Hence, the hypothesis that restricted pigs will exhibit an increased foraging behaviour in the range area compared to non-restricted pigs can be verified in terms of rooting behaviour in particular for pigs in grass paddocks. LP pigs in grass paddocks rooted 44% of total observation time compared to 19% for HP pigs, whereas rooting activity was lower in the alfalfa system (28 vs. 16%). The observed difference in rooting behaviour between HP and LP pigs in alfalfa and grass paddocks is suggested primarily to be due to an effect of cropping system. The well-established alfalfa had developed deep main roots, which were suggested to hamper rooting. On the contrary, grass paddocks were newly-established and thereby considerably easier to uproot.

As described in the introduction, previous studies indicate that when limiting protein or amino acid content of an otherwise balanced ration, pigs respond by increasing food intake in order to compensate (Kyriazakis 1994). Furthermore, in an indoor experiment Jensen *et al.* (1993) observed a significantly higher rooting activity in pigs restricted in protein compared to non-restricted pigs. In the present experiment protein restricted pigs received only 52% of recommendations, which resulted in a significantly higher rooting activity (36% of total observations) compared to non-restricted pigs (17%), indicating that protein level was an important contributing factor. This is underpinned by main effect of concentrate feed on total resting behaviour with LP pigs resting significantly less (39%) compared to HP pigs (58%).

Andresen & Redbo (1999) suggest that other factors such as amount and quality of herbage may have more impact on foraging behaviour compared to protein restriction. Daily dry matter availability of grass was higher compared to alfalfa, whereas alfalfa nutrient availability was higher. Rachuonyo *et al.* (2005) observed a significantly higher grazing activity for pigs on newly-established alfalfa compared to newly-established grass, which was ascribed to the higher palatability of alfalfa and ease of grazing compared to grasses, which are more fibrous. Pigs are selective grazers and prefer easily digestible protein-rich crops such as legumes (Carlson *et al.* 1999; Gustafson & Stern 2003; Rachuonyo *et al.* 2005). This indicates that crop affected foraging behaviour and explained the significantly higher grazing activity observed in alfalfa paddocks (10.3%) compared to grass paddocks (4.2%). The significant effect of forage crop on grazing behaviour complies with the hypothesis that pigs foraging on alfalfa have a higher forage intake compared to pigs foraging on grass-clover. Furthermore, motivation for foraging is reduced if pigs are offered forage containing high levels of fiber (Braund *et al.* 1998). Hence, the significantly lower grazing activity of pigs in grass paddocks compared to alfalfa paddocks may partly be ascribed to a higher fiber content in grass compared to alfalfa. According to the literature alfalfa has a high crude fiber content, which differs considerably between different crop stages (Blair 2007). Alfalfa was in the pre-blooming stage and is therefore suggested to have had a lower fiber content compared to grass. Since forage crops were not analyzed for crude fiber content this cannot be verified.

Another aspect is whether rooting behaviour was only motivated by nutrition purposes. For sows released into a semi-natural area, rooting behaviour from day 1-4 were significantly higher compared to rooting 19-20 days after release (Wood-Gush *et al.* 1990). In this study the initial high rooting activity was suggested to be exploratory aiming at assessing potential resources in the area. This was also indicated in experiments with growing pigs on pasture given weekly access to new pasture (Andresen & Redbo 1999; Stern & Andresen 2003). In the present experiment access to new pasture was practiced twice a week, suggesting that rooting behaviour just after access may also have been motivated by inspective exploration. However, since all pigs were subjected to “strip grazing”, the significant effects of feed and forage crop treatments on rooting behaviour suggest that it was primarily related to nutrition.

Compared to previous studies observing domestic free-range pigs under semi-natural conditions (Stolba & Wood-Gush 1989; Wood-Gush *et al.* 1990; Petersen 1994) frequencies of rooting behavior in the present study were similar or even higher. In terms of grazing, frequencies were considerably lower compared to the study by Stolba & Wood-Gush (1989) and Rodríguez-Estévez *et al.* (2009) but similar to recordings in Wood-Gush *et al.* (1990) and Petersen (1994). Although, it must be noted that pigs were nose-ringed in the study by Rodríguez-Estévez *et al.* (2009), which increases grazing at the expense of rooting. Furthermore, Wood-Gush *et al.* (1990) performed observations during winter and Petersen (1994) partly during autumn where forage above ground is limited thereby decreasing grazing activities. Compared to previous experiments observing growing pigs in pasture systems restricted in energy or protein (Andresen & Redbo 1999; Stern & Andresen 2003; Kongsted *et al.* 2013) rooting frequencies in the present study were considerably higher. On the contrary, grazing was significantly lower compared to previous studies (Andresen & Redbo 1999; Stern & Andresen 2003; Rivero *et al.* 2013). However, in the latter study pigs were nosed-ringed and the two former studies were performed during summer, suggesting that grazing was increased at the expense of rooting due to a harder soil surface combined with access to good quality pasture. For comparison, non-restricted growing pigs in a system with energy crops rooted 19% of total observation time, whereas grazing was only observed in 0.5% of all observations (Horsted *et al.* 2013) stressing the effect nutrient restriction has on foraging behaviour.

5. Discussion

Pigs were kept in stable groups of three at low stocking rates. However, in practice forage based systems would include larger groups, which would most probably increase social or hierarchical interactions between pigs, creating more incidences of intrusion on individual pig space and antagonistic interactions and as a consequence affect foraging behaviour. Wood-Gush *et al.* (1990) observed that sows released in a semi-natural area increased aggressive interactions and had shorter distances between individuals during day 1-4 compared to day 19-20. It was suggested to be due to the novelty of the area and or the discovery of feed items by one pig leading to competition for access to resources. Similar situations may arise in forage based systems, in particular if strip-grazing is practised since it may be assessed as a potential resource. However, effect on foraging behaviour is suggested also to depend on stocking density as found by Andresen & Redbo (1999) and spatial structure of paddocks. Likewise, restricted concentrate feeding is suggested to be assessed as a limited resource affecting social behaviour with increasing antagonistic interactions at feeding, although this can partly be mitigated by management incentives. Andresen (2000) points to the disadvantage of feeding large groups of pigs in outdoor pasture system by use of feed troughs, due to the large space required for all pigs to be able to eat simultaneously. Clearly, more information on social interactions and effect of group size in growing pigs in forage based systems is needed.

The twelve paddocks were situated right next to each other and only separated by a two strand electrified wire fence. Thus, a group of pigs in one paddock were able to see groups of pigs in other paddocks and have snout contact with pigs in neighbouring paddocks. Since pigs are very social animals and prefer to eat and sleep simultaneously, it cannot be excluded that behaviour performed by pigs in one group affected behaviour of pigs in neighbouring paddocks. Independently, the two observers suggested play to be transmitted from one group of pigs to neighbouring groups but since play was not recorded, this cannot be verified. However, the clear effect of concentrate feed treatment on frequencies of total activity (41 and 43% for HP pigs in grass and alfalfa paddocks vs. 65 and 57% for LP pigs in grass and alfalfa paddocks respectively) suggests that any possible effect of social transmission of behaviours between pigs did not override effect of feed treatment. It would have been possible to exclude effect of social transmission by situating paddocks as to avoid visual contact between pigs. In practise, this would mean that paddocks had to be placed on different fields, excluding possibilities to control for soil type, which was important in terms of effect of forage crop.

5.3 Paddock appearance

Deep rooted areas were almost exclusively observed in grass paddocks and the highest percentage (5%) was observed in grass paddocks with LP pigs. This is suggested primarily to be due to the grass-paddocks being established in spring just a few months prior to the start of the experiment and therefore relatively easy for the pigs to uproot. Furthermore, as described in section 5.2, the well-established alfalfa crop had developed a net of deep main roots, which is suggested physically to have prevented pigs from accessing deeper soil layers. Hence, rather than comparing alfalfa and grass as two different forage crops, two different cropping systems were compared. To be able to compare forage crops, the optimal solution would have been for both forage crops to be either newly-established or well-established. Alfalfa was of primary interest due to its expected qualities as a forage crop for pigs. Originally, it had been established at the research station for other purposes and thus, the aim was to find a suitable crop for comparison. Since forage based systems include integrating pigs into crop rotations, it seemed relevant to compare alfalfa with grass-clover, which in practice on farms is under-sown with grain as cover crop and after harvest of the grain crop pigs can get access to the grass-clover. In addition, it was important to avoid establishing paddocks in various fields with different soil types impeding comparison even further. Hence, when integrating pigs into crop rotations and providing conditions to access food items below ground, crop characteristics as well as cropping system must be considered. Furthermore, capabilities of pigs for rooting must be included in the crop rotation. Hence, it may be relevant to introduce pigs to a second year clover-grass field during spring and summer, which anyway must be ploughed during autumn. During autumn, pigs could then be moved to a well-established alfalfa field and during wither reside in a field with root crops such as Jerusalem Artichokes or maybe as “cleaners” if combined with vegetable production.

The relatively subjective method used for paddock assessment proved difficult, in particular regarding assessment of percentage shallow rooted and deep rooted areas. The pigs´ rooting activities resulted in grass turfs being piled up, whereby parts of rooted areas visually could be estimated as deep rooted rather than shallow rooted. A ruler was used to estimate rooting depth. It may have been relevant to use a RTK (Real Time Kinematic) technique that uses satellite navigation in conjunction with GPS, where rooting depth it estimated by comparison with “normal” ground level (measured prior to pig insertion) and therefore suggested to provide more precise estimates.

Surprisingly, in grass paddocks the percentage of deep rooted areas decreased during the experimental period. This is suggested to be ascribed to the pigs´ high frequency of rooting and trampling activities levelling out the soil surface.

5.4 Estimated availability and nutrient content of forage crops

Estimated yields in paddocks with grass and paddocks with alfalfa (including dandelion) were at similar levels with 1630 and 1556 kg dry matter ha^{-1} respectively. However, it must be noted that the values were based on available dry matter during the 40-days experimental period. Under Danish conditions, yields of alfalfa by cutting for silage are around 10-14 tons dry matter ha^{-1} $year^{-1}$ (DLF Trifolium 2013). Thus, total yield potential of alfalfa is high and can be sustained for 2-3 years (Danish agricultural advisory service 2013). The alfalfa was into the third year in use, which could be one factor related to the low yield. In all alfalfa paddocks approximately 50% of the area had been cut on the 9^{th} of August. In this area crop density was reduced considerable and growth weak and in some paddocks the alfalfa had a brownish colour, which is suggested to be caused by boron deficiency leading to reduced growth (Danish agricultural advisory service 2013).

Chemical composition of forage crops changes during a growth season (Andresen 2000). However, this was not observed in the present study, which was ascribed to the sampling period being too short to detect any significant changes in crop deterioration. For alfalfa the range of crude protein values (27.5-31.4% DM basis) were considerably higher compared to the values found in the literature with 15.5-24% (Møller *et al.* 2005) and 11.7-17.4% depending on cut and year (Cupic *et al.* 2001). On the contrary, protein values for grass (12.1-14.7% DM basis) were lower compared to the literature with 19-22% (Møller *et al.* 2005). Interestingly, dandelion had relatively high crude protein contents (mean level of 25.5% DM basis) in between that of alfalfa and grass. The literature is sparse regarding information on protein in dandelion but values in the range of 13.8-22.8% (DM basis) have been reported (Bergen *et al.* 1999). In terms of crude protein dandelion seems to have potential as a forage crop for pigs and deserves further investigation.

Regarding pig nutrition, essential amino acid content is of major importance. Lysine and methionine content in alfalfa (pre- and post-grazed) was in the range of 3.9-17.4 and 0.9-4.5 g kg^{-1} dry matter respectively with the lowest values in grazed alfalfa, which are within the range reported in the literature (11.5 and 2.7 g kg^{-1} dry matter for lysine and methionine respectively) (Misciattelli *et al.* 2002). As expected, lysine and methionine contents in grass were considerably lower with 7.1 and 2.2 g kg^{-1} dry matter respectively. The values reported in the literature are slighter higher with 9.9 and 3 g kg^{-1} dry matter respectively (Misciattelli *et al.* 2002). According to analyzed dandelion samples lysine and methionine amounted to 14 and 4.6 g lysine and methionine kg^{-1} dry matter respectively, which were slightly lower than values for alfalfa. However, it was not possible to find comparable figures in the literature.

Another important aspect in terms of pig nutrition is forage crop digestibility, which is sparsely described in the literature. Forage crops were analyzed for in vitro total tract energy digestibility and coefficients in cut alfalfa, with and without dandelion, ranged from 69-77%. For dandelion values were 80 and 84% and for grass 49-58% confirming the potential of dandelion. In the literature, in vivo energy digestibility coefficients for fresh forage crops (clover, grass, tall fescue and plantain) were recorded to be within 29-65% (Quijada *et al.* 2012). The range is somewhat lower compared to the present study, which is partly suggested to be due to methodology (in vivo vs. in vitro). It might have been relevant to analyse forage crops in terms of total tract crude protein digestibility. Clearly, more information on energy and protein digestibility of different types of forage crops is required.

As briefly touched upon in the literature review, availability and nutritional quality of forage crops as well as feed efficiency are key issues in relation to development of eco-efficient systems for growing pigs foraging in the range area. In order to improve resource efficiency yield and nutritional value must be maximized on a given forage area. Otherwise, more land is needed to produce the same amount of products. For the individual farmer it may have economic implications since land is expensive and reduced yields are connected to increased amounts of purchased feed. A related challenge in pasture systems is the lack of possibility to control nutrients in the form of deposited manure, which in indoor systems can be collected and evenly distributed at an appropriate time. Keeping nutrient losses at a minimum is of major importance in terms of avoiding negative effects on the environment but also in terms of maintaining high crop yields. Previous studies indicate that it is possible to stimulate pigs to deposit faeces and urine more evenly by moving hut and feeding facilities regularly (Quintern & Sundrum 2006; Salomon *et al.* 2007)) and by practicing “strip grazing” (Andresen & Redbo 1999; Stern & Andresen 2003; Quintern & Sundrum 2006).

5.5 Estimated earthworm availability and nutrient content

Investigations on wild boar and feral pigs have shown that vegetable feed constitutes the majority of food items ingested (Schley & Roper 2003). However, depending on season and location, soil living invertebrates such as e.g. earthworms are also readily ingested. In a study of village pigs, daily number of earthworms was recorded to range between 414-1224 (Rose & William 1983) and according to stomach analysis of wild boar 300 earthworms have been found in a single individual (Hanson & Karstad 1959). Hence, pigs seem to be able to ingest large amount of earthworms.

Estimated mean earthworm biomass per m^2 amounted to 189 g in alfalfa paddocks and 107 g in grass paddocks (fresh weight) within a depth of 20 and 25 cm. In alfalfa paddocks it was higher compared to values reported in the literature under north European conditions, ranging from 48-160 g earthworm biomass per m^2 (within depths of 20, 25 and 30 cm) (Lagerlöf *et al.* 2002; Eekeren *et al.* 2010; Holmstrup *et al.* 2011). As described in section 2.4.3 several investigations have reported on earthworms` sensibility to soil tillage (Chan 2001). Thus, higher densities have been found in pasture systems compared to conventional tillage systems (Chan 2001). However, this has not been observed consistently throughout studies, e.g. Lagerlöf *et al.* (2002) reported a considerably higher earthworm biomass in a cultivated field compared to pastures. Hence, this suggests that other factors such as crop type may also influence earthworm biomass densities (Eekeren *et al.* 2010).

5. Discussion

The difference in earthworm biomass between alfalfa and grass paddocks is suggested to be due to an effect of cropping system. Alfalfa paddocks were well-established (2010), whereas grass paddocks were newly established (spring 2013). Soil tillage kills earthworms but communities have been reported to recover within twelve months, which is believed partly to be due to the large amount of organic matter ploughed into the soil serving as food for earthworms (Chan 2001). As the grass paddocks were established in spring 2013, the time elapsed between soil bed preparation and collection of soil samples was probably too short for earthworm populations to re-establish.

Merely collection of soil samples is capable of disturbing earthworm communities, in particular anecic earthworms, which quickly dissipate into deeper layers of the soil (Coja *et al.* 2008). Soil samples were collected by spade, which was done as efficient and quickly as possible to minimize earthworm dissipation. Due to the well-established alfalfa it was difficult to access the soil compared to the grass paddocks. Thus, sampling time was prolonged, which may have led to an under-estimation of earthworm biomass in alfalfa paddocks. After soil sample collection another factor of relevance is the method of hand sorting for earthworms. Soil samples were stored at 5˚celcius for several days prior to sorting. Hence, earthworms were relatively immobile, which encumbers identification of in particular small earthworms. In addition, hand sorting is liable to miss out small or juvenile earthworms (Coja *et al.* 2008) thereby under-estimating true earthworm biomass. There are other methods available to extract earthworms from soil. Chemical expulsion methods are widely applied, which involves irrigating the soil with a chemical solution that irritates the earthworms and drives them to the soil surface. Another method is by use of voltage, which is impressed on a soil column and irritates the earthworms forcing them to the surface (Coja *et al.* 2008). Due to additional collection of roots from soil samples, in practice, hand sorting was the only possible method. In addition, it allowed sampling of other soil living invertebrates.

The higher earthworm biomass in alfalfa paddocks compared to grass paddocks was reflected in dry matter availability for the pigs. In alfalfa paddocks 203 g earthworm dry matter pig^{-1} day^{-1} was available compared to grass paddocks with 115 g, corresponding to 748 and 434 g fresh weight pig^{-1} day^{-1}. In terms of crude protein, pigs in alfalfa and grass paddocks had access to 84 and 55 g pig^{-1} day^{-1} respectively. In the literature a crude protein content of 610 g kg^{-1} dry matter was reported by Bassler *et al.* (2000), which was somewhat higher compared to the estimated values in the present study with a mean of 421 and 463 g kg^{-1} dry matter in alfalfa and grass paddocks respectively. Contents of lysine and methionine in earthworms across alfalfa and grass paddocks amounted to 25 and 7.3 g kg^{-1} dry matter, which is considerably lower compared to values reported in the literature with a mean of 43 and 9.2 g lysine and methionine respectively kg^{-1} dry matter across species (Pokarzhevskii *et al.* 1997). This is suggested to be due to differences in earthworm species composition. Recommended minimum norms of digestible crude protein, lysine and methionine for growing-finishing pigs weighing 55-105 kg is 112, 7.2 and 2.2 g FU^{-1} respectively (Tybirk *et al.* 2013). According to analyses, 651 and 717 g crude protein FU^{-1} was available in earthworms from alfalfa and grass paddocks respectively. For lysine the value was 39 g FU^{-1} across forage crops. Assuming that crude protein and lysine digestibility of earthworm biomass is close to 100%, it pinpoints the potential of earthworms` contribution to nutrient requirements of pigs.

5.6 Estimated nutrient intake

5.6.1 Forage crop samples

As described in section 3.4.2 and 3.4.3 alfalfa intake was estimated by collecting pre- and post-grazed crop samples, whereas this method could not be used for estimating grass intake. Alfalfa intake turned out not to be significantly affected by protein feed treatment although, there was a tendency towards a significantly higher alfalfa dry matter intake in LP pigs compared to HP pigs. Estimated mean alfalfa dry matter intake amounted to 330 and 470 g pig^{-1} day^{-1} for HP and LP pigs respectively, corresponding to 14.5 and 19.8% of total dry matter intake (DM in alfalfa plus supplemental feed). Intake was higher compared to previous studies of feed restricted pigs in pasture systems with 131 g organic matter pig^{-1} day^{-1} in modern hybrid growing pigs (Kikuyo grass) (Kanga *et al.* 2012) and mean intake of 242 and 314 g DM pig^{-1} day^{-1} in growing European wild boar (ryegrass, plantain, white clover) (Rivero *et al.* 2013; Hodgkinson *et al.* 2009) but similar to grass intake recorded in Iberian finishers (435 g DM pig^{-1} day^{-1}) (Rodrígues-Estévez *et al.* 2009) and modern hybrid finishers (415 g DM pig^{-1} day^{-1}) (Riart 2002). On the contrary, intake was considerably higher compared to growing pigs on grass-clover pastures fed concentrates *ad libitum* with less than 2% of DM intake (Kelly *et al.* 2007) and 4% of total organic matter intake (Mowat *et al.* 2001).

In terms of daily energy intake of alfalfa, estimated values were 0.32 and 0.35 FU pig^{-1} (3.9 and 4.3 MJ ME) for HP and LP pigs respectively, corresponding to 12.5 and 13.9% of total energy intake (energy in forage plus energy in supplemental feed). Regarding crude protein and lysine, intake was estimated to supply HP pigs with a mean of 128 g crude protein and 6.95 g lysine pig^{-1} day^{-1} corresponding to 24 and 25% of total crude protein and lysine intake respectively. For LP pigs estimated values were 144 g crude protein and 7.7 g lysine, corresponding to 41 and 48% of total daily crude protein and lysine intake respectively (nutrients in alfalfa plus offered supplemental feed).

Forage crop samples were cut 6 cm above soil level, which was not in accordance with cutting heights recorded in previous studies with sampling performed at soil level or 1-2 cm above (Andresen & Redbo 1999; Rivera Ferre *et al.* 2001; Gustafson & Stern 2003; Fernández *et al.* 2006; Hodgkinsom *et al.* 2009; Rivero *et al.* 2013). As a result forage intake may have been underestimated. According to paddock assessments of zone 3, alfalfa was reduced to approximately 5 cm on day 37, a height which was assessed to be representative for remaining zones, indicating that cutting height was appropriate. In contrast, forage intake may have been overestimated due the pigs´ selective grazing behaviour as described by Rivero *et al.* (2013). Hence, it may have been relevant to study the pigs´ foraging behaviour prior to deciding on crop cutting height.

Post-grazed alfalfa samples were collected one week after collection of pre-grazed samples. This allowed time for the crop to grow and the pigs to take up additional forage and as a consequence intake may have been underestimated (Hodgkinson *et al.* 2009). The alfalfa did begin to grow by setting new leaves. However, the extent of growth was assessed not to make significant contributions to additional forage intake. To accommodate the challenge that pigs were able to take up additional forage after post-grazed sample collection one solution could have been to collect all post-grazed crop samples at the end of the experiment. At collection of post-grazed crop samples it was assumed that the forage, which could not be accounted for was consumed by the pigs. However, forage may have been destroyed by pigs´ trampling activities or by crop deterioration and as a result forage crop intake may have been over-estimated (Rivera-Ferre 2007). Grass intake was not estimated due to paddocks being quickly uprooted and grass intake suggested being of minor importance. In addition, it would have been difficult or impossible to perform crop sampling due to grass turfs and soil being piled up, a situation also described by Stern & Andresen (2003).

5.6.2 Earthworms

In order to exploit the potential of earthworm biomass, pigs must be able to access an appropriate amount of earthworms. Soil samples were collected at a depth of 25 and 20 cm respectively. According to paddock assessments the total area in grass paddocks was shallow rooted (< 10 cm) (Table 4.1) whereas in alfalfa paddocks it was 80-95%. Furthermore, deep rooted areas (>10 cm) were only observed in grass paddocks constituting 5% of the total area in paddocks with LP pigs. Earthworms arrange themselves in clusters and within each cluster earthworms tend to keep close to the places where they can find shelter and food, which is around plant roots (Binet *et al.* 1997). Taking this into consideration, it is estimated that pigs in alfalfa and grass paddocks had access to approximately 60-65% and 70-75% of available earthworm biomass respectively. Table 5.1 shows the daily available dry matter and nutrient content in earthworms according to a mean of 62.5 and 72.5% of total earthworm dry matter and nutrient content from soil samples collected in alfalfa and grass paddocks respectively.

Table 5.1. Daily availability of earthworm nutrient content according to a mean of 62.5 and 72.5% of total nutrient availability in earthworms from soil samples collected in alfalfa and grass paddocks.

	Earthworm nutrient content, g pig^{-1} day^{-1}	
	Alfalfa paddocks	Grass paddocks
Dry matter	127	83
FU* pig^{-1} day^{-1}	0.08	0.05
Crude fat	4.4	2.9
Crude protein	**53**	**40**
Lysine	**3.2**	**2.1**
Methionine	0.92	0.61

*FU: Danish Feed Unit for growing-finishing pigs, 1 FU = 12.2 MJ ME (Christiansen 2010).

No other soil living organisms were accounted for but it cannot be excluded that pigs benefitted from them nutritionally. In addition, root biomass was not accounted for and thus any nutrient contribution from roots cannot be excluded. According to paddock assessments grass paddocks were intensely rooted and it was noticed that pigs rooted just below the root system, indicating access to grass roots. Alfalfa root length and size is considerable and if pigs have access and roots are palatable, they may contribute nutritionally.

5.6.3 "Backwards calculations"

The method of "backwards calculations" provided estimates for daily energy and crude protein intake in the range area. The point of departure was the daily energy norm (2.8 FU or 34.2 MJ ME) for a conventional indoor pig (60-90 kg) growing 950 g day^{-1} (Anonymous 2008) and corrected according to mean daily weight gain observed in the pigs subjected to the four different treatments. However, nutrient demands of outdoor pigs are expected to be considerably higher due to increased activity and exposure to outdoor climatic conditions. Hence, estimates for daily energy requirements according to thermoregulation and locomotory activity were calculated.

Thermoregulation

Energy required for thermoregulation was set to 17 kJ ME kg^{-1} metabolic live weight ($LW^{0.75}$) per degree below a lower critical temperature, which is a mean of the values suggested by Close and Poornan (1993) and Rodríguez-Estévez *et al.* (2010). According to Nyachoti *et al.* (2004) the thermo neutral zone for growing pigs ranges between 18-21˚C. Accordingly, a mean temperature of 19˚C was chosen as the lower critical temperature. From Foulum climate station data on mean daily temperature during the 40-days experimental period was extracted to calculate daily number of degrees below 19˚C. For HP and LP pigs in alfalfa and grass paddocks respectively, average daily live weight was calculated based on average daily weight gain.

Locomotory activity

Energy required for locomotory activity depends on distance, speed of movement and weight of the pig (Edwards 2003). However, the literature is sparse regarding quantification of energy requirement for activity and distances walked in growing pigs. Hence, estimates were based partly on estimated distances walked and partly on estimated minutes of standing. Energy for standing was set to 0.29 kJ ME kg^{-1} ($LW^{0.75}$) $minute^{-1}$ standing, which is an average value reported by Noblet *et al.* (1993). Regarding number of minutes standing it was assumed that an activity level above that of conventional pigs in indoor systems corresponds to the extra energy required by outdoor pigs. Guy *et al.* (2002) reported growing pigs (weaning to slaughter) in indoor systems to be active 27% of the day. Thus, pigs were estimated to require extra energy for standing in terms of the number of minutes they were active above 27% of total observation time. Accordingly, HP pigs in alfalfa paddocks were estimated to be active 16% of the time, corresponding to 101 minutes standing during observation time (630 min). For LP pigs in alfalfa paddocks, HP and LP pigs in grass paddocks number of minutes standing were estimated to be 189, 88 and 239 respectively. The pigs were observed throughout the day time and suggested to rest in the hut during evening and night time until feeding the next morning.

Net energy required for movement in a levelled area was set to 0.003 kJ kg^{-1} LW m^{-1} walked (Rodríguez-Estévez *et al.* 2010). For transformation of net energy to metabolizable energy an efficiency of 0.8 was assumed (Rodríguez-Estévez *et al.* 2010). Estimated meters walked were based on percentage of time pigs were active. HP pigs were observed to be active 43 and 41% of observation time in alfalfa and grass paddocks respectively. For LP pigs the figures were 57 and 65%. Taking this into account, as well as estimates found in the literature (1-3.9 km day^{-1}) (Larsen & Kongsted 2001; Rodríguez-Estévez *et al.* 2010), HP pigs were assumed to walk 2 km day^{-1} and LP pigs in alfalfa and grass paddocks were assumed to walk 2.4 and 3 km day^{-1} respectively (Scenario1). As rooting is suggested to be associated with considerable force, energy requirements for HP pigs walking 2.5 km, LP pigs in alfalfa paddocks 2.9 km and LP pigs in grass paddocks 3.5 km day^{-1} were also estimated (Scenario 2). Figures from scenario 1 were suggested to resemble the actual level of locomotory activity to a higher degree than scenario 2 and were therefore included in the further calculations. Table 5.2 shows the estimated energy requirements for thermoregulation and locomotory activity (standing + walking) for pigs subjected to the four different treatments.

Table 5.2. Estimated daily energy required for cold thermogenesis, standing and walking (km, two scenarios) for HP and LP pigs in alfalfa and grass paddocks, shown as FU pig^{-1} day^{-1} and MJ ME in brackets. HP=high protein feed; LP=low protein feed.

	FU* pig^{-1} day^{-1} (MJ ME pig^{-1} day^{-1})									
	Thermo-regulation	Activity							Thermo-regulation + activity	
		Standing	Walking				Total activity			
			Scenario				Scenario		Scenario	
			1		2		1	2	1	2
Treatment:			km		km					
HP, Alfalfa	0.27 (3.3)	0.06 (0.76)	2	0.05 (0.57)	2.5	0.06 (0.72)	0.11 (1.33)	0.12 (1.48)	0.38 (4.6)	0.39 (4.8)
LP, Alfalfa	0.26 (3.2)	0.11 (1.37)	2.4	0.05 (0.66)	2.9	0.06 (0.79)	0.17 (2.03)	0.18 (2.16)	0.43 (5.2)	0.44 (5.4)
HP, Grass	0.27 (3.3)	0.05 (0.66)	2	0.05 (0.57)	2.5	0.06 (0.71)	0.10 (1.23)	0.11 (1.37)	0.37 (4.5)	0.39 (4.7)
LP, Grass	0.25 (3.1)	0.14 (1.68)	3	0.06 (0.79)	3.5	0.08 (0.92)	0.20 (2.47)	0.21 (2.60)	0.46 (5.6)	0.47 (5.7)

*FU: Danish Feed Unit for growing-finishing pigs, 1 FU = 12.2 MJ ME (Christiansen 2010).

Crude protein

Estimated daily crude protein intake was calculated on the basis of energy and protein:energy requirement for a conventional indoor pig, corrected according to observed growth. Recommended minimum norm of digestible crude protein for growing-finishing pigs weighing 55-105 kg is 112 g FU^{-1} (Tybirk *et al.* 2013). A digestibility coefficient of 0.80 was used to transform figures for digestible crude protein (Jørgensen *et al.* 2012).

Estimated daily energy and crude protein

Table 5.3 presents estimated daily energy and crude protein intake according to the four different treatments. The method used for estimating daily indoor energy requirements was verified by use of the NRC excel program (NRC 2012) calculating estimates of 2.73 (33.3 MJ ME) and 2.65 FU (32.3 MJ ME) for HP pigs in alfalfa and grass paddocks respectively. These values were slightly higher compared to the method based on energy norm for a conventional indoor pig.

According to a daily weight gain of 900 and 878 g pig^{-1} for HP pigs in alfalfa and grass paddocks respectively, total energy requirements amounted to 2.9 FU (35.3 MJ ME) and 2.82 FU (34.5 MJ ME) pig^{-1} day^{-1}. This is 0.65 and 0.55 FU (7.8 and 7 MJ ME) more than provided by concentrates, suggesting that direct foraging supplied HP pigs in alfalfa and grass paddocks with approximately 22 and 20% of total energy requirements respectively. These estimates were comparable with figures recorded by Rodríguez-Estévez *et al.* (2010) but considerably lower than pigs foraging Jerusalem Artichokes, providing 60% of energy requirements (Kongsted *et al.* 2013). However, these pigs received 25% of recommended energy allowance, whereas pigs in the present study received 80% of recommendations. Estimates for energy requirements for LP pigs illustrate that protein was a limiting factor in terms of utilizing available energy for growth. It remains a challenge to estimate energy intake from the range area for LP pigs.

The extra energy required for thermoregulation and activity for HP pigs in alfalfa and grass paddocks respectively was equivalent to an increase in concentrate feed of approximately 15%. This is equivalent to the 15% on an annual basis under north European conditions suggested by Edwards & Zanella (1996). In the study by Rodríguez-Estévez *et al.* (2010) thermoregulation and energy for activity amounted to 5.5 and 6.3 MJ ME respectively, which were considerably higher than estimated in the present study. However, the Iberian pigs were much heavier (110-160 kg), they were assessed to be out in harsh weather and resided on 111 ha sloped area, which adds to the energy needed for activity.

In terms of crude protein, the negative values associated with intake in the range area for HP pigs (Table 5.3) illustrate that they were oversupplied with protein, which adds to the nutrient load in the outdoor area, thereby reducing resource efficiency of the system. In general organic feed mixtures for growing pigs contain high levels of protein, a challenge in organic feeding that needs addressing. Intake of crude protein in the range area for LP pigs in alfalfa and grass paddocks amounted to 87 and 28 g pig^{-1} day^{-1} respectively corresponding to 30 and 12% of total daily crude protein intake. Regarding protein and lysine efficiency, the alfalfa system showed an improved performance compared to grass. LP pigs in alfalfa paddocks had 38 and 50% lower feed crude protein and lysine use kg^{-1} weight gain respectively compared to HP pigs in alfalfa paddocks. In comparison, LP pigs in grass paddocks had 24 and 40% lower feed crude protein and lysine use kg^{-1} weight gain respectively compared to HP pigs.

It must be noted that uncertainties are related to the method used for estimating energy requirements according to observed growth. In addition, uncertainties are related to figures used for estimating energy required for thermoregulation and activity. In particular heavy rooting is suggested to be related to considerable force and accordingly values for activity may have been underestimated. Prior to behavioural observations it may have been relevant to divide rooting into light and heaving rooting (arched back), since they are related to different levels of activity thereby resulting in different energy requirements. It was assumed that pigs were exposed to observed environmental temperatures throughout the day. However, during evening and night time pigs were suggested to spend majority of time inside the insulated huts with plenty of straw where the effective temperature might have been very close to their lower critical temperature. This may have been offset by the pigs being outdoors and exposed to environmental temperatures, which are relatively lower than actual measurements due to factors such as wind speed and rainfall (Close and Poornan 1993). However, it was not accounted for in the calculations and has thus added to the uncertainty of the estimates. Clearly, more information on quantification of energy requirements for activity in outdoor growing pigs is needed in terms of how far they walk during a day but also in terms of energy required for rooting.

Table 5.3. Estimated daily energy and crude protein intake from the range area for HP and LP pigs in alfalfa and grass paddocks. Based on estimated outdoor requirements and energy and protein received in concentrates. Outdoor energy requirements = indoor requirements + cold thermogenesis + standing + walking. HP=high protein feed. LP=low protein feed.

	FU* pig^{-1} day^{-1} (MJ ME pig^{-1} day^{-1})				Crude protein, g pig^{-1} day^{-1}		
Treatment:	Received in concentrate	Indoor requirement	Outdoor requirement	Intake from paddocks	Received in concentrate	Outdoor requirement	Intake from paddocks
HP, Alfalfa	2.25 (27.5)	2.52 (30.7)	2.90 (35.3)	0.65 (7.8)	399	352	-46
LP, Alfalfa	2.17 (26.5)	2.07 (25.3)	2.50 (30.5)	0.33	203	290	87
HP, Grass	2.25 (27.5)	2.5 (30)	2.87 (34.5)	0.62 (7.0)	399	344	-54
LP, Grass	2.17 (26.5)	1.6 (20.1)	2.10 (25.7)	-0.07	203	231	28

*FU: Danish Feed Unit for growing-finishing pigs, 1 FU = 12.2 MJ ME (Christiansen 2010).

Table 5.4. Estimates of daily energy, crude protein and lysine intake pig^{-1} from the range area according to crop samples, "backwards calculations" and available earthworm biomass. HP=high protein feed. LP=low protein feed.

	Energy, FU* (MJ ME) pig^{-1} day^{-1}		Crude protein, g pig^{-1} day^{-1}				Lysine, g pig^{-1} day^{-1}		
			From crop and soil samples				From crop and soil samples		
Treatments:	Crop samples	Backwards calculations	Crop samples	Earthworms	Total	Backwards calculations	Crop samples	Earthworms	Total
HP, Alfalfa	0.32 (3.9)	0.65 (7.8)	128	53	181	-46	6.9	3.2	10.1
LP, Alfalfa	0.35 (4.3)	-	144	53	197	87	7.7	3.2	10.9
HP, Grass	-	0.55 (7.0)	-	40	-	-54	-	2.1	-
LP, Grass	-	-	-	40	-	28	-	2.1	-

*FU: Danish Feed Unit for growing-finishing pigs, 1 FU = 12.2 MJ ME (Christiansen 2010).

5.7 Conclusions on estimated energy and nutrient uptakes from the range area

Table 5.4 shows the estimated figures on daily energy, crude protein and lysine intake pig^{-1} from the range area according to crop samples, “backwards calculations” and available earthworm biomass. For energy the estimated daily intake is suggested to be within the range of 0.32 and 0.65 FU pig^{-1} (3.9-7.8 MJ ME) corresponding to 11-22% of outdoor energy requirements. Estimates based on crop samples were lower compared to estimates based on “backwards calculations”, which can partly be ascribed to the latter comprising total intake from the range area. Furthermore, estimates for energy intake in crop samples may have been under-estimated due to forage cutting height (section 5.6.1).

Regarding crude protein, estimates based on crop samples and available earthworms are considerably higher compared to estimates provided from backwards calculations. According to protein intake based on crop samples and available earthworm biomass, this would supply pigs with the majority of requirements, which is clearly over-estimated. However, the estimates indicate the potential from forage crops and earthworms in terms of mitigating protein requirements, which also depends on the ability of pigs to utilize the ingested feed. Overall, estimates are associated with several uncertainties and more studies are required to quantify energy and nutrient intake from the range area more precisely.

Regarding use of methods to estimate forage intake, the n-alkane marker technique was rejected for practical reasons. The pigs were fed in groups and therefore it was not possible to measure the actual intake for each individual pig. In addition, it would be difficult to avoid fodder spill during feeding. The direct in situ observation method had been practiced in a pilot study a few months prior to the present experiment (Jakobsen 2013, *pilot study*) where it turned out not to be possible to observe feed intake below ground. In addition, the method is time consuming and can easily interfere with pig foraging behaviour.

6. Conclusions

The project consisted of two parts. The first part, the literature review, was related to the overall scientific aim, which was to identify factors important for nutrient availability, foraging behaviour and forage intake in growing pigs in free-range pasture systems.

The literature review provided the basis for performing the experiment (second part), which included the specific objectives of the project. In the experiment effect of protein allowance and cropping system on foraging activity, forage intake, growth and feed conversion ratio was investigated according to the proposed hypotheses.

Hypotheses

- Pigs restricted in protein will exhibit increased foraging behaviour in the range area compared to pigs receiving a protein level according to recommendations.
- Pigs restricted in protein are expected to have a higher intake from direct foraging in the range area and by that to some extent compensate as reflected in growth and feed conversion ratio compared to pigs fed a protein level according to recommendations.
- Pigs foraging on alfalfa are expected to have a higher forage intake and a performance, which is less affected by protein restriction compared to pigs foraging on grass.

According to the literature review, an important factor for foraging behaviour is forage crop preference. Previous studies found strong indications that pigs are selective grazers and prefer easily digestible protein-rich forage crops. Furthermore, experimental work has indicated that protein and energy restriction are promising in terms of increasing foraging activity and thereby forage intake.

According to the performed experimental work, a significant effect of protein feed and forage crop interactions was found on rooting behaviour for pigs on both forage crops but not on grazing activity. Thus, the hypothesis that protein restricted pigs will show an increased foraging behaviour compared to non-restricted pigs could be verified for rooting behaviour. LP pigs in grass paddocks rooted 44% of total observation time compared to 19% in HP pigs, whereas in alfalfa paddocks rooting amounted to 28 and 16% for LP and HP pigs. Hence, the effect of protein restriction was more pronounced in the grass system compared to alfalfa. Grazing turned out to be significantly affected by forage crop with 10.3% of total observations in alfalfa paddocks compared to 4.2% in grass paddocks, which was suggested to be related to cropping system. The alfalfa was well-established, which impeded rooting behaviour, whereas the grass was newly established and easy to uproot. Furthermore, it was suggested to be due to the nutritional value of alfalfa compared to grass.

6. Conclusions

Based on alfalfa crop samples there was a tendency to a significantly higher forage intake in LP treated pigs compared to HP pigs. Estimated daily alfalfa dry matter intake amounted to 470 and 330 g pig^{-1} for LP and HP pigs respectively, corresponding to 15 and 20% of total daily dry matter intake. Energy, crude protein and lysine intake day^{-1} from alfalfa was higher for LP pigs compared to HP pigs but the difference was not significant.

Based on crop samples and "backwards calculations" estimated daily energy intake in both cropping systems was suggested to be within the range of 0.32 and 0.65 Danish Feed Units pig^{-1} (3.9-7.8 MJ ME) corresponding to 11-22% of outdoor energy requirements. However, the proposed estimates are associated with considerable uncertainty, in particular due to lack of information when estimating energy required for activity in outdoor growing pigs.

Earthworm dry matter availability was higher in alfalfa paddocks compared to grass paddocks (203 vs. 115 g pig^{-1} day^{-1}), which was suggested to be due to the well-established alfalfa as opposed to the newly-established grass. Available earthworm crude protein amounted to 84 and 55 g pig^{-1} day^{-1} in alfalfa and grass paddocks respectively, indicating the potential in terms of mitigating protein requirements of growing pigs.

Daily weight gain and feed conversion ratio were significantly affected by interactions between protein feed and forage crop. In grass paddocks LP treated pigs had 33% lower daily weight gain compared to HP pigs (589 vs. 878 g) and 31% poorer feed conversion ratio (3.75 vs. 2.59 kg feed kg^{-1} weight gain). However, in alfalfa paddocks LP pigs only had 18% lower daily weight gain compared to HP pigs (900 vs. 741 g) and a 14% poorer feed conversion ratio (2.95 vs. 2.54 kg feed kg^{-1} weight gain). Thus, the hypothesis that protein restricted pigs are expected to have a higher forage intake as reflected in performance, compared to non-restricted pigs, thereby indicating some extent of compensation, could be verified for LP pigs in alfalfa paddocks. As LP pigs foraging on alfalfa had an increased performance compared to LP pigs foraging on grass, they were less affected by protein restriction, verifying the third proposed hypothesis. Interestingly, LP pigs used 169 g less feed crude protein kg^{-1} weight gain compared to HP pigs foraging on alfalfa, whereas in grass paddocks the difference between LP and HP pigs was 109 g crude protein.

The results of the experiment indicate the potential of foraging on alfalfa in terms of protein supply, thereby contributing to increasing resource efficiency of forage based system with organic growing pigs

7. Perspectives

Effect of concentrate feed and forage crop treatments on pig behavior and performance was pronounced, indicating the future perspectives in developing forage based systems for free-range growing pigs as a mean to improve resource efficiency. Clearly, the area is unexploited and many aspects need further investigation. In terms of improving nutrient recirculation it is important to provide conditions in order to avoid nutrient hot spots. “Strip grazing” was implemented not only to facilitate a higher forage intake but also due to expectations of a more even distribution of faeces and urine (Stern & Andresen 2003; Quintern & Sundrum 2006). The result of these incentives is investigated in the near future. Additionally, nitrogen balances of the system will be calculated.

Development of eco-efficient forage based systems includes an optimization of crop rotations, which ensures that nutrients deposited by the pigs are taken up by the following crop and or by energy crops. A system combining willow and free-range growing pigs has proven successful in terms of reducing nutrient losses (Horsted *et al.* 2012). In this study the pigs primarily deposited their urine and faeces around the willow, which has a deep root system that takes up the nutrients. The produced willow can then be harvested as biomass and used for energy. It may be possible to combine a forage based system with inclusion of energy crops thereby maximizing production on a given area. In addition, energy crops provide an environment with shelter and shade for animals, thus imitating a more natural environment and contributing to animal health and welfare.

The present experiment included pigs in groups of three. The next step is to up-scale by performing on farm experiments with larger groups of pigs, including other types of forage crops. Furthermore, due to climatic conditions forage based systems, which combine direct foraging with allocation of roughage or root crops during winter months (ground frost) must be developed, unless seasonal production of pigs proves economically viable. Continuous access to new pasture seems promising in terms of increasing forage intake. From a practical perspective it must be combined with development of technological solutions in order to decrease and ease the workload related to regularly movement of fences. The same applies for daily concentrate feeding.

One of the objectives of the project was to try to quantify nutrient intake below ground. Within the time frame of this project it was not possible to perform analyses on all collected material. However, from soil samples roots were collected, which must be analyzed for chemical composition and at the end of the 40-days experimental period one pig from each paddock (in total 12 pigs) were slaughtered and their stomachs frozen for later analysis. As described in section 2.5.1 investigation of stomach content has been a frequently used method to identify composition of diets in wild boar and feral pigs. The objective is to quantify earthworm intake by identifying and counting earthworm setae in stomach content. The pigs were slaughtered in the evening in order to have a full stomach after a day of foraging. However, a remaining challenge is to go through the practical aspect of how to end up with a reliable estimate. Additionally, faeces samples were collected once a week with the aim of estimating ingested earthworm biomass. The challenge with faeces samples is similar to that of stomach content analysis and thus, an objective is to find a reliable and practical applicable method to estimate biomass intake below ground.

The experiment did not include investigations of effects of protein level and forage crop treatments on carcass characteristics. However, meat quality in terms of tenderness, taste and colour is important in relation to marketing. Restricted feeding has been found to reduce tenderness compared to *ad libitum* feeding (Danielsen *et al.* 2000; Hansen *et al.* 2006). In addition, level of polyunsaturated fatty acids in back fat increases (Danielsen *et al.* 2000) and intramuscular fat decreases (Hansen *et al.* 2006). Furthermore, a higher lean meat content has been reported in restricted fed pigs compared to *ad libitum* fed pigs. Effects are suggested to be somewhat similar in the present study, although the effects of inclusion of relatively high levels of fiber-rich forage crops on carcass quality need further investigation.

Currently, the breeding material used in organic pig production is the same as in conventional production. However, the appropriateness of modern hybrids, bred for indoor intensive systems, in outdoor free-range systems has been questioned. Furthermore, the organic principle emphasizes use of traditional breeds adapted to local conditions and extensive production systems (Edwards 2005). In this context it is highly relevant whether traditional breeds are better suited to forage based systems in terms of foraging behavior and abilities to utilize fiber-rich feed compared to modern hybrids. One hypothesis is that old or traditional breeds through times have been adapted to fiber-rich feed and as a result have a considerable fermentation in the caecum and colon (Edwards *et al.* 1991). As opposed to this, the modern conventionally bred genotypes have received high energy diets throughout selection processes and therefore have reduced fermentation abilities. The relatively sparse literature on the area indicate that modern intensively bred hybrid pigs are as efficient in utilizing fibre-rich feed as traditional breeds (Hodgkinson *et al.* 2008; Heimendahl *et al.* 2010). However, of equal importance are robustness, temperament and carcass characteristics.

Finally, forage crops might have potential in terms of contributing to supply of minerals, vitamins and trace elements (Edwards 2003). In addition, forage based systems may be a way to diversify organic pig production and increase marketing, in particular by means of different types of forage crops.

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Appendix 1

	Block 1				Block 2				Block 3			
	Paddock No.											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Week 36												
Zone	1											
Area available, m^2	125	125	125	125	125	125	125	125	125	125	125	125
Week 37, day 5												
Zone	2											
Fence moved, m	3	3	3	3	3	3	3	3	3	3	3	3
Area available, m^2	162	162	162	162	162	162	162	162	162	162	162	162
Week 38												
Zone	3											
Fence moved, m^2												
Day 13	1	1	1	1	3	3	3	3	1	3	3	1
Area available, m^2	175	175	175	175	200	200	200	200	175	200	200	175
Day 14	1	1	1	1	-	-	-	-	1	-	-	1
Area Available, m^2	187.5	187.5	187.5	187.5	200	200	200	200	187.5	200	200	187.5
Day 15	1	1	1	1	-	-	-	-	1	-	-	1
Area Available, m^2	200	200	200	200	200	200	200	200	200	200	200	200
Zone	4											
20th of September	3	3	3	3	3	3	3	3	3	3	3	3
Area Available, m^2	237.5	237.5	237.5	237.5	237.5	237.5	237.5	237.5	237.5	237.5	237.5	237.5
Week 39												
Zone	5											
Fence moved, m												
Day 20	3	3	3	3	1	1	1	1	3	1	1	3
Area available, m^2	275	275	275	275	250	250	250	250	275	250	250	275
Day 21	-	-	-	-	1	1	1	1	-	-	-	-
Area Available, m^2	275	275	275	275	262.5	262.5	262.5	262.5	275	275	275	275
Day 22	-	-	-	-	1	1	1	1	-	-	-	-
Area Available, m^2	275	275	275	275	275	275	275	275	275	275	275	275
Zone	6											
Day 23	3	3	3	3	3	3	3	3	3	3	3	3
Area Available, m^2	312.5	312.5	312.5	312.5	312.5	312.5	312.5	312.5	312.5	312.5	312.5	312.5
Week 40												
Zone	7											
Fence moved, m												
Day 27	1	1	1	1	3	3	3	3	1	3	3	1
Area available, m^2	325	325	325	325	350	350	350	350	325	350	350	325
Day 28	1	1	1	1	-	-	-	-	1	1	1	1
Area Available, m^2	337.5	337.5	337.5	337.5	350	350	350	350	337.5	350	350	337.5
Day 29	1	1	1	1	-	-	-	-	1	1	1	1
Area Available, m^2	350	350	350	350	350	350	350	350	350	350	350	350
Zone	8											
Day 30	3	3	3	3	3	3	3	3	3	3	3	3
Area Available, m^2	387.5	387.5	387.5	387.5	387.5	387.5	387.5	387.5	387.5	387.5	387.5	387.5
Week 41												
Zone	9											
Fence moved, m												
Day 34	3	3	3	3	1	1	1	1	3	1	1	3
Area available, m^2	425	425	426	425	400	400	400	400	425	400	400	425
Day 35	-	-	-	-	1	1	1	1	-	1	1	-
Area Available, m^2	425	425	425	425	412.5	412.5	412.5	412.5	425	412.5	412.5	425
Day 36	-	-	-	-	1	1	1	1	-	1	1	-
Area Available, m^2	425	425	425	425	425	425	425	425	425	425	425	425
Zone	10											
Day 37	3	3	3	3	3	3	3	3	3	3	3	3
Area Available, m^2	462.5	462.5	462.5	462.5	462.5	462.5	462.5	462.5	462.5	462.5	462.5	462.5
Weeks 42												
Zone	11											
Fence moved, m												
Day 40	3	3	3	3	3	3	3	3	3	3	3	3
Area available, m^2	500	500	500	500	500	500	500	500	500	500	500	500

Appendix 2

Day	Kg feed pig^{-1} day^{-1}				FU pig^{-1} day^{-1}				Norm FU pig^{-1} day^{-1}
	HP treated pigs		LP treated pigs		HP treated pigs		LP treated pigs		2.63
	HP feed	LP feed	HP feed	LP feed	HP feed	LP feed	HP feed	LP feed	2.63
0	1.13	0.367	1.13	0.367	1.1413	0.357	1.1413	0.357	2.63
1	1.5	0.5	1.5	0.5	1.515	0.487	1.515	0.487	2.63
2	1.13	0.367	1.13	0.367	1.1413	0.357	1.1413	0.357	2.63
3	1.13	0.367	1.13	0.367	1.1413	0.357	1.1413	0.357	2.63
4	1.13	0.367	1.13	0.367	1.1413	0.357	1.1413	0.357	2.63
5	1.5	0.5	1.5	0.5	1.515	0.487	1.515	0.487	2.63
6	1.5	0.5	1.5	0.5	1.515	0.487	1.515	0.487	2.63
7	2		1	1	2.02		1.01	0.974	2.63
8	2			2	2.02			1.948	2.81
9	2			2	2.02			1.948	2.81
10	2			2	2.02			1.948	2.81
11	2			2	2.02			1.948	2.81
12	2			2	2.02			1.948	2.81
13	2			2	2.02			1.948	2.81
14	2			2	2.02			1.948	2.81
15	2			2	2.02			1.948	2.81
16	2.3			2.3	2.323			2.2402	2.85
17	2.3			2.3	2.323			2.2402	2.85
18	2.3			2.3	2.323			2.2402	2.85
19	2.5			2.5	2.525			2.435	2.85
20	2.5			2.5	2.525			2.435	2.85
21	2.5			2.5	2.525			2.435	2.85
22	2.5			2.5	2.525			2.435	2.85
23	2.5			2.5	2.525			2.435	2.85
24	2.5			2.5	2.525			2.435	2.85
25	2.5			2.5	2.525			2.435	2.85
26	2.5			2.5	2.525			2.435	2.85
27	2.5			2.5	2.525			2.435	2.85
28	2.5			2.5	2.525			2.435	2.85
29	2.5			2.5	2.525			2.435	2.85
30	2.5			2.5	2.525			2.435	2.85
31	2.5			2.5	2.525			2.435	2.85
32	2.5			2.5	2.525			2.435	2.85
33	2.5			2.5	2.525			2.435	2.85
34	2.5			2.5	2.525			2.435	2.85
35	2.5			2.5	2.525			2.435	2.85
36	2.5			2.5	2.525			2.435	2.85
37	2.5			2.5	2.525			2.435	2.85
38	2.5			2.5	2.525			2.435	2.85
39	2.5			2.5	2.525			2.435	2.85
mean	2.23		2.23		2.25		2.19		2.8

Appendix 3

DATO: ____ Senest udvidet d. ______

Foldnr Fx 11, 12, osv	Foldenes udseende – pct. del med den givne overflade Hele folden Vandret sum = 100							Græs/ lucerne Højde på det oprejste (mm)	Lucerne: Andel stgl uden blade, % af	
	Pløre		Tørt		Plantedække		Evt. andet, noter: ______			
	Oprodet, dybt >10 cm	Oprodet, lige under jordoverflade	Oprodet dybt >10 cm	Oprodet, lige under jordoverflade	Oprejst	Nedtrådt			Oprejst	Nedtrådt

Appendix 4

Adfærd slagtesvin Foulumgaard Dato: Fold: Areal til rådighed, m^2:

	Urin/fæces (u,f)											Zone 0 (1-3)					Zone 1 (1-3)						Zone 2 (1-3)					Zone 3 (1-3)					Zone 4 (1-3)				
Kl.	Zone 0	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Zone 9	I hytte (1-3)	Hvile	Rode	Rode og tygge	Græsse	Andet	Hvile	Rode	Rode og tygge	Græsse	Æder foder	Andet	Hvile	Rode	Rode og tygge	Græsse	Andet	Hvile	Rode	Rode og tygge	Græsse	Andet	Hvile	Rode	Rode og tygge	Græsse	Andet

Dato: Fold:

	Zone 5 (1-3)					Zone 6 (1-3)					Zone 7 (1-3)					Zone 8 (1-3)					Zone 9 (1-3)				
Kl.	Hvile	Rode	Rode og tygge	Græsse	Andet	Hvile	Rode	Rode og tygge	Græsse	Andet	Hvile	Rode	Rode og tygge	Græsse	Andet	Hvile	Rode	Rode og tygge	Græsse	Andet	Hvile	Rode	Rode og tygge	Græsse	Andet


23.09.2013