AARHUS UNIVERSITY
DEPARTMENT OF AGROECOLOGY

Master's thesis

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Free-range organic pigs foraging Jerusalem artichokes (*Helianthus tuberosus*) – effect of feeding strategy on feed intake, feed conversion, growth, animal behavior, nutrient balances and profitability

Dansk title:
Slagtesvin på jordskokker - effekt af fodringsstrategi på tilvækst, foderudnyttelse, adfærd, næringsstofbalancer og økonomi

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Abstract

Free range organic pig production, as it is practiced today in Denmark, is mainly on grassland and may have benefits in terms of animal welfare. However, high stocking rate and high inputs of concentrated feed are associated with high feed costs and high risks of nutrient leaching. The aim of the present experiment was to study the potential of implementing pigs foraging Jerusalem artichokes (*Helianthus tuberosus*) in order to compensate for a low supply of concentrate. Additionally, the goal was to study the effect of two different feeding strategies of supplemented feed offered to the pigs - *ad libitum vs.* restricted. The experiment was conducted on a Danish organic farm from November 2011 until February 2012. Thirty six crossbred growing pigs were randomly divided into six groups. During the experimental period of 40 days, three groups of pigs were fed with restricted amount of high protein mixture (0.8 SFU/pig/day) plus JA *ad libitum*. The pigs had an average area of 308 m^2/pig. The remaining three groups were fed with a standard diet mixture *ad libitum* plus JA ad libitum. The pigs in the *ad libitum* system had an average area of 124 m^2/pig. Average daily weight gain was 583 g and 1238 g in the restricted and *ad libitum* feeding systems, respectively. The huge difference was mainly due to a low concentrate input in the restricted system. This resulted in around 62% lower feed use per kg live weigh gain, when it comes to the feed conversion rate of concentrate and lower cost by about 4.5 DKK/kg gain. There was also a huge difference in daily energy intake from Jerusalem artichokes. In the restricted system, by reducing feed concentrate allowance, the pigs received roughly 55% of energy intake from foraging Jerusalem artichokes, while in the *ad libitum* system only 6% came from a field. As a result, higher intake of Jerusalem artichokes in the restricted system resulted in lean meat content, which was higher by about 2.5% compared to pigs fed *ad libitum*. Consequently, the average price per kg slaughter meat was 0.3 DKK higher in the restricted system. However, the total cost of feed was 4.8 DKK/kg gain higher in the restricted system compared to *ad libitum* due to a lower daily gain and higher occupied area. In the behavior observation, a significantly higher frequency of foraging Jerusalem artichokes tubers was observed in the restricted system, while in the *ad libitum* system the pigs spent more time on eating concentrate. There were no significant differences in other behaviors among the two feeding strategies. The defecation and urination behavior was more frequent near the huts, feeding and drinking areas in both systems, which created nitrogen hot spots with high risk of nitrogen leaching. However, lower stocking rate and lower input of concentrated feed in the restricted system resulted in lower nitrogen surplus of 51 kg/ha compared to *ad libitum* system, where the surplus was 284 kg. In conclusion, pigs foraging Jerusalem artichokes have a great potential for the farmers, but it seems that the pigs fed restrictively received too low an amount of supplemented feed, which resulted in a low daily gain. In order to find an optimal level of supplemented feed future research is needed.

Preface

This thesis is completed as part of my MSc programme in Agro Environmental Management at Aarhus University and was done at Research Centre Foulum.

The aim of this thesis was to evaluate a system based on pigs foraging Jerusalem artichoke (JA) in relation to feed cost and environmental impact. This project should give some ideas for farmers about replacing grass with more yielding forage, such as Jerusalem Artichokes, in the production of free-range pigs.

In general it has been a great challenge for a 'cowgirl' to work on the subject related to organic free-range pigs. I am thankful to my very good friend Henrik Bækstrøm Lauritsen for helping me realize that there are also other animals in the world than cows, and also for answering all my questions.

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September 1st 2012 *Karolina sikala*

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Abbreviations

EU	European Union
CP	Crude proteins
DM	Dry matter
JA	Jerusalem artichoke
AU	Animal Unit
ME	Metabolizable Energy
MJ	Megajoule
GJ	Gigajoule
SW	Slaughter weight
LW	Live weight
FCR	Feed conversion ratio
OM	Organic matter
LMC	Lean meat content

Definitions

Restricted system: System in which the pigs were fed restricted with high protein mixture and JA *ad libitum.*

***Ad libitum* system:** system in which the pigs were fed *ad libitum* with standard diet mixture and JA *ad libitum.*

High protein mixture: Natur SL t 35 delivered from DLG Company, produced for organic pig production.

Standard diet mixture: Based on homemade ingredients (oats, triticale, wheat) plus concentrate Natur SL t 35.

1 Introduction

Organic pig production in all European Union (EU) countries is based on the Council Regulation (EC) No 834/2007 from 28 June 2007, formulated by the Council of the European Union (EC, 2007) plus some additional, country-specific private certification rules. The EC regulations show the basic standards for the origin of the animals, housing conditions, feeding, disease prevention and animal health treatment, cleaning and disinfection. Behind these standards the main principles are to create freedom and access to natural behaviours, such as foraging behaviour for the animals, and to balance the production of crop and livestock in order to achieve sustainable nutrient cycles (Borell and Sorensen, 2004). Additionally, all animals must be fed with roughage all year round (Hermansen *et al.,* 2004). In Denmark, organic pig production is based on an outdoor housing system, where the pregnant sows are kept on pasture for at least 150 days, as in the current EU rules. The weaning age is extended from 40 days in the EU regulations to 7 weeks as a minimum (Friland A/S, 2012, EC, 2007).

However, most of the weaning and fattening pigs are kept indoors with free access to a concrete outdoor run, and thus do not comply very well with organic principles concerning the ability to express natural behaviour. Consumers also expect that organic farming achieves high level of animal welfare, and that the animals can carry out their natural behaviour (Hermansen *et al.,* 2004). Providing these conditions increases the costs related to appropriate housing conditions, which is mainly due to the larger area, which is required in order to provide a better environment for animals.

Nevertheless, several organic farmers practice growing finishing pigs in a free range system, where the pigs are kept outside on the field with some vegetation and with small huts as a shelter. This system is reflected in figure 1, where the field nutrient balance is shown. The field requires some inputs, such as manure, animals, seeds and feed, and outputs - animals and crops. As presented in the figure, there are also some losses, which should not be neglected. In this system, semi-natural conditions are created for the pigs to use their natural foraging behaviour and their time-budget to seek for food on the soil surface and below (Stolba and Wood-Gush, 1989).

The advantage of the free range system is lower investment (lower costs of buildings and equipment), and it is assumed that animal welfare and health, which are important factors for achieving high meat quality, are improved. In this system, replacing feed intake by forage intake might also save on concentrate costs, which consist of harvest and storage costs. Moreover, from the consumers' point of view, it is more natural and more environmentally friendly (Gourdine *et al.,* 2010).

However, there are also some problems related to this system. The free range pig production, as it is practiced today, is mainly on grassland and is characterized in high stocking rate (1.4 Animal Unit/ha) and high labor input (Stern and Andresen, 2003). They are also able to receive from grass and other herbage of up to 20% of the daily dry matter intake (Carslosn *et al.*, 1999). Nevertheless high input of concentrated feed is needed in order to obtain optimum growth of finishers what might give a result of high feed use per kg gain. This system, compared to an indoor system, requires 10-15% higher feed input due to feeding losses due to spillage by pigs near feeding trough (Edwards, 2007), yet it shows lower feed intake and slower growth rate (Hoffman *et al.*, 2003). Furthermore, the pigs' natural grazing and rooting behaviour, on which they spend around 50% of their time budget (Stolba and Wood-Gush, 1989), favours quick removal of vegetation and as a result, the uptake potential.

Uneven nutrient distribution, and their greater accumulation called 'hotspots' near huts, feeding and drinking areas, are the results of feeding losses and uneven urine and faeces distribution recorded in these areas (Miao *et al.*, 2004 ; Eriksen *et al.*, 2006). Furthermore, Williams *et al.* (2000) noticed soil compaction in these areas, which favours nutrient losses via denitrification, and inhibits root growth. Bare soil also exhibits higher risks of nutrient losses (mainly nitrogen) by leaching to the water bodies, volatilization to the atmosphere and, which contributes to eutrophication, global warming and acid rains (Strudsholm and Hermansen 2005, Salomon *et al.*, 2007). Several investigations proved that the losses from free range pig production are relatively high, and vary among stocking rates, diet plus management of the paddocks (Eriksen *et al.*, 2002; Eriksen *et al.*, 2006). According to Worthington and Danks (1994), after moving the pigs, there is a residue of 419 kg N /ha/year available for leaching. Furthermore, uneven nutrient distribution and their losses may contribute to a low yield in the next crop (Sommer *et al.* (2001).

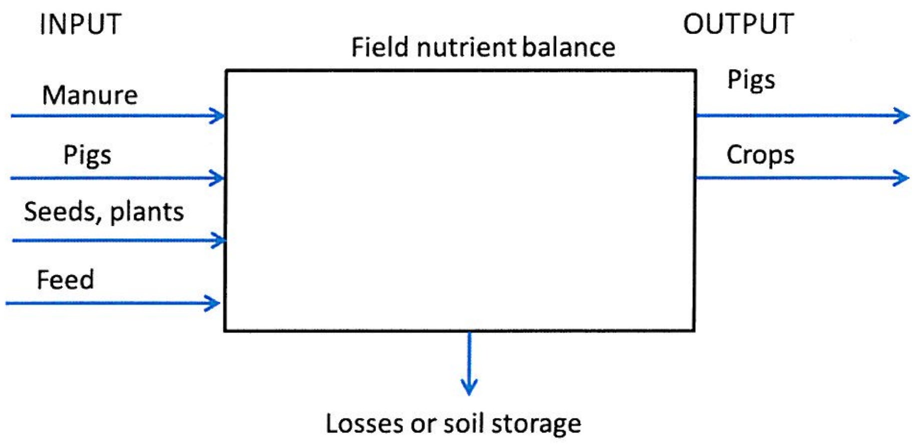

Figure 1 Field nutrient balance in a free range pig production system.

Due to a relatively low intake from the grass field and other herbage, and the losses of nitrate, it is relevant to investigate alternative possibilities of feeding strategy. By replacing concentrated feed intake by more efficient fodder intake, it might be possible to obtain a profitable and sustainable production (Watson *et al.,* 2003). One of the solutions might be the rearing of free range pigs on high-yielding fodder crops, such as Jerusalem artichokes (JA). The JA is characterized as a high yielding crop, and the tubers' productivity ranges from 9.1 - 12.6 t/ha of fodder units (FU) and 105-142 GJ/ha of metabolizable energy (ME) (Bogomolov and Petrakova, 2001). High yield, which will supply daily pigs feeding ration, might contribute to lower feed input to the system, and consequently lower feeding costs and reduced nutrient losses, which were caused in a large degree by high concentrate input (Quintern and Sundrum, 2006). JA is also rich in inulin which, according to Farnworth (1994), is utilized in pigs by increased number of beneficial microorganisms, which have the positive side effect of reducing intestinal parasites (a major problem in outdoor pig production). As a consequence, the beneficial microorganisms have advantageous effects on growth, metabolism and health. The decreased numbers of pathogenic bacteria in the intestine increase meat quality, due to reducing the putrefactive products causing the boar taint (e.g. skatole). This may be one of the solutions which can be implemented from 2014, when the castration of male pigs will be banned (Jensen, 2011). Furthermore, pigs are able to harvest tubers themselves, which reduces the costs related to harvest, storage and extra mechanical soil tillage before seeding (Andresen *et al.,* 2000).

1.1 Problem statement

Nowadays, outdoor production of growing-finishing pigs is characterized by high concentrate feed consumption, high feed costs and nutrient losses due to their accumulation (hot spots).

In order to produce pigs in a more sustainable manner, meet customer expectations including issues such as providing for the pig's optimum welfare conditions, and at the same time to reduce the costs for concentrated feed and impact on the environment, organic farmers should search for some solutions.

1.2 Overall aim and objectives

The overall aim is to evaluate a production system based on pigs foraging JA in relation to feed costs and environmental impact.

Specific objectives were to investigate the effect of feeding strategy (*ad libitum* vs. restricted) on:

- Feed intake (allocated feed and JA)
- Feed conversion rate
- Growth
- Meat percentage of finished pigs
- Animal behavior
- Nitrogen balance (on paddock level)

This was done by literature review, and by analyzing data from an experimental assessment.

2 Literature review

2.1 The pigs' natural foraging behaviour

The domestic pigs' behaviour very closely resembles that of the European Wild boar, from which they originated. Several investigations indicate that under semi-natural condition the pigs' behaviour is similar to that of wild boars and feral pigs (Jensen 1985; Gustafsson *et al.* 1999). Furthermore, they are omnivorous and eat almost anything that they find, *e.g.* grass, berries, acorn, small vertebrates, tubers, eggs, and carrion. Feral pigs in nature spend most of their time and energy on foraging behaviour like rooting, chewing and smelling. Foraging behaviour, besides searching for the nutrients, has another purpose - exploring the environment (Price, 1999). In the free range system the pigs are kept under semi-natural conditions, but still there are huge differences. According to Price (1999), the differences are mainly due to huge human activities in the free-range system. One of the differences is higher density, which may result in higher competition for food, water and shelter.

Work by Buckner *et al.* (1997) shows, that foraging activity in pigs depends on the time of the day and year. However, Andresen and Redbo (1998) described more factors affecting pigs' foraging behaviour. They divided them into two groups, internal and external. In the internal group he put factors, such as nutritional needs due to their high daily activity, genetics, diet, and adaptation abilities to the new surroundings. In external factors he considered weather conditions (temperature, wind and precipitation), forage crop quality and yield, soil type and moisture, management of the area and equipment, supplementary feed and stocking rate. Some of these factors were studied deeper by different researchers in their experiments. For example, Andresen and Redbo (1998) noticed that the foraging motivation may change with the amount and quality of herbage. Additionally, fibre content of the diet has a huge influence - increased amount of fibre will decrease foraging behaviour of the pigs (Stern and Andresen 2003; Braund *et al.*, 1998). Furthermore, they did not notice any differences in rooting behaviour in relation to temperature - they only discovered that in temperature around 20°C, the pigs increased rooting behaviour in drinking and wallowing area, due to easier digging in this area. This result was confirmed by Graves (1984), who noticed more intensive rooting behaviour in wet areas. Frequent change of the area has also stimulated an increased level of foraging and explorative activity.

More investigation about the change of pig time-budget was done by Young and Lawrence (1996). They manipulated the rate of the reinforced feed given to the pigs to find out how this affected their foraging behaviour. The result showed that the pigs' foraging behaviour increased with decreased level of the feed reinforced.

Moreover, several investigations indicate that pigs' time budget is used mainly for foraging behaviours (40-70%), and they prefer working for food rather than getting food for free (Jonge *et al.*, 2008; Edwards, 2003). Stolba and Wood-Gush (1989) have done an observation of pigs' behaviour in a semi-natural environment. In 52% of the scan observations the pigs were using the time on foraging (grazing 31% and rooting 21%) and 23% on exploring the environment. The observation was made over the autumn period, during the hours of daylight, and they also noticed that the pigs moved to another area as a group.

In summary, the integration of pigs in the cropping system might give an opportunity to express their foraging behaviour when searching for food and, at the same time, create semi-natural conditions for the pigs. Their foraging behaviour might be used for harvesting the crops and, as a result, reducing concentrate intake. Nevertheless, further research is needed in order to find an optimal crop, which greatly meets the daily nutritional need.

2.2 Nutritional value from foraging and the effect of feeding strategy

Pigs are characterized by the ability to consume a wide range of feeds in order to meet their nutritional need, which gives a possibility to use cheaper nutrient resources such as forages, proving to be a significant source of nutrients (Rodriguez-Estevez *et al.*, 2009). In a free-range system, the pigs can be introduced to the cropping system and they are able to get some nutrient intake themselves from foraging. However, the nutritional intake depends on the age and physiological state of a pig, which have an effect on their needs (Edwards, 2003). To forage a larger part of their requirements and to produce pigs based on this diet, and at the same time to reduce the concentrate input, proper cropping system and proper feeding strategy is needed. Additionally, Edwards (2003) described some factors which are affecting nutritional contribution from pasture, and these factors are: availability and type of feedstuff, herbage nutrient content and intake. They will be described more in details below.

2.2.1 Availability

One of the factors, which affect the nutritional contribution, is availability or, in other words, the accessibility and the type of herbage used on pasture. In case of herbage, the nutritional intake is low compared to root crops, such as potato or fodder beet, due to foraging activity through which the pigs rapidly remove and destroy the herbage (Edwards, 2003). According to Rivera Ferre *et al.* (2001), the availability of herbage differs in the season from 2.6 t/ha OM to 5 t/ha organic matter (OM) in the spring and summer, respectively. Each kg of OM corresponds to 19 MJ, which gives 49400 MJ/ha and 95000 MJ /ha, respectively. However, Fernandez *et al.* (2006) concluded that growing sows on clover/grass pasture, and by having 2 weeks of the resting period after one week of continuous grazing, it is possible to increase the clover percentage in the pasture and their availability for the pigs. At the same time, their study shows that on the field with continuous grazing the dead materials' and plant stems' percentage increase, which decreases clover percentage.

2.2.2 Nutrient content and digestibility

Another factor is the nutrient content of herbage and their digestibility by pigs, which besides the voluntary eating has huge effects on the nutrient intake (Edwards, 2003). Before showing further results of the different feedstuff digestibility by the pigs, it is necessary to define this word. McDonald *et al.* (2002) define the digestibility of a food as the proportion of food which is not excreted in the faeces, but is rather absorbed by the animal. It is commonly expressed in terms of DM, as a coefficient or a percentage. The herbage is characterized by a high proportion of poorly digested fibre, compared *e.g.* to the typical cereals with very low level of fibre used in a pig diet. Because of this has lower effectiveness of energy utilization. The soluble fibre is easier to ferment and further to digest, due to slower passage rate through the intestinal tract, compared to insoluble fibre which absorbs the water from the digestive system and it is slow or incompletely digested, due to faster passage through the intestinal tract (Graham *et al.*, 1986; Low, 1985). In general, dietary fibre, which is defined as the sum of nonstarch polisaccharides and lignin, is characterized by lower digestibility (below 50%) compared to other nutrients, which are 80-100% digestible (Noblet and Milgen, 2004). Furthermore, it is described as ingredients which are not digestible by endogenous enzyme of monogastric animals. For example, the digestibility of insoluble fibre such as lignin (source: wheat straw) is around zero, whereas for a highly water-soluble dietary fibre such as pectin (source: sugar beets, soyabeen hulls) it might be easier degraded by the microfloral enzymes of the gut and reach 0.80-0.90 (Noblet and Goff, 2001). Even so, diet with high-fibre contents has a positive effect on animal health (Low, 1985; Carlson *et al.*, 1998).
Digestibility in growing pigs was measured in more detail by Carlson *et al.* (1998), where they compared two diets from grass-clover mix: one with high herbage intakes (12%-15% DM intake), and one with low herbage intakes (6% - 9% DM intake). As a consequence, the high herbage intakes reduced digestibility of DM in the total diet, due to an increase in the rate of passage and other negative effects on the digestion of other feeding components by fibre (Rivera Ferre *et al.*, 2001), *e.g.* on crude proteins and fat (Noblet and Milgen, 2004).

However, herbage composition varies and depends on the species mix and the time of the year. In table 1 below, there are some results investigated by Vestergaard *et al.* (1995) about the composition of the mix dried grass meal made of ryegrass and red clover cut in 3 different dates. It is possible to conclude that the dried grass meal derived from the last cut made August 26th has a 60% lower sugar content compared to the first cut made in the end of May. At the same time, crude fibre % increased by around 20%, which contributed to a decreased apparent DM digestibility. In case of growing pigs, the apparent digestibility of DM dropped from 58% to 40% and from 62% to 50% in sows. It is also possible to see that the digestibility increases with the pigs' age, and the sows are able to digest much more herbage compared with the finishing pigs of the live weight between 40-60 kg (Vestergaard *et al.*, 1995). The improved digestibility of fibre with increasing pig's age and live weight is due to the voluminous large intestine and cecum, which contain a bigger microbial population and more extensive fermentation (Kass *et al.*, 1980; Noblet and Goff, 2001).

Table 1 Difference between the dried grass meal (ryegrass (Lolium spp.) and red clover (Trifolium pratense)) composition from 3 seasonal cuts, and their DM apparent digestibility in growing pigs and sows (Vestergaard *et al.*, 1995)

	Cut 1 31 May	Cut 2 7 July	Cut 3 26 August
Composition of grass meal (g/kg DM)			
Crude fibre	231	275	286
Cellulose	165	208	212
Sugar	141	99	57
DM apparent digestibility %			
Growing pigs (40- 60 kg live weight)	58	45	40
Sows (adult 200 kg)	62	53	50
Metabolisable energy (MJ/kg DM)			
Growing pigs	9.6	7.4	6.3
Sows	10.1	8.8	8.3

More studies of herbage quality among the two different species (Perennial Ryegrass *Lolium perenne* and ribwort plantain *Plantago laceolata*) grazed in different seasons in Chile by the wild boars were done by Hodgkinson *et al.* (2009). In both species the nutritional quality measure in the spring and in the summer was similar. This differed from the previous studies mentioned above, according to which the nutritional value of the plant during the summer is lower (due to the plant entering the reproductive stage where the seed develop). Also, during the summer the amount of dead material increased in *Plantago laceolata* and *Lolium perenne* from around 4% up to 10 and 30% respectively. The dead material consists of cellulose (fibre), of which the nutritional value is very low, if any. The energy content from each pasture in the spring and summer had a similar value. When it comes to crude fibre, the content was lower in the summer in both pastures, whereas for *Plantago laceolata* it was notably lower. They also conclude that wild boar consumed less of both types of pastures during the summer than in the spring. In case of grazing the *Lolium perenne* pasture, the wild boar could satisfy their daily maintenance of digestible energy requirement up to 90 and 45 % in the spring and in the summer, respectively.

2.2.3 Herbage intake

The nutrient intake from foraging also depends on the herbage intake, which in large extent depends on the physical stage of the animals (Edwards 2003; Rivera Ferre *et al.*, 2001). Previous investigations made by Fernandez *et al.* (2006) in sows, showed the daily intake of energy from clover grass of 1.63 SFU on average, which contributes to 61% of their daily intake. Furthermore, the amount of concentrate offered for animals did not influence the intake from clover grass. The studies done by Rivera Ferre *et al.* (2001) show, that the sows' herbage intake from ryegrass/clover mix ranged from 5.8 kg of fresh herbage in the spring to 7.3 kg in the summer (1.1 to 1.5 kg of OM), and in this case the amount of concentrate did not affect the herbage intake either. Nevertheless, Rodriguez-Estevez *et al.* (2009) made a study of producing finishing Iberian pigs grazing natural pasture in the dehese (conservation of grazed oak woodland) (Huntsinger *et al.*, 2004) in Spain without any additional feed. The goal was to produce the pigs in a more sustained way by using natural resources, such as acorn, grass, berries, bush roots etc. However, the two main resources were acorns and grass, and the pigs' daily intake was 3.1-3.6 kg of DM and 0.38-0.49 kg DM respectively, and they were able to obtain physical and nutritional satiety.

Furthermore, the herbage intake also depends on the feeding strategy. For example, by feeding the pigs with different concentrate levels, the forage intake will change too, as it was shown by Carlson *et al.* (1999). Their experiment was based on feeding concentrate, restricted and *ad libitum*, plus the herbage *ad libitum*. The small pigs of about 30 kg body mass, fed restrictive with the concentrate, were able to consume grass and other herbage of up to 18-19% of the daily DM intake. Likewise, a reduction of 20% of the feed allowance increased the nutrient intake from herbage by about 5% (Stern and Andresen 2003). Nevertheless, in restricted concentrate feeding the growth rate might be reduced by 10-15%, and the pigs have higher lean content (Hermansen *et al.*, 2004). In case of feeding the pigs *ad libitum* with the concentrate, the herbage intake is not that high, ranging from 2% to 8% of daily DM intake (Hermansen *et al.*, 2004). This is also proved by several investigations, which indicate that the pigs fed *ad libitum* with a concentrate resolutely decreased herbage intake to below 5% of the nutrient requirements (Mowat *et al.*, 2003; Edwards, 2003).

2.2.4 Alternative fodders for pigs

The abovementioned studies show that the nutritional value of foraging herbage is relatively low in growing pigs, and it is difficult to obtain their satiety, which will result in fast removal of vegetation. This emphasizes the need for looking for alternative foraging crops. Common feed crops for pigs are root crops like potato and sugar beets used in many countries. Their intake is much higher, compared to herbage, and according to Chambers *et al.* (1986) dry sows, by foraging on potato and sugar beets directly from the ground, were able to intake 20-

30 kg fresh weight per day. This was more than enough to meet the sows' maintenance requirements for energy and amino acids. In table 2 below an analysis of different feedstuffs, which are used for the pigs, is shown. Fodder beet and barley have similar fibre content. Even so, according to Olesen *et al.* (2001), the fibre from sugar beet is fermented to a higher degree compared to cereals. Potatoes have the lowest % of crude fibre, clover grass and JA have a higher one. Furthermore, the digestible energy MJ/kg DM in JA and barley is the biggest. The % of crude protein in DM is the highest in clover grass.

Table 2 Analysis of different feed components.

Feed	Clover grass (Danielsen *et al.*, 2000)	Potato (Handbook-University of Newcastle (2002)	JA (pers.comm., Kongsted 2012)	Fodder beet (Handbook-University of Newcastle (2002)	Barley grains (Videcenter for Svineproduktion 2011)
DM%	17.8	20.0	21.5	18.0	85.0
Crude fibre % in DM	19.6	2.5	10.34[1]	5.6	5.3
Digestible energy MJ/kg DM	13.8[2]	11.0	15.0[3]	13.3	15.2
Crude proteins % in DM	21.8	11.0	7.8	5.6	8.9

In addition, according to Danielsen *et al.* (2000), potato tubers are an excellent source of energy (11- 16 MJ DE/kg DM). Their protein content varies from 62 to 124 g/kg DM with proteins' biological value (proportion of food protein which can be utilized by animal (McDonald *et al.* 2002)) of 70. Furthermore, their yield is relatively high - around 26 t/ha (Henriksen *et al.*, 2007), and can be eaten by pigs fresh, boiled, dried or as silage (Woolfe, 1992). However, starch in raw tubers is resistant to digestive enzymes of the pigs, and in order to increase the digestibility, a physical preparation is needed. This was proven by Naskar *et al.* (2008), who compared the digestibility in weaning and grower pigs feed of fresh *vs.* boiled potato. In both groups of pigs, the DM and CP digestibility of boiled sweet potato tubers was higher, which could be because of gelatinization of starch molecules during boiling. Cooked potatoes, compared to raw, are more palatable to all groups of pigs (Whittemore, 1977), but at the same time contribute to higher production costs. Also, feeding the pigs with green potato (the potatoes become green after prolonged exposure to light or when they have sprouts) might cause some digestive problems due to the toxin solanine.

[1] (Ly 2000)
[2] (Moller *et al.*, 2000)
[3] (Ly *et al.*, 1995)

In summary, in pigs the nutrient intake from foraging differs due to many important things, which were described above. To obtain the optimal intake from forage, and to reduce the concentrate input, proper feeding strategy, motivating the pigs to seek for feed together with proper forage crops (which providing higher intake), is essential. In the next chapters the importance of an alternative crop, such as JA which seems to be an excellent fodder for pigs, is described.

2.3 Jerusalem Artichokes as a foraging crop

The energy intake from pasture by pigs is low due to a relatively low yield from grass and a quick removal of vegetation by pigs due to their natural behaviour, such as foraging within a limited area. Grazing and rooting activity favour the fast removal of ground cover and can result in the reduction of animal welfare. Furthermore, production cost increases due to a huge use of concentrated feed, their losses and the negative impact on the environment (Braund *et al.,* 1998). It has been suggested that one method to reduce the high input of concentrate is to use a high-yielding fodder crop, such as JA, and to use pigs' natural behaviour for seeking the food (Watson *et al.,* 2003).

2.3.1 Nutritional value and digestibility of Jerusalem artichoke

JA (*Helianthus tuberosus*) is a plant native to North America. The nutritional composition of the JA tuber consists of 16-24% DM (Schweinen, 1992), 9.2 to 9.7% of crude protein and 4.1-4.8% of crude fibre. The JA tuber is characterized by a high content of inulin - around 44 % of DM (Farnworth, 1994) and is a source of soluble fiber. Inulin is a non-sugar carbohydrate belonging to the dietary fibre class called the fructans. Inulin is a non-digestible polysaccharide, which means that it cannot be degraded by pig enzymes, but it can potentially be degraded by microbial fermentation, and the digestibility of non-starch polysaccharides differs with pig's age (see table 3). It is possible to notice that growing pigs and sows show higher digestibility of non-starch polysaccharides compared to small piglets. Furthermore, the digestive capacity of the total tract is much higher compared to the small intestine (Knudsen *et al.,* 2012).

Table 3 The coefficient of digestibility of starch and non-starch polysaccharides in the small intestine and in the total tract of piglets, growing pigs and sows. Source: Knudsen *et al.,* (2012)

	N	Small intestine		Total tract	
		Starch	NSP	Starch	NSP
Piglets, 0–10 days post-weaning[a]	9	0.75	0.03	0.99	0.57
Piglets, 14–28 days post-weaning[b]	8	0.95	0.14	1.00	0.67
Growing pigs[c]	78	0.96	0.21	1.00	0.70
Sows[d]	3	0.93	0.30	0.99	0.64

Data from: [a]Lærke et al. (2003) and Hopwood et al. (2004). [b]Gdala et al. (1997), Jensen et al. (1998) and Pluske et al. (2007). [c]Bach Knudsen et al. (2008), and [d]Serena et al. (2008b).
N = number of diets.

As a result, non-starch polysaccharides pass through much of the digestive system and they can be fermented by bacteria in the large intestine producing volatile fatty acids, which can be absorbed and metabolised by pigs (Low, 1985). Furthermore, the volatile fatty acids, such as acetic acid, propionic acids and butyric acids, can contribute by up to 30% to the energy supply (Williams *et al.*, 2001). According to the studies by Graham *et al.* (1986), around 40% of tubers' DM was digested in the pig terminal ileum. Still, in this a larger part of 50% of JA was digested in the large intestine.

The digestibility of JA tubers differs and depends on the pigs' age. In the young pigs the digestibility is relatively low, but increases with the pig's age, which makes JA an ideal feed for pigs at the late fattening stage and for sows (Iannone and Faeti, 2003). Besides the digestibility, also the availability of JA tuber increases with pigs' age. In several studies it has been shown that pigs of lightweight 30 kg have had difficulties in chewing JA roots. The pigs over 50 kg live weight showed better interest in eating JA, and the intake in these pigs increased significantly (Jost 1992; Iannone & Faeti, 2003).

However, the harvesting time and storage conditions of tubers can affect the digestibility by the pigs. Farnworth (1994) analyzed the JA tubers in the autumn and in the winter season. The analysis showed that the tubers harvested during the autumn are rich in inulin, a longer chain fructan. This fructan is not possible to be broken down and, as a result, is not metabolized in the mammal body (Kaldy *et al.*, 1980) due to the fact, that they miss the specialized enzymes which would do the work. But, by storing tubers over the winter, the inulin can be broken down naturally to the simple fructooligosaccharides (short chain fructan) which are easy to break down.

Furthermore, it is also proven that JA tubers are carbohydrate rich feed and have a high metabolizable energy (ME) content of about 15 MJ of per kg DM, this is 105-142 GJ/ha (Bogomolov and Petrakova, 2001). However, JA is low in protein (see table 2), which makes this crop useful only partly in the feeding ration (Mesini, 1996). To fulfil pig's nutritional demand some amino acids, which are essential for the pigs (for example lysine and methionine), should be delivered to pigs with proper feeding ration (Lammers *et al.*, 2007). Improper ration can reduce pigs' gain (muscle and mass development) and can have a negative effect on pigs' health. As a consequence, in order to keep a good nutrient balance in the diet, supplementary feed such as concentrate mix or cereals have to be implemented for pigs as a source of protein.

In many studies the high intake of JA tubers by weaned pigs has been seen (Farnworth *et al.*, 1995; Piloto *et al.*, 1998; Ly *et al.*, 1994). The feed efficiency and body weight gain in pigs varies with the amount of JA included in their diet. According to Farnworth (1994), the young pigs, which consumed high amount of fresh tubers, increased body weight gains, but decreased feed efficiency. Piloto *et al.* (1998) fed the pigs of the starting weight of about 14.6 kg with a diet containing 0, 33, 66 and 100% of JA raw tubers instead of maize meal. There were insignificant differences in feed intake, daily gain and feed efficiency in pigs fed 33% of JA. However, in a diet of 66 and 100% JA, the body weight gain and feed efficiency were significantly reduced compared 0 and 33%.

2.3.2 Jerusalem Artichokes – yields and cultivation aspects and challenges

As already mentioned, JA is a crop of great potential for feed production. The crop gives a high yield for relatively low production costs, as it can grow and give high yield also on poor quality soils. Low cost is also due to minimal fertilizer addition (Rodrigues *et al.*, 2007). This makes it a perfect crop to produce organically due to the high resistance against many common pests, diseases and cold temperature (Kosaric *et al.*, 1984). The plant does not require weed control, because it is a fast growing plant and might well compete with weeds (Barthomeut *et al.*, 1991).

Table 4 Yield of Jerusalem Artichoke tubers found in the literature.

Reference	Yield, t/ha	Yield DM/ha	Yield, SFU/ha
Bogomolov & Petrakova (2001)		8.4-12.3	9.100-12.600
Henriksen and Bjorn (2003)	40-70		
Zonin (1987)			5
Marchenko & Terentieva (1979)	40-60		25.000-30.000

As indicated in table 4, the yields of JA vary from 5.000 to 30.000 SFU/ha, and are very high compared to the crops usually used for pig feed, such as barley yielding from 3744 to 4348 SFU/ha, (Hansen *et al.*, 2005) or grass (1000 SFU/ha). This makes production of JA very attractive for organic pig producers.

However, JA production might also cause some problems in the cropping system due to a difficult harvest. According to Wunsch *et al.* (2011), about 1/3 of JA tubers harvested by a combine stay in the soil and are ready to germinate in the next year. JA is very competitive to following crop and will dominate the field. Nevertheless, this problem can be minimized by using pigs, which are able to harvest more tubers than a combine. This was proven by Wunsch *et al.* (2011) which result showed that in the area where the pigs were used, only 3 tubers were lost per m^2. On the field harvested mechanically, an average of 74 tubers per m^2 was found left on the field. The count was done also on the following crop. On the field harvested by pigs, only 1 tuber was found, and 31 tubers were found on the field harvested mechanically. The number decreased from 3 to 1 due to mechanical cultivation.

2.3.3 Other characteristics of JA

JA tuber used in the diet shows a desirable side-effect. For example, high concentrations of fructooligosaccharides and inulin in JA tubers have shown promising effect as prebiotics in animal nutrition. More precisely, they stimulate the growth of lactic acid bacteria (for example *Lactobacillus*), which protect the pig gut from infection (Knudsen *et al.*, 2012). In general, growth of positive bacteria reduces the amount of pathogenic bacteria and parasites in the intestine. Furthermore, they stimulate the immune system and reduce the risk of many diseases and infections (Roepstorff *et al.*, 2005).

Another desirable side-effect of JA in a diet noticed by Farnworth (1995) is that pigs eating the diets containing 3 to 6% of JA had less of skatole smell. Skatole, together with androsterone, can be reduced even to zero if the inulin intake will be up to 450 g/day, two or one week before the slaughter (Hansen, 2006). The reduction of skatole in the hindgut and in the fatty tissue might be the result of a decrease in *Clostridium perfringens* bacteria, due to the increase in short chain fatty acids and lower pH (While *et al.*,2012). Additionally, the carcass quality of pigs fed on JA was higher than that of the pigs fed conventionally (Jost, 1992), which gives better price for each kg of sold meat.

Furthermore, the JA compared to *e.g.* legume crops does not contain any anti-nutritional factors, which are able to lower the amino acids' absorption and energy utilisation by the pigs or other animals (Seabra *et al.*, 2001). This could negatively affect the health and growth (McDonald, 2002).

In summary, JA is a crop which can be biologically harvested by pigs due to their foraging behavior. Supplied also with appropriate feeds, such as concentrate rich in proteins, vitamins and minerals, JA creates a suitable free range environment for the pigs. By allowing the pigs dig up raw tubers according to their needs, it is possible to keep a constant level of energy consumption and create semi-natural conditions for them (Ly *et al.*, 1994).

2.4 Potential loss of nutrients from free-range system and the consequences

As already mentioned in the introduction, the free range pig system practiced in Denmark on grass, characterized by the difficulty in maintaining grass cover together with high input of concentrated feed, and high stocking rate. This results in a low nutrient intake from the pasture. The nutrient losses from the paddock in the free range system (mainly in the feeding and drinking area), which are not absorbed by plants, might be lost in the form of nitrate leaching, ammonia volatilization and denitrification. Some can be accumulated in soil as organic matter (see figure 1) (Williams *et al.,* 2000). There is no precise information about the nutrient losses from free range pigs on pasture, however, according to Eriksen *et al.* (2006) the losses are relatively high. More detailed information about the N losses is provided by Eriksen *et al.* (2002), who investigated the fate of the N input in sow outdoor paddocks. 44% of N was consumed by the piglets and the rest was lost via: ammonia volatilization (13%), denitrification (8%) and nitrate leaching (16-35%). They added that the nutrient was unevenly distributed due to the same position of huts and feeding troughs during the grazing period. The high nutrient losses to the water bodies and to the atmosphere contribute to global warming, acid rain and eutrophication, which makes water unsuitable as drinking water (Eriksen *et al.,* 2006). Besides the environmental costs, this might also affect the production costs due to insufficient nutrient content in the soil for the next crop. In an area with too high N supply, this can cause lodging in cereals crops (Williams *et al.*, 2005; Eriksen and Kristensen, 2001). For example, Eriksen and Kristensen (2001) noticed that the yield of the potato crop established on the field after removing the sows varied from 630 to 3585 kg DM/ha, however uneven nutrient distribution explained only 17% of the total difference in DM production, probably due to low nutrient efficiency.

Moreover, Williams *et al.* (2000) noticed soil compaction near the huts, feeding and drinking areas. It was caused by intensive pigs' traffic, which caused immobilization of N in the soil due to reduced infiltration rate of the soil. Several investigations indicate that in these areas the highest number of defecation and urination were found (Stern and Andersen, 2003; Salomon *et al.,* 2005; Williams *et al.,*2000), and the leaching potential in these areas was around 20 times higher (Quintern and Sundrum, 2006). Eriksen (2001) reported that the concentration of inorganic N in the paddock, which was unevenly distributed, caused hot spots sensitive to leaching, and the highest value was also found near the feeding areas. In the measuring period of 18 months, he noticed that nitrate leaching inside the paddock after grazing by lactating sows was on average 320 kg N/ha. Larsen *et al.* (2000) observed the surplus of 330- 650 kg N/ha/year on organic farms in Denmark. The surplus was still much lower compared to a conventional system, where the values of 500-800 kg N/ha/year are recorded. Additionally, the surplus and the N leaching vary among different plots in different distances from the feeding place. In a distance of 10 m from the feeding place, the leaching losses were on average about 500 kg N/ha, 16 m from the feeding place they were 330 kg N/ha, and 22 and 28 m further away from the feeding place the leaching losses were around 200 kg N/ha (Eiksen, 2001).

Additionally, uniform distribution of nutrients is related to the excretory behaviour of the pigs to a large extent (Eriksen and Kristensen, 2001). Furthermore, the higher leaching losses were noticed in a period of high rainfall (Eiksen, 2001). The nutrient losses also differ in terms of stocking rate. Williams *et al.* (2005) noticed different N surplus in paddocks after 2 years of stocking. In the paddocks with a high stocking rate of 25 dry sows /ha, the N surpluses were 576 kg/ha. In the paddock with 18 and 12 dry sows, the N surpluses were 398 and 265 kg N/ha, respectively. Furthermore, the lower stocking rate makes the grass swards possible to recover and, as a result, reduce the risk of soil erosion.

Furthermore, bad management strategy, such as improper crop rotation, favours nutrient losses. The following crops must take up accumulated nutrients in order to ensure their efficient usage and crop growth, and the proper way of integrating pig into crop rotation (Quintern and Sundrum, 2006). Furthermore, the diet offered to the animals has a huge influence on the degree of nutrient losses either. The nutrient composition in the diet has an effect on the composition of dung and urine. By applying a diet with lower amounts of N and P, it is possible to decrease the environmental impact compared with conventional diet, but it is not possible to change the defecation and urination behaviour in pigs and the nutrient distribution (Watson *et al.,* 2003).

In summary, it is possible to notice that the excessive supply of concentrate to the pigs which lower nutrient intake from the field, contributes to nutrient losses due to their accumulation caused by uneven nutrient distribution. The hot spots, caused by nitrogen accumulation mainly in feeding, are where the highest number of defecation and urination were found as well, and they are sensitive to leaching. To prevent the environmental impact of the free range pig production due to nutrient losses, and at the same time to reduce production costs by decreasing the concentrate input, an alternative solution is needed. For example, by rising pigs on a field with high yielding forage crop such as JA, which will provide more closely dietary need to the requirement. Additionally by extending the durability of the forage it is promising to reduce concentrate input excreted on land and at the same time motivating pigs to seek feed which will cause a more even nutrient distribution.

3 Material and methods

The main goal of the experiment was to evaluate how foraging of the root JA could contribute to the nutrition of growing pigs and to evaluate the environmental and economic consequences. The experiment was carried from November 2011 to February 2012 at Karl Schmidt's farm, located in the region of Southern Denmark in Jutland (55°23'N, 9°19'E). The soil type of the field, where JA crop was grown, is sandy soil JB3 containing 5-10% clay (see appendix 1 for future description of the soil class).

3.1 Experimental design

A total number of 36 pigs were randomly allocated to 6 different pens with two concentrate treatments. In 3 pens the pigs were fed with a standard diet mixture *ad libitum*, and in the other 3 pens the pigs received the high protein mixture restricted. All pigs had access to JA ad libitum. The experiment ran for around 40 days, where after the feeding ration was changed after heavy frost, and difficulties in digging up JA by pigs.

3.2 Area

For this experiment the area of about 1 ha was used. JA tubers (no data about variety) were planted to the field in April 2011 by using a seeding machine for potato. Around 2000 kg of JA per ha were planted with a density of around 3-4 plants per m^2. On the same area the year before, pigs were kept on grass. The yield was on average 18 t/ha with an energy value of 4.5 kg/SFU, which gives around 4.000 SFU/ha. The yield was estimated by digging up and weighing JA /m^2 from 7 different plots across the field on 17.11.2012. The yield per m^2 varied from 1.1 to 3.4 kg.

The experimental area was established on 17.11.2011 and the field was divided into 6 equal plots with an area of 1304 m^2 (16.3 m width *80 m length) by using two electrical wires. On average, in the restricted system each pig had an area with JA of 294 m^2, and in the *ad libitum* system the area was 113 m^2. Each of the six plots was divided into 3 smaller plots. The first plots had an area of 473 m ^{2} (16.3m *25m JA field plus 4 m grass field). Every 10 days the fence was removed to give the pigs' access to new plots. The pigs did not have access to the whole area at once in order to have the possibility to measure the amount of JA consumed, as it was intended from the beginning. Each first plot contained a hut, a water supply, and a trough. The facilities were not moved during the experimental period. The area of JA used for each paddock is shown in table 5 below and the layout in figure 2.

Table 5 Area of JA in m^2 per paddock and pig for each system.

Paddock	Area JA m2/paddock	Area JA m2/pig	Total m2/paddock	Total m2/pig
1R	1630	271.7	1711.5	285.3
2 L	815	135.8	880.2	146.7
3R	1630	271.7	1711.5	285.3
4L	815	135.8	880.2	146.7
5R	2037	339.5	2118.5	353.1
6L	407.5	67.9	472.7	78.8

R- Restricted system

L- *Ad libitum* system

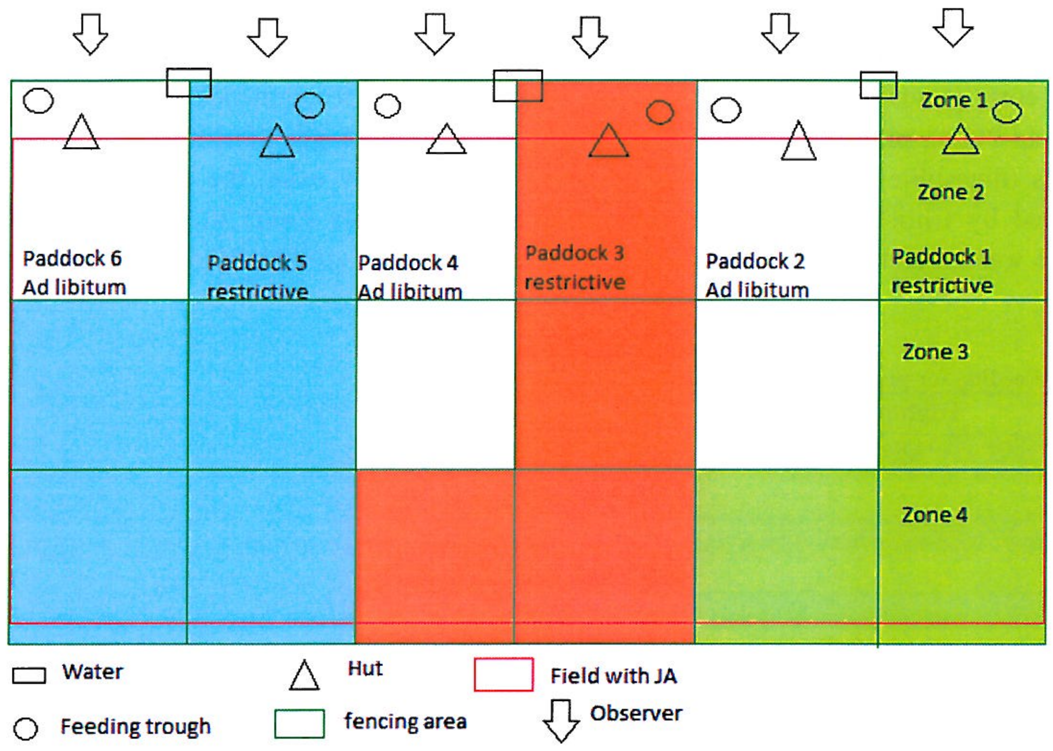

Figure 1 Layout of experimental area for 6 groups.

3.3 Animals

For this research, 36 crossbred pigs (Landrace x Duroc) of average liveweight (LW) 45.8 kg were brought from inside the stable into the paddocks on the 22.11.2011. In each paddock there was a group of 6 pigs. The adaptation period of a few days was allowed for all the pigs to maximize the consumption of JA, to adjust them to outdoor conditions and to become familiar with the electric fencing. During this period all pigs were fed by the same feed. At the start of the experiment the average LW of the pigs was around 63.8 kg in the restrictive group, and 61.4 kg in the *ad libitum* group.

3.4 Feeding

In this experiment the pigs were fed in two ways. In paddocks 1,3 and 5 the pigs were fed by the high protein mixture "Natur SL t 35" restricted, whereas in paddocks 2,4 and 6 they were fed *ad libitum* with the standard diet mixture (see table 6). In addition, all pigs had access to JA *ad libitum*.

During the adaptation period all pigs were fed *ad libitum* with the standard diet mixture (see standard diet mixture in table 7). The pigs fed restrictively at the start of experiment were getting a standard diet mixture plus the high protein mixture, which is shown in table 6 below. A few days after, the pigs were getting only high protein mixture - 0.8 SFU/pig/day which corresponds to approximately 30% of the Danish recommendation (Håndbog i svinehold 2008), plus JA *ad libitum*. The high protein mixture was used in order to supply proteins (digestible lysine) to the pigs and was calculated by using the envelope method presented by Christiansen (2004). The supply with digestible lysine in the high protein mixture was around 83%. The digestible lysine should be 6.7 g/SFU (Håndbog i svinehold 2008).

Table 6 Feeding for pigs fed restricted in the acclimatization period.

Day	High protein mixture	Standard feed mix.
	kg/day/paddock	kg/day/paddock
0	3	14
1	5	9
2	5	6
3	5	3
4	5	0
5	5	0
Per pig	0.8 SFU	0

The standard diet mixture used in both treatments was based on homemade ingredients plus the high protein mixture "Natur SL t 35", containing 12.2 MJ ME/SFU. The digestible lysine content of standard diet mixture was 8.35 g/SFU and 19.5g/ SFU of high protein mixture. The analysis of Jerusalem artichokes shows the digestible lysine content of 1.4 g/SFU (Jost 1992; Kosaric *et al.*, 1984; John Hermansen, personal communication August 2012). For the % composition of different ingredients see table 7 below.

Table 7 Standard diet mixture (%) of the experimental diet for all pigs plus the prices and dig. lysine content.

Feed	%	SFU/100 kg	SFU	Price DKK/kg	Price DKK/SFU	Price DKK/SFU mix	Lysine (g dig./SFU)
Natur SL t 35	35	87	30.45	4.2	4.8	1.69	19.5
Wheat	25	115	28.75	2.5	2.2	0.54	2
Triticale	20	113	22.6	2.25	2.0	0.40	2.12
Oats	20	87	17.4	2	2.3	0.46	2.99
Total FU/100kg			99.2				
Total price/SFU mix						3.09	

The pigs fed *ad libitum* had a 24 h per day access to the feed, whereas the pigs feed restrictive were getting feed once a day at the same time around 9.00 o'clock in the morning.
The pigs were individually weighed every 7-8 days. The high protein mixture and the standard diet mixture offered for the pigs were recorded daily in each paddock.

3.5 Calculations of fed intake from JA

The assumption was that besides the high protein mixture or standard diet mixture intake, the remaining energy came from JA tubers, given that the JA aerial parts were mainly used by pigs together with a little amount of grass to play with. To estimate (since it was not possible to find a method 100% accurate) the feed intake from JA by pigs in both systems, two methods were used:
A: theoretical methods *vs*. B: removed amount of JA from occupied area
A: Theoretical:
Restricted and *ad libitum* feeding system
In all paddocks, in order to estimate the amount of JA eaten by the pigs, some assumptions were made. However, it was very difficult to find the right figure reflecting the accurate need per kg gain in the system as such. In order to get some ideas, the figures presented by Strudsholm and Hermansen (2005) were used. According to their experience, the feed conversion in terms of MJ ME/kg gains in the outdoor system was 36 and 42.3 in pigs fed restricted and *ad libitum*, respectively.
From the lab analysis it is known that 1 SFU of feed used in this experiment equals to 12.2 MJ ME.

B: Removed amount of JA:
In both feeding systems the assumption was that besides the standard diet mixture and high protein mixture the pig ate all JA from the occupied area. The amount of JA was calculated as a total area per paddock multiplied by 1.8 kg of JA/m^2 and converted into SFU.

3.6 Comparison of feed costs in both systems

To compare the costs in both feeding systems, the market price of different ingredients was used (see table 7). The high protein mixture "Natur SL t 35" cost was 4.80 DKK/SFU, and the standard diet mixture's cost was 3.09 DKK/ SFU. The cost of JA was calculated as the cost of production of JA. This included the "lost" of gross margin for occupying the area which could be used to produce for instance winter wheat, plus the specific cost related to production of JA. For calculating the gross margin, Okologikalkuler was used. The gross margin of producing the winter wheat was calculated as 5090 DKK and included some income from sold grain, straw and subsidies. The variable costs were seeds, manure/slurry plus some additional field operations. The cost of JA plants was 3333 DKK/year (from the assumption that the tubers were planted every 3 years) plus some mechanical operation amounting to 1000 DKK/year. So, the total costs were 9423/ha, which gives 0.94 DKK/m^2. For detailed calculations, see appendix 3. In case of not including the costs of producing winter wheat, the cost of growing JA per m^2 was 0.43 DKK.

3.7 Behaviour

The pigs were observed in the experimental period once a week, with three or four 1.5-hour sessions from 0800-1600. The observations were done from a car parked in a distance of 10 m from the huts. To observe the pigs at the other end of the paddocks, a binocular were used. Each group was observed for a period of 12 min and the record of the behaviour was made for each individual pig within the group at two-minute intervals. The behavioural scan of the pigs was interpreted according to some definitions.

Foraging JA tubers: biting, rooting for, and chewing JA tubers.

Manipulating JA stems: Biting, rooting or chewing JA stems/leaves.

Eating high protein mixture*:* Eating allocated high protein mixture in trough or searching for leftovers.

Rooting: Snout movements along or into the soil surface.

Grazing: Biting off, chewing and swallowing plant materials from grass.

Resting: Lying with eyes closed or open, body immobile.

Other activities: Playing, walking, standing and drinking.

Excretory behaviour: was recorded continuously for each individual pig in the scan group, and was divided into urination and defecation. To record the distribution of the feces and urine across the area of the paddocks, each paddock was divided into 4 zones. The number of observed excretory behaviours is represented as percentage in each zone area.

Zone 1- Grass area (16.3m x4m) with feeding and drinking facilities.

Zone 2- First area with JA (16.3m x 25m) where the huts were located.

Zone 3- Second area with JA (16.3m x 25m) of about 407.5 m^2 per group.

Zone 4- Very end area with JA (16.3m x 25m) extended by 1 m field with grass (see figure 2). The distance between zone 1 and zone 4 was around 70 m.

Data was calculated as average in both systems and presented as percentage of different times spent on different behaviours.

Manure mapping

Excretory behavior was also recorded by using manure mapping. The data was collected twice during the experimental period, after snowfall, by traces of faeces and urine on the snow. The first mapping was done 10 hours after the snow has stopped falling, and the second one after 2 days.

3.8 Statistical analysis

All calculations were made by the author in Excel spreadsheet. However, the behavioral data, which was showed as the % of the total number of observations, was processed in SAS by the author's supervisor. To test the differences between paddocks where the pigs were fed *ad libitum vs.* restricted, student t-test was used. Individual data was average per paddock. The data was significantly different if the p-value was <0.05.
The distribution of faeces and urine of the pigs was evaluated by using chi-squared test in the excel sheet. In order to calculate the expected distribution of faeces and urine across the different zones of the paddocks, the sum of observations within the zones was multiplied by % of the occupied area in the recorded zone, and divided by the number of zones in the experimental paddock, then tested with the sum of observed values. The distribution of faeces and urine was also tested among two different feeding strategies.
The chi-squared test was also used to test the sum of faeces and urine observations in order to have a bigger number of observations, since the chi-squared test does not give reliable results when the expected values are too small (less than 5).
To analyze the distribution of faeces and urine from the mapping system, all records in different zones were added and analysed in excel sheet by using the chi-squared test.

3.9 Nitrogen balance at the paddock level

The intake of the standard diet mixture and high protein mixture were recorded daily in each group, and calculated as an average in both feeding systems in the experimental period. The nitrogen content of high protein mixture Natur SL t 35 was analysed in the lab and the crude protein (CP) was 31.2%. To calculate the CP of the home-made ingredients, the feed table (Moller *et al.*, 2001) was used. According to that table, the CP /SFU in triticale was 67 g, in wheat it was 67g, and in oats - 89 g. To calculate kg N in feed, the CP of the feed was divided by 6.25 (conversion factor from CP to N) (PowerPoint Slides - Kristensen, 2011). An example of a calculation of the kg N in triticale is shown below.
1 SFU feed of triticale
Crude protein 67 g in SFU
1 SFU* 0.067/6.25= 0.011kg N/kg feed
Nutrient input to the paddock did not include JA crop.
In both systems the figure for atmospheric N deposition was assumed to be 15 kg N/ha, and it was taken from PowerPoint Slides by Kristensen (2011).

N balance was calculated for each feeding system (restricted, *ad libitum*) as N input in feed, plus atmospheric deposition, minus the outputs: N in produced meet during the experimental period. The N content in 1 kg LW of pig meat was assumed to be 27 g (Poulsen *et al.*, 2000), and it was calculated for the kg gain during the experimental period.

3.10 Calculation of price for kg slaughter weight

The price was calculated by using figures (see table 8 below) from week 28 from Danish Crown website. The way of calculating was explained by Jens Peter Nannerup during a personal communication on the 05th July 2012.

Table 8 Price regulations according to Danish Crown slaughterhouse, where the pigs from the experiment have been sold.

Price regulations	Price DKK/kg
Basic price SW 70-87.9 kg	11.3
LMC[1] over 56%	2
LMC over 61.1-65%	0.1
LMC over 57-60.9%	-0.1
LMC over 50-56.9%	-0.2
Organic	13.25
SW[2] 88.0-88.9	-0.1
SW 89.0-89.9	-0.2
SW 90.0-90.9	-0.3

[1]LMC- lean meat content
[2]SW- Slaughter weight

The cost of the total production, from the start of the experiment to time when the pigs achieved SW, was calculated by adding additional costs to the total cost calculated during the experimental period. The additional costs were calculated from the end of the experiment until SW, and divided by kg weight achieved from the start of the experiment until SW.

4 Results

4.1 Production results: weight gain and feed conversion ratio

The pigs were introduced to the field with whole JA plants. They adapted to the environment very fast, and they were able to find JA very easily. In the adaptation period, one of the pigs died for unknown reasons. However, in general the pigs were in good health and body condition during the experiment. The average temperature during the experimental period was 3.5°C, min temp -3°C, and the max temp 8°C.

The results of the production data are given in table 9 below, where the results show a significant difference in a daily gain and feed conversion ratio of the concentrated feed. Pigs fed with standard diet mixture *ad libitum* grew 1238 g/day on average, whereas pigs fed restricted grew 583 g/day on average. As a result, the daily gain increased by around 53%

when fed *ad libitum*. The feed conversion ratio (FCR) of the concentrated feed, defined as the feed requirement in SFU or MJ feed per kg body weight gain, was 1.3 SFU or 16.3 MJ ME/kg gain in concentrated feed, and 3.4 SFU or 41.8 MJ ME/kg gain when fed restricted and *ad libitum*, respectively. Looking into SFU, the pigs fed restrictively received daily 0.8 SFU/pig from high protein mixture. The remaining amount came from JA and it is described in more detail below. The pigs fed *ad libitum* by a standard diet mixture consumed 4.2 SFU/pig daily.

There were insignificant differences in the initial average live weight of the pigs. By the end of the experimental period (39.7 days in restrictive system, and 39.3 days in the *ad libitum* system) the end weight was significantly different. Pigs fed restrictively increased weight on average from 63.8 kg up to 86.9 kg. In the paddocks where the pigs were fed *ad libitum*, the average weight increased from 61.4 up to 110 kg (see figure 3). The JA area per pig in the restricted system was around 62% bigger than in the *ad libitum* system. The idea was that the pigs fed restricted should have more JA to supply the energy demand from.

Table 9 Production results in growers fed restrictive or *ad libitum* by high protein mixture and standard diet mixture.

	Restricted	***Ad libitum***	**P-level (n=3)**
Number of paddocks	3	3	
Number of pigs in each paddock	6	6	
JA m2/ pig	294(±39)	113(±39)	<0.01
Days in experiment	39.7	39.3	
Initial live weight, kg	63.8 (±1.5)	61.4 (±3)[1]	NS[2]
End of experiment live weight, kg	86.9 (±3.0)	110 (±3.2)	<0.001
Daily gain g	583 (±35.6)	1238 (±29.4)	<0.01
MJ ME/SFU per day	9.5 (±1)/**0.8**	51.8(±4.3)/**4.2**	<0.01
Feed conversion ratio of concentrated feed			
[3]**MJ ME/SFU per kg LW gain**	16.3 (±1.8)/**1.3**	41.8 (±3.5)/**3.4**	<0.01
Kg concentrated feed/kg gain	1.5(±0.2)	3.5(±0.3)	<0.01

[1](standard deviation)

[2](NS, insignificant)

[3](MJ and SFU respectively needed/kg LW gain)

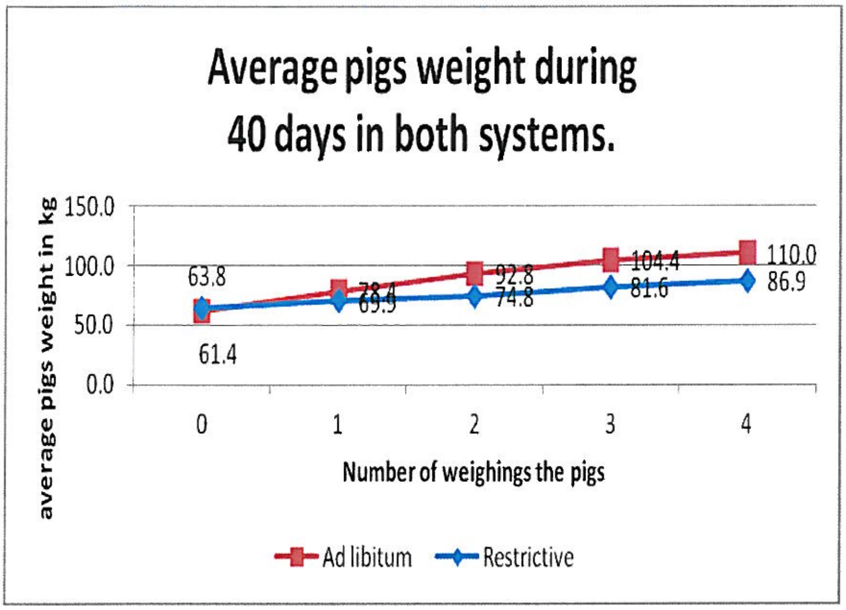

Figure 2 Average pig weight during different measurements of the experimental period.

4.2 Production costs during the experimental period

The cost of growing JA was 0.94 DKK/m^2 and 0.43 DKK/m^2 when excluding winter wheat income. In table 10, the production costs in both systems are lined up. The costs of concentrated feed in the *ad libitum* system were 70% higher than those in the restricted system per pig, and 42% higher per kg gain, and the differences were significantly different. In case of the total feed costs per pig, in the restricted system they were lower by about 31%. The t-test shows insignificant different of costs per kg gain, however in the restricted system they were higher by around 25%. The total cost per pig, where the specific cost related to winter wheat produced instead of JA was excluded, was on average 282 DKK/pig higher in the *ad libitum* system. Looking into kg gain it was higher by about 0.5 DKK in the ad libitum system also, and the difference was insignificant.

Table 10 Comparison of the production costs of concentrated feed and total feed in both systems.

	Restricted	*Ad libitum*	P-level
Cost of concentrated feed DKK/pig	154(±2)[1]	514(±40)	<0.01
Cost of concentrated feed DKK/kg gain	6.1(±0.7)	10.6 (±0.9)	<0.01
Cost of total feed exclude wheat prod. DKK/pig	281(±18)	563(±52)	<0.01
Cost of total feed exclude wheat prod. DKK/kg gain	11.1(±1.4)	11.6(±1.1)	NS[2]
Cost of total feed DKK/pig	431(±38)	621(±68)	<0.05
Cost of total feed DKK/kg gain	17.1(±0.14)	12.8(±1.4)	NS

[1](standard deviation)

[2] (insignificant different)

4.3 Estimated feed intake from JA in both systems

It was very difficult to estimate the feed intake from JA by pigs, since they dug up the tubers themselves. To try to estimate the intake from JA, two methods were used. The results in both methods (theoretical and completed removed of JA, described in material and methods) show different energy intake from JA.

In the theoretical system the assumption was that the pigs fed restricted needed 2.95 SFU/kg gain, while the pigs fed *ad libitum* needed 3.47 SFU/ kg gain. The result shows that in order to reach the demand per daily gain, the pigs in the restricted system received 1.7 SFU, 0.8 SFU of which came from the high protein mixture and the remainder of around 1 SFU (4.5 kg JA) came from JA. In the *ad libitum* system, according to the calculations, the pigs received only 0.1 SFU (0.4 kg) from JA per day.

In the second method the assumption was that the pigs ate all the JA from the occupied area. Thereby, in the restricted system the pigs ate 3.0 SFU/ day, and in the *ad libitum* system – 1.2 SFU/day. In this manner per day the pigs consumed 13.5 kg JA in restricted system and 5.4 kg in *ad libitum*.

Table 11 Estimated feed intake.

	Restricted	***Ad libitum***	**P-level**
A: Theoretical requirement			
MJ ME/SFU needed/kg gain	36/**2.95**	42.3/**3.47**	
MJ ME/SFU needed/day	20.7/**1.7**	52.5/**4.3**	<0.01
MJ ME/SFU concentrated feed/kg gain	15.9/**1.3**	41.5/**3.4**	<0.01
MJ ME/SFU concentrated feed/ day	9.8/**0.8**	51.2/**4.2**	
Difference MJ ME/SFU per kg gain	20.1/**1.65**	0.8/**0.07**	
Difference MJ ME/SFU per day	10.9/**0.9**	1.3/**0.1**	
Daily need in kg from JA	4.0	0.4	
Need per kg gain in kg from JA	7.4	0.3	
B. Removed JA from all area			
MJ ME/SFU per day from removed JA	36.6/**3.0**	14.6/**1.2**	
kg JA/day	13.5	5.4	

Overall, in the restricted system the pigs ate 0.8 SFU high protein mixture/day/pig, which gives 15.6g/day /pig of digestible lysine. From JA the pigs consumed roughly 1.2 SFU/day (5.4 kg), which gives 1.7 g/day of digestible lysine. Per day they consumed approximately 17 g of digestible lysine per pig what gives 10 g/SFU of digestible lysine.

In the *ad libitum* system they received on average 3.4 SFU/day of standard diet mixture, which equals to 28.4 g/day of digestible lysine per pig. From JA they got around 0.3 SFU, which gives 0.4 g of digestible lysine /day/pig. On average, the digestible lysine content in the diet was 8.5 g/SFU.

4.4 *Behavior*

4.4.1 Behavior data in relation to treatment

Figure 4 below shows the expression of different behaviours of the pigs fed by two different feeding strategies: restricted and *ad libitum*. In both systems the pigs spent most of their time budget (66.4% in the restricted system 74.4% in the *ad libitum* system) resting, however in the *ad libitum* system the pigs spent 8% more time on resting (but this was insignificant). In general, rooting behaviour was significantly higher ($p<0.05$) in both systems than grazing.

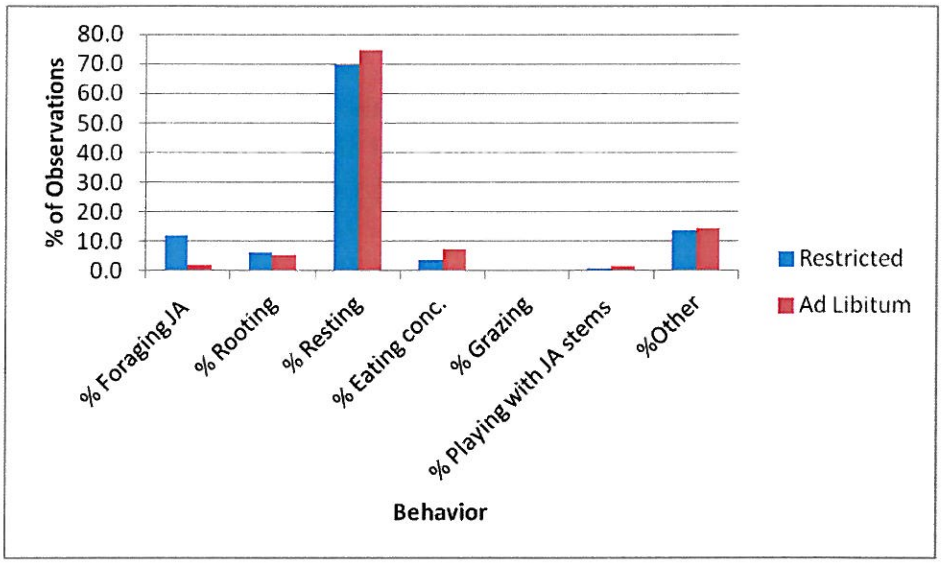

Figure 3The mean expression of different behaviors frequency by free range pigs in two different systems: fed restricted and *ad libitum* amount of high protein mixture.

Overall, in both systems pigs spent 86% of the observation time on foraging JA, rooting, resting, eating concentrate and playing with JA stems. There were insignificant differences in time budgets of two treatments (restricted and *ad libitum*) for rooting (res. 6.0%, lib. 0.3%, $P>1$), grazing (res. 0%, lib. 0.3%, $P>1$) and playing with JA steams (res. 0.8%, lib. 1.4%, $P>1$). There was an insignificant difference in other behaviour.

The pigs on the restricted diet spent significantly more time on foraging JA tubers compared to pigs fed *ad libitum* (res. 14%, lib. 0.6%, $P<0.01$). Furthermore, the pigs fed *ad libitum* spent significantly more time on eating high protein mixture (res. 5.4%, lib. 7.3%, $P<0.05$).

4.4.2 Defecation and urination behavior in pigs in relation to treatment and zones

According to the chi-squared test, there were significant differences among two feeding strategies (faeces: P<0.0001), urination: P<0.0001). The defecation and urination behavior in different zones was significantly different compared to a uniform distribution made in the chi-squared test (faeces: P<0.0001, urination: P<0.0001). To make the test more reliable, the sum of the faeces and urine in different zones among the two different feeding strategies was tested. Even so, the test shows significant differences as well among the different zones, and in among two different feeding systems. This means that the pigs did not distribute urine and faeces uniformly and, as illustrated by figure 5 below, the frequency of faeces was 39% higher in the paddocks where the pigs were fed *ad libitum*, and in case of urination 43% higher in the restricted paddocks. In the restricted system, the highest number of recorded faeces was recorded in zone 2 (71.4%) and 3 (28.6%). In paddocks where the pigs were fed *ad libitum*, a larger proportion of faeces was recorded in zone 2 (69.6%). The larger proportion of the urination behavior was recorded in zone 1 (65.2%) in the restricted system and in zone 2 (21.7%), in the *ad libitum* system also in zone 1 (53.8%) and 2 (46.2%).

Looking into the sum of faeces and urine presented as % of observations (see figure 6) in the *ad libitum* system, the higher observation was recorded in zone 2 (57.1%) and zone 1 (34.7%). In the restricted feeding, the frequency of defecation was higher in zone 1 (50%) and zone 2 (33.3%).

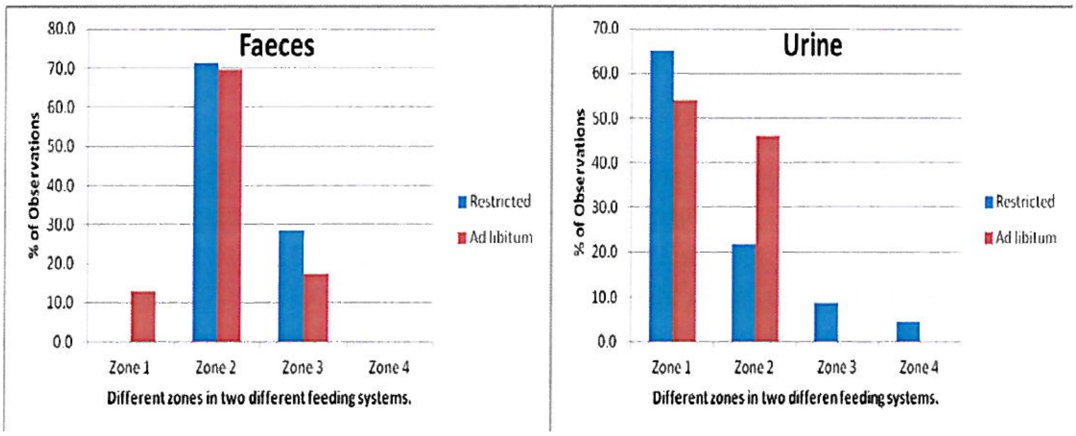

Figure 4 Distribution of defecation and urination behavior within 4 zones in restricted feeding and 3 zones in *ad libitum* feeding presented as percentage of observations recorded during the behavioral observation.

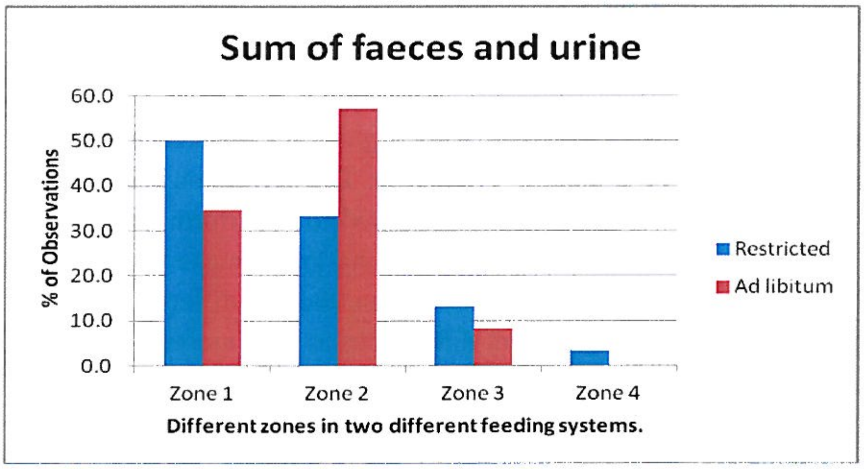

Figure 5 Sum of faeces and urine within 4 zones in restricted feeding and 3 zones in *ad libitum* feeding presented as percentage of observations.

The uneven distribution of faeces and urine among the different zones and two different feeding systems is also shown in the manure map and in figures 7-10, which were based on the maps (see appendixes 4 and 5). The chi-squared test showed significant differences ($p<0.0001$) too among the two feeding strategies and zones. According to the maps by around 19% higher frequency of faeces (black dots) and 21% urine (yellow dots) over 10 hours were recorded in *ad libitum* system. Looking into the distributions among the different zones, 50% of faeces were recorded in zone 3 and 26% in zone 4, in the restricted system. In the restricted system the higher distribution of urine was recorded in zone 4 (46.4%) and in zone 2 (28.6%). In the *ad libitum* system, 76.5% was recorded in zone 2 and 23.5% in zone 3. When it comes to urine, 54.5% was traced in zone 2, 36.4 % in zone 1. The sum of faeces and urine in the restricted system was 34.3% in zone 4 and 32.95% in zone 3, whereas in the *ad libitum* system 67.9% was recorded in zone 2 and 17.9% in zone 3.

In the maps made over 2 days the snow stopped falling, 31% more of the faeces were recorded in *ad libitum* system. The urine amount was 27% higher in restricted system. The higher number of faeces was recorded in zone 2 (39.2%) and 3 (32.8%) in the restricted system, and in the *ad libitum* system also in zone 2 (47.2%) and 3 (30.2%). The urine was higher in zone 2 (42.3%) and zone 1 (34.6%) in the restricted system. In the *ad libitum* system, the higher % of records was in zone 2 and zone 1 – 52% and 36.8%, respectively.

In the sum of faeces and urine observations, the higher % was recorded in zone 2, in case of restricted feeding 40.2%, and 48.1% in *ad libitum* feeding. The second area with high defecation record was zone 3 - 26.4% restricted, 26.9% *ad libitum*.

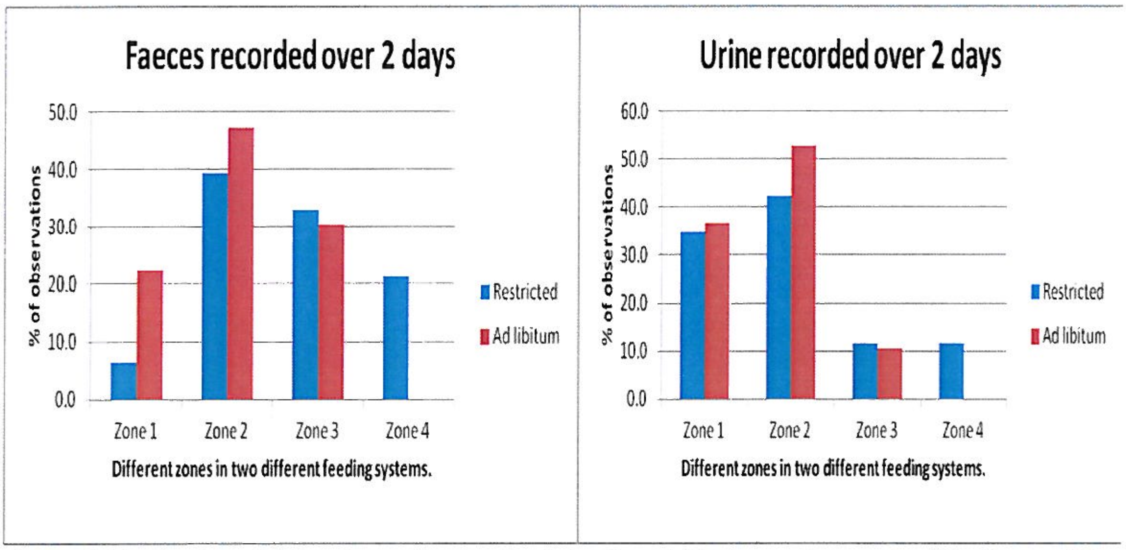

Figure 6 Distribution of defecation and urination behavior within 4 zones in restricted feeding, and 3 zones in *ad libitum* feeding presented as percentage of observations recorded by tracking method.

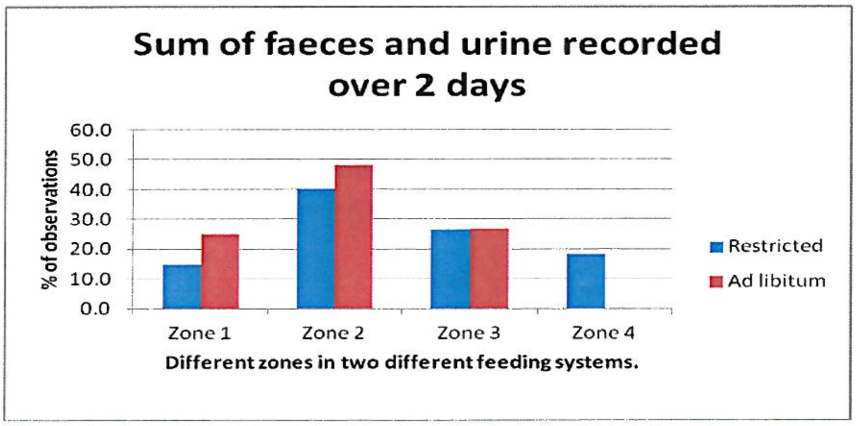

Figure 7 Sum of faeces and urine within 4 zones in restricted feeding and 3 zones in *ad libitum* feeding presented as percentage of observations recorded by tracking method.

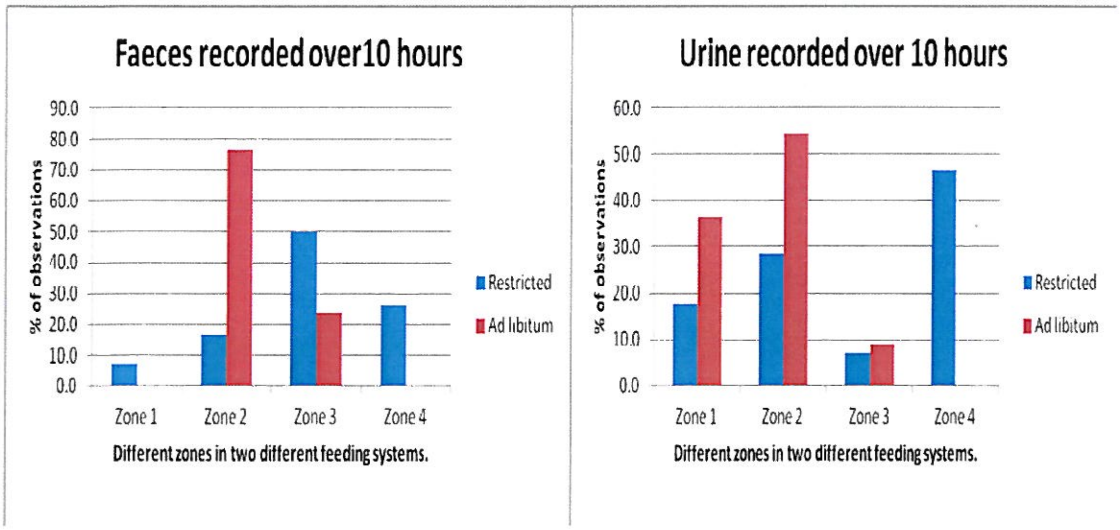

Figure 8 Distribution of defecation and urination behavior within 4 zones in restricted feeding, and 3 zones in *ad libitum* feeding presented as percentage of observations recorded by tracking method.

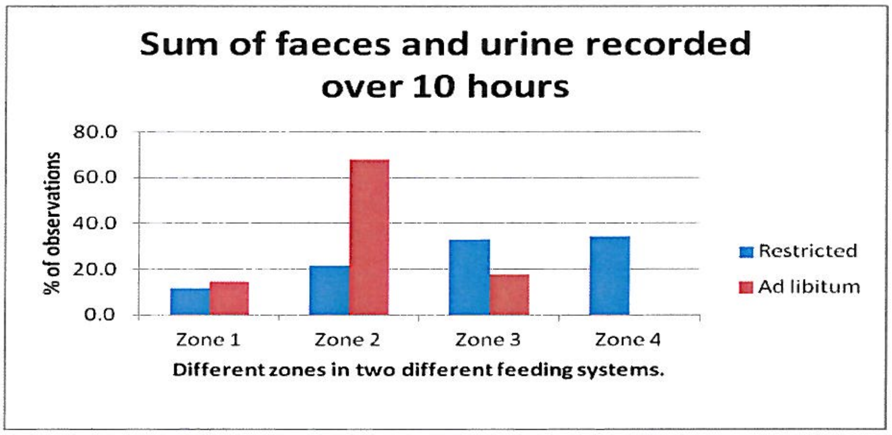

Figure 9 Sum of faeces and urine within 4 zones in restricted feeding and 3 zones in *ad libitum* feeding presented as percentage of observations recorded by tracking method

4.4.3 Nitrogen balance

As it is presented in table 12 below, in the experimental period the feed input on average was 1.8 kg/pig, corresponding to 58 kg N/ha in the restricted system, and 4.65 kg/ pig corresponds to 375 kg N/ha where the pigs were fed *ad libitum*. The atmospheric deposition per ha in both systems was 15 kg N, what gives 0.05 kg/N per pig in restricted system and 0.02 kg N in *ad libitum*. The average gain per pig where the pigs were fed *ad libitum* was 53% higher, and as a result the output in meat in kg N/pig in the restricted system was 0.7, compared to 1.3 in the *ad libitum* system. The output per ha corresponded to 22.3 kg N and 105.6 kg N in the restricted and the *ad libitum* system, respectively. In the *ad libitum* system the stocking rate was much higher than in the restricted system. The average area per pig in the restricted system was 60% larger than in the *ad libitum* system. During the experimental period, the N surplus was 51 kg N/ha (1.2 kg N/pig) in the restricted system, compared to 284 kg N/ha (3.35 kg N/pig) in the *ad libitum* system. Per kg gain, the surplus in the *ad libitum* system was 33% higher than the one in the restricted system.

Table 12 Nitrogen balance in paddocks with finishing pigs in two different feeding systems.

	Restricted	*Ad libitum*	P-level
kg N input in average from feed/pig	1.8	4.6	<0.01
kg N input in average from feed/ha	58	375	<0.01
Atmospheric deposition kg N/pig in experimental period	0.05	0.02	NS
Atmospheric deposition kg N per year/ha	15	15	
Average area m2/paddock (pig)	1847 (308)	744 (124)	
Average gain kg/pig	25.5	48.5	<0.01
Output in meat kg N/pig	0.7	1.3	<0.01
Output in meat kg N/ha	22.3	105.6	
Kg N surplus/pig	1.2	3.3	
Kg N surplus/ha	51	284	
Kg N surplus/ kg gain	0.046	0.069	<0.01

4.5 Final data: meat percentage, slaughter weight and the price per kg live weight

After the experimental period of around 40 days the rest of the pigs from the restricted system were fed *ad libitum* with the standard diet mixture. Looking into the data (see table 13) from the start of the experiment to the slaughter date, the lean meat content (LMC) in the restricted feeding was significantly higher (2.5% on average) than in pigs fed *ad libitum*. During the whole period (from the start of the experiment until SW) the daily gain was on average 706 g/day in the restricted system. From the end of the experiment until SW, the pig gained around 1000 g. The feed conversion was roughly 3.3 SFU (40.6 MJ ME) per kg gain for concentrated feed. Looking into the growing days, almost all pigs (16 out of 18) fed *ad libitum* reached the SW during the experimental period. Overall, the pigs in the *ad libitum* system reached the final weight 27 days earlier than the pigs fed restricted. There were no significant differences in the slaughter weight.

Table 13 LMC and slaughter weight of pigs as a result of two rearing strategies: fed restricted vs. *ad libitum*.

	Restricted	*Ad libitum*	P-level
LMC[1]	61.9 (±0.3)	59.4(±0.4)	<0.01
SW in kg	82.4(±0.9)	84.4 (±0.7)	<0.05
Growing days	68(±1.5)	41 (±2.5)	<0.001
Final LW in kg	111 (±2.3)	112 (±1.4)	NS
Daily gain in g until SW	706	1225	<0.0001

[1]LMC- Lean meat content, %

According to Danish Crown pricing system, the farmer's revenue from the pigs fed restricted was 39386 DKK, which gives the average price per kg SW of 26.6 DKK. The revenue from pigs fed *ad libitum* was 39941 DKK, and the price per kg SW was 0.30 DKK lower. In the *ad libitum* system, the total SW was 36 kg higher compared to restricted feeding. In the restricted system, 77% of the pigs were sold for the maximum price of 26.7 DKK/ kg SW, whereas in the *ad libitum* system only 22% of pigs had the LMC over 61%. In the *ad libitum* feeding, a larger proportion of SW (67%) was sold for 26.5 DKK/kg SW, which was paid for pigs having LMC from 57 to 60.9%. In case of restricted feeding, there were no pigs with LMC below 56.9%, whereas in case of the *ad libitum* system one pig had the LMC below 56, and one below 56.9%. The revenue for all pigs was 555 DKK higher in the *ad libitum* system. After the end of the experiment, the variable costs were in the restricted system 5.5 DKK/kg gain on average. In the *ad libitum* system, the additional costs were only 0.4 DKK/kg gain. Looking at the production cost from the start of the experiment to the end, the pigs fed restricted cost on average 22.6 DKK/kg gain, and the pigs fed *ad libitum* 13.2 DKK/kg gain.

Table 14 Price per kg SW according to Danish Crown standards, and the production cost from start of the experiment to slaughter weight.

	Price DKK/kg SW	Restricted	*Ad libitum*
LMC <56%/kg SW	24.4	0	86
LMC >56<56.9%/kg SW	26.4	0	81
LMC >57<60.9%/kg SW	26.5	418	1014
LMC >61%/kg SW	26.7	1064	337
Total kg SW		1482	1518
Deduction SW over 87.9		-36	-99
Revenue per pig		2188	2219
Average price /kg SW		26.6	26.3
Cost of concentrated feed from end experiment until SW DKK/kg gain		5.5	0.4
Cost of all feed from start experiment until SW DKK/kg gain		22.6	13.2

5 Discussion

The aim of the thesis was to evaluate a system based on pigs foraging JA in relation to feed cost and environmental impact. Furthermore, the thesis aimed at evaluating the feed intake from allocated feed and JA, feed conversion rate, growth, meat percentage of finished pigs, comparison of animal behavior and the nutrient balance at the paddock level in both systems (pigs fed *ad libitum* by standard diet mixture *vs.* restricted fed by high protein mixture).

5.1 Production performance and economic considerations

5.1.1 Growth performance

The pigs fed *ad libitum* with a standard diet mixture had twice as much daily gain than the pigs fed restricted with high protein mixture. In restricted system the daily gain was reduced by 53%. However, this was expected due to the extreme restriction in energy intake which was 30% of the Danish recommendation. A reduction in growth rate due to restriction in energy offered for the pigs combined with free access to forage has previous been observed in *e.g.* Danielsen *et al.* (1999). Still, the magnitude of the reduced daily gain was surprising in our case compared to pigs fed *ad libitum* whose daily gain was amazingly high. Furthermore, the reduction was higher than reported by Hermansen *et al.* (2004), according to whom the pigs' growth rate can be reduced by 10-15% when fed restrictively. Nevertheless, Hermansen's *et al.* (2004) finding does not mean that this always is the case, because it depends in a large degree on the level of restriction. This was presented by Farke and Sundrum (2005) in which the pigs foraging JA *ad libitum* plus concentrate at 80% of their daily requirement gained 770 g. It is expected that the difference from our studies was due to higher concentrate input by 50%. The reason for the reduction in growth rate in the restricted system compared to the *ad libitum* one could likely be caused by the lack of digestible lysine in the feed, as it is usually the first limiting amino acids in pig diet (Kumar *et al.*, 2012). Nevertheless, the result shows that the pigs apparently were not in lack of lysine in *ad libitum* and restrictive system, characterized by the amounts of 8.5 g digestible lysine/SFU and 10 g/SFU, respectively.

Looking at the pigs fed *ad libitum*, their average daily gain of 1238 g was very high compared to previous studies made by Strudsholm and Hermansen (2005) of 737 g/day in pigs reared at pasture and fed *ad libitum* from 18.3- to 94 kg body weight. Significantly high increase in pigs' gain which received besides supplemented feed raw tubers was noticed also by Farnworth (1994). The average daily gain in pigs fed *ad libitum* was also high compared with the investigation of Hansen *et al.*, (2006), where the conventionally reared Danish pigs fed with concentrate *ad libitum* and reared indoor grew 999 g/day from 40- 114 kg LW. High daily gain in an outdoor, *ad libitum* system was shown by Gentry *et al.* (2002), who concluded that the average daily gain in an outdoor system might be better than in an indoor system during the summer. Even if the presented study was done during the winter, the low temperature still does not make the daily gain lower than in an indoor system when feed the same diets *ad libitum*. However, the high gain in our case could be due to eating raw tubers of JA by pigs, which could increase stomach volume (Guillemet *et al.,* 2006) and at the same time increase the amount of consumed feed while it was offered *ad libitum*.

When it comes to the feed conversion ratio of concentrated feed in both systems, the differences were significant. The pigs fed restricted had 60% lower concentrated feed use per kg live weight gain, compared to the pigs fed *ad libitum*.

5.1.2 Intake from foraging

The literature review showed a difference in the energy intake of pigs from foraging, and some of the issues affecting their intake were discussed. Some authors have reported that the pigs fed by a restricted diet have a herbage intake of up to 20% of DM, while in an *ad libitum* system the intake was reduced to 2% (Carlson *et al.,* 1999; Hermansen *et al.,* 2004). In the presented studies the pigs, besides being offered concentrated feed, used the energy mainly from JA tubers, while the areal part of JA had low nutritional value (Ly *et al.*, 1995) and were very fast destroyed by pigs.

It was very difficult to calculate the accurate intake of JA tubers in both systems, since the pigs harvested JA themselves, and also due to uneven yield distribution among different plots. Therefore, the determined forage intake was estimated by two methods (theoretical requirement and all removed JA, see table 11). In the restrictive system from the beginning the assumption was that the pigs should get a lower amount of concentrated feed in order to increase the intake of forage. According to the theoretical method the pigs fed restricted ate 1.7 SFU daily, and in this around 0.9 SFU (4.0 kg JA), which corresponding to around 53% of their daily energy, which was consumed directly from the field. In the other method, where the assumption was that the pigs ate all JA from the occupied area, the result shows that they consumed 3.0 SFU daily from JA, corresponding to 13.5 kg JA daily. It seems that the first method is estimating too low energy intake from tubers, while the other method too high. It can't be realistic that the pigs consumed only 0.9 SFU from JA, since the studies made by Piloto *et al.* (1998) show that with an increased amount of JA tubers, the feed conversion ratio significantly increased too. This could be due to the bulkiness caused by high content of dietary fibre and low digestibility of Jerusalem Artichokes showed by Ly *et al.* (1995). When it comes to the second method, the result is not reliable too, in view of the fact that the pigs did not consume all the tubers. Some of them were left on the field, but it was not possible to measure the accurate amount. Some of the tubers were under the soil surface. It is more likely that the pigs in the restricted system consumed something around 1.2 SFU/day, giving 5.4 kg JA/pig. According to this result, the pigs received around 55% of the daily energy intake from JA, which compared to other results, mentioned in the literature review, is very high. The high contribution from foraging JA, compared to *e.g.* herbage intake in this case, could be due to the higher availability, higher energy density what result in higher energy consumption in shorter period. This gives a higher nutritional contribution, discussed already in the literature review.

When it comes to *ad libitum* system, the first method shows that the pigs consumed almost all the needed energy from the concentrate. This cannot be true, because during the behavior records the pigs ate some of the JA tubers. In addition, it was possible to notice less and less JA on the soil after each week when the observation of pigs was done. According to the second method the pigs have received 1.2 SFU daily from JA what corresponds to 5.4 kg JA and it can't be true since a lot of JA remained on the field. Additionally, according to this result the pigs consumed 5.5 SFU per day, which resulted in a high feed use per gain. However, high input of standard diet mixture could be due to spillage during the feeding discussed in literature review. Roughly, the pigs fed *ad libitum* ate 0.3 SFU (1.3 kg of JA) daily, which eventually gives 6% of the daily energy intake from field. This might be realistic since low intake from foraging by pigs fed *ad libitum* was noticed before in several investigations (Stern and Andresen, 2002, Mowat *et al.*, 2003, Carlson *et al.*, 1999).

5.1.3 Economy

When it comes to the cost of production shown in table 10, the pigs fed restricted had lower costs per paddock in terms of concentrated feed and total costs. The cost of concentrated feed per kg gain was 6.1 and 10.6 DKK, for restricted and *ad libitum* respectively. This difference was caused by the lower amount of concentrated feed offered for pigs in restrictive system, for which the market price was relatively high. However, in terms of concentrated and JA costs, the pigs fed *ad libitum* had significantly better economy per kg gain. The higher total cost per kg gain in the restricted system was due to significantly lower daily gain and larger occupied area per pig compared to *ad libitum* system. The larger area per pig with JA (on average 60% bigger) in the restricted system was in order to provide sufficient amount of JA for pigs, since the yield was much lower than expected (18t/ha-4.000 SFU/ha), and also lower than previous studies showing very high yield ranging from 40-70 t/ha (Bogomolov & Petrakova, 2001); Henriksen and Bjorn, 2003; Zonin, 1987); Marchenko & Terentieva, 1979).

In case of not including the cost of occupying the area which could be used for cash crops, the economy was better in the restricted system by about 0.5 DKK/kg gain (see table 10). This could be for example by growing JA on a field, where the production of other cereals will be not possible. As mentioned in the literature review, JA is not such a demanding a crop in terms of nutrients, comparing for example to cereals or vegetables, and it is resistant to cold, pests and diseases.

Looking at the data presented in table 13 in chapter 4.5, the pigs in the restricted system grew 27 days more than pigs fed *ad libitum*. This was also shown by Jost (1992), where the pigs fed by JA with supplementary feeds reared 4 weeks longer compared to conventional reared pigs. However, even if the pigs grew more days that in *ad libitum* system, they were still reared outdoors, which reduced the production cost related to buildings (Tvedegaard, 2005). Furthermore, compared with an indoor system, where the pigs are fed by harvested crops, this solution could give lower production costs. The pigs' foraging behaviour enabled them to dig up the tubers themselves. This reduced the harvesting and storage costs, and in case of cereals harvested in Danish conditions, also the drying costs.

Still, comparing the two systems, almost all pigs in the *ad libitum* system achieved the slaughter weight during the experimental period, which resulted in lower feeding expenses after the experimental period, presented in table 14. In the restricted system, the additional costs were 5.5 DKK per kg gain. High feed cost after the experimental period was due to a high intake of standard diet mixture given *ad libitum* to all remaining pigs. The high intake by pigs was in order to satisfy their satiety, which was higher probably due to a larger stomach volume, which was a result of high intake of JA characterized in bulkiness already mentioned in the discussion. Looking at the conversion rate of, the pigs after the experimental period and until SW, it can be seen that they consumed 3.3 SFU/kg gain (40.2 MJ ME), and this result was 4% lower from the pigs fed *ad libitum* from the start of the experiment.

The total revenue per pig in the *ad libitum* system was 31 DKK higher. This was mainly due to a significantly higher SW in pigs fed *ad libitum* (around 2 kg per pig), even if the difference between final LW was insignificant between two systems (1 kg higher per pig fed *ad libitum*). The reason of lower SW in the restricted system could be due to a larger proportion of digestive system in animals fed restricted, which is not included in SW. Still, looking at the average price per kg SW in the restricted system, it was 0.3 DKK higher. The higher price was mainly due to a higher LMC in pigs eating larger proportion of JA. Additionally, in the restricted system over 70% of the pigs, and in *ad libitum* only 33% of pigs had LMC over 61 %. This affected the average price, which is determined according to the criteria of a leading enterprise Friland A/S (where the pigs were sold) presented in table 8 for LMC %. So, as discussed in the literature review higher LMC, was one of the positive side effects of including JA in the diet. Nevertheless, the slightly higher price per kg SW was too low to compensate to some degree for the higher production costs of pigs fed restricted, which were caused by a low daily gain and higher occupied area per pig, as well as the cost related to the occupied area, which could be allocated for producing *e.g.* winter wheat.

Summing up, the pigs are able to consume larger proportion of their daily energy need from foraging JA. By restricting their daily concentrate input up to 0.8 SFU/pig we noticed the daily intake of 1.2 SFU/pig from JA. In the *ad libitum* system the intake per pig was roughly 0.3 SFU since they mainly ate concentrate. It can be concluded that the pigs were forced to look for more forage by restricting them with supplemental feed. However, higher energy intake from concentrates fed in the *ad libitum* system resulted in higher daily gain. It might be concluded that in order to increase the daily gain in pigs fed restricted the increase of concentrated feed is essential. Nevertheless, too high a supply of concentrated feed can discourage the pigs from searching and consuming the tubers. Furthermore, from the economic point of view, the system where the pigs were fed restricted was more expensive when the cost for occupied area was included than the *ad libitum* system, which does not support our problem statement that JA could be a cheaper nutrient source. Therefore, in order to make this production profitable for a farmer, a premium price offered by Friland is needed. It might also be questioned whether the consumers are willing to pay a premium price for it. As mentioned early in the thesis, the consumers show a growing interest in the meat quality and production approach, including issues such as animal welfare and environment pollution.

5.2 Behavioral, practical and environmental considerations

5.2.1 General behaviors

The pigs fed restricted spent significantly more time on foraging JA compared to pigs fed *ad libitum*, from which they supplied the energy. Foraging JA in pigs fed a restricted diet was significantly higher that grazing and rooting, which to a large degree could be driven by restriction in energy from concentrate. Furthermore, in this study the rooting behaviour was significantly higher than grazing in both systems, which was opposite to earlier studies (Stern and Andresen, 2003; Wood-Gush, 1989). The higher rooting behavior in our both systems was due to the large availability of JA tubers. The pigs, during the observation, spent very little time on playing with JA stems. It was also obvious that the pigs fed *ad libitum* would spend significantly more of their time budget on eating the concentrate, to which they had access *ad libitum* 24 hours a day compared with pigs fed restricted.

Overall, the pigs spent their time budget mainly on resting in both systems. In this study the pigs fed *ad libitum* spend 74% of their time budget on resting, which was comparable to the findings of Laister and Konrad (2005),showing that the pigs fed *ad libitum* spent from 70 up to 78% of the observation time on resting. However, both presented systems were not comparable with the findings of Stolba and Wood-Gush (1989) described in the literature review, that the pigs in a semi-natural environment spent up to 75% on rooting, grazing and examining the environment. The high resting time could be due to low temperature, as the experiment was run during the winter. However, in the literature review different studies show no effect of temperature on the active behaviour. Still, hard soil could discourage pigs from a more active behaviour.

There were insignificant differences in the time budget of rooting, resting, eating concentrate and plying with JA stems among the two feeding strategies. It could be argued that the pigs fed restricted should spend significantly more of their time budget on seeking for the feed than the pigs fed *ad libitum*, which could lead to significant differences in the resting time. It can be argued that perhaps the pigs fed restricted show a higher activity after the observation period. The other reason could be that the pigs' natural behaviour, such as rooting and grazing, was presented no matter how much concentrated fed was offered to them. This was proven by Andresen and Redbo (1999), but disproven by Young and Lawrence (1996), as mentioned in the literature review. Furthermore, in another studies made by Stern and Andresen (2003), significantly more time on rooting was spent by pigs fed a restricted amount of concentrate (80%), compared to 100% of concentrate.

5.2.2 Defecation behavior of the pigs and nutrient distribution

In this research, two methods of registration of the defecation behavior were used. According to the registration of the behaviour, the pigs fed restricted had significantly more defecation behavior than pigs fed *ad libitum* mainly due to higher frequencies of urination in pigs fed restricted. The percentage of faeces and urine observations was also significantly different among the different zones in both feeding systems. As a result, the nutrients were unevenly distributed, which caused hot spots. In both systems, the faeces were mainly recorded in zone 2 where the huts were located. However, the urine was recorded mainly in zone 1, in front of the huts where the feeding and drinking equipment was located. This was also shown by Quintern (2005). Looking at the two feeding strategies, the pigs fed *ad libitum* left more faeces in zone 1 than the pigs fed restricted. This could be explained by the fact that the pigs fed *ad libitum* spend more time eating the standard diet mixture which was served in zone 1, which was available for them 24 hours a day. In zone 1, the sum of urine and faeces in the restricted system was higher by around 15% from the observation made in the *ad libitum* system. While, in zone 2 the pigs fed *ad libitum* had 24% more observations compared to the restricted system. In the restricted system, the sum of observations in zone 1 was 45% higher compared to zone 4, and in the *ad libitum* system - around 20% higher in zone 1 than in zone 3. The high defecation behavior in these areas was also showed in the literature review, where the pigs' defecation behaviour was mainly around huts and drinking and feeding areas, where they also spent most of their time budget.

However, looking at the mapping method where two maps were recorded, one over 2 days and the second one over 10 hours the snow has stopped falling, some of the results are different. For example, the most defecation behaviour, as a sum of the faeces and urine, was observed in zone 2, but also in zone 3 in both feeding systems. Also, in this method there were significant differences among the zones and the two feeding strategies. Comparing figures 6 and 8, it is possible to notice that in case of the mapping method, (figure 8) the defecation behavior was more uniformly distributed compared to figure 6. However, the differences were insignificant.

The difference between the methods could be due to the fact that the observations were only done once a week for a very short period from 8.00-16.00. Low defecation registration in zones 3 and 4 in the behavioral observation method could be because the observer was far away from zones 3 and 4, and the defecation behavior could go unnoticed. Also, it could be argued that the lower defecation behavior in zone 1 in the mapping method could be due to a higher traffic of the pigs in the feeding and drinking area, which could erase the track of defecation behavior.

5.2.3 Nitrogen balance

The aim of the N balance calculation in both feeding systems was done to compare the nitrogen surplus, stocking rate among the two feeding strategies. According to our studies, the N input was 61% higher per pig, and 85% higher per ha in the *ad libitum* system compared to the restricted system. Even if the output in kg N per ha was higher in the *ad libitum* system due to a significantly higher daily gain, the surplus in the ad libitum system was still 284 kg N per ha while it was only 51 kg N per ha in the restricted system. That large difference can be explained by a significantly lower stocking rate in the restricted system compared to *ad libitum system*, where the pigs had huge area in order to compensate for the lower energy intake from concentrated feed, plus low input of concentrated feed.

High N surplus in ad libitum system could give some ideas in terms of improving the feeding strategies. By lowering the amount of N in the diet, less N can be extracted by pigs in faeces and urine, which was also reported by Watson *et al.* (2003). Lower stocking rate can also explain the difference between our results and those by Eriksen *et al.* (2006), who showed a surplus of 388 kg N/ha in the case of restricted feeding and 507 kg N/ha in the case of an *ad libitum* system. In their study the pigs had an area of 110.8 m^2 in both systems, while in our restricted system the pigs had around three times as much space.

The average surplus of 284 kg N/ha in paddocks were the pigs were fed *ad libitum* created a huge risk of N leaching. As already discussed in the literature review and shown in the result, the nutrients were unevenly distributed. In our studies the main concentration of faeces and urine was noticed near the huts, feeding and drinking areas in both systems. The literature review showed the same trend for nutrient distribution.

The potentially high concentration of N from fodder losses, faeces and urine, crop residues, which cause N accumulation "hotspots" and, N in form of nitrate (NO_3-) are very susceptible to leaching due to negatively charged soil surface like nitrate mainly in wet conditions (Eriksen and Kristensen, 2001; Eriksen *et al.*, 2006) Additionally, cultivation of soil by pigs due to their rooting behavior can cause mineralization of organic N into inorganic N in the form of ammonium (NH_4^+) and nitrate (NO_3^-) (Silgram and Shepherd, 1997). Furthermore, in our studies there was no vegetation on the soil to uptake the excessive N, which was also reported by Strudsholm and Hermansen (2005).

As a result, very low surplus of N in the restricted system, compared with 140 kg N per ha allowed to be used by the European Commission (2000), might give a possibility to increase the stocking rate in the future or increase the amount of supplemented feed. Additionally, for a homogenized distribution of nutrients from the pigs, the frequent location change of the huts, drinking and feeding equipment is necessary.

5.2.4 Practical difficulties

During the experimental period, heavy frost stopped the experiment which should run to the end of gaining the slaughter weight by pigs in both systems. To prevent the soil from frosting on some of the areas, straw was used. During the behavioral registration more pigs were registered in the areas with straw, which make pigs able to have some of the JA tubers. A few times during the heavy frost harrowing of the frozen soil was conducted. The purpose was to break the frozen soil and put some JA on the soil surface, to make it available for the pigs. Nevertheless, even though the two methods were implemented, the pigs were not able to receive sufficient energy from JA to grow, and the feeding was changed. The energy from the concentrated feed of 0.8 SFU/pig was sufficient for maintenance only.

Furthermore, there are also some difficulties related to JA production. According to Schittenhelm (1996), at harvest JA tubers were lost and left in the soil which became a weed problem for the following crop in several cropping seasons. The most effective method used to get rid of JA residues is mechanical and chemical control, and this solution does not correspond to the principles of organic farming which Karl (owner of the study farm) complies with. JA can also be produced at one field for several years, and that solution will decrease the costs of establishing JA (Piskier, 2006). However, the yield and the quality of JA in the succeeding years will be lower and lower mainly on organic farms, which will have an effect on the production of SFU/ha. Further problems related to growing homogenous crop at the same field are according to Quintern & Sundrum (2006), accumulation of nutrients and the corresponding higher risk of leaching.

Other problem related to growing JA at the same field for several years and using pigs to harvest the tubers, is the regulation which says that the pigs should be introduce to the same field every second year.

This section illustrates that there were significant differences in animal behavior among the two feeding strategies only in foraging JA which was dominating in the restrictive system, and in eating concentrate dominating in the *ad libitum* system. In both systems the pigs' excretory behavior was recorded near the feeding and drinking equipment and near the huts, which caused nutrient accumulation. The restricted system confirmed our problem statement that by reducing the concentrated feed and by producing pigs in a low stocking rate it seems to be more environmentally friendly. The N surplus in the restricted system was 80% lower per ha than in the *ad libitum* system. Still, the difficulties in establishing a following crop after JA might discourage farmers from producing free range pigs on JA.

6 Conclusion

This report demonstrated the production of pigs foraging JA in two different feeding strategies (*ad libitum* vs. restricted). The main findings were:

- Pigs fed restrictively grew only 583 g a day, which was very low compared to pigs fed *ad libitum* having a daily growth of 1238 g. As a result, the pigs in the restricted system needed 27 days more before they reached slaughter weight compared to pigs fed *ad libitum*.

- Pigs fed by a reduced amount of high protein mixture significantly increased the JA intake, which contributed to around 55% of their daily energy intake. Daily energy intake from JA constituted only 6% for the pigs fed *ad libitum*.

- The feed conversion ratio of concentrated feed per kg gain in restricted system was 62% lower than in ad libitum system.

- The pigs fed restricted had lower concentrated feed cost by 4.5 DKK/kg gain compared to pigs fed *ad libitum*. However, total feed cost in *ad libitum* system was lower by 4.3 DKK/kg gain than in pigs fed restricted. This was due to twice as much daily gain in *ad libitum* system compared to the restricted system and lower area occupied with JA.

- The pigs fed restricted had 2.5% higher LMC than the pigs fed *ad libitum*, which increased the average price per kg slaughter weight by 0.30 DKK.

- In both systems the pigs spent most of their time budget on resting. The behavior of foraging JA was observed more often in the restricted system compared to the *ad libitum* system and the behaviour of eating concentrate was observed more frequently in the *ad libitum* system. There were no significant differences in rooting and grazing behaviors in both systems.

- In the restricted system the N surplus was only 51 kg N/ha, while in the *ad libitum* system it was 284 kg N/ha. The huge difference was mainly due to a high concentrate input and 60 % lower area offered per pig.

- A higher defecation and urination behavior was noticed near the huts, feeding and drinking areas in both systems, which caused an uneven nitrogen distribution. This probably created nitrogen "hotspots" which generate a high risk of leaching. In order to reduce this problem frequent movement of the facilities is needed.

- Using their natural rooting behavior, pigs can harvest JA tubers themselves, the machinery for harvest is not necessary.

Overall, it is a huge advantage to grow pigs foraging JA due to the possibility of using their foraging behavior to dig up the tubers, as well as a relatively high daily energy intake which compensates the lower input of concentrate. Lower input of concentrate resulted in low N surplus in pigs fed restrictively, which led to less leaching. However, future research is needed in order to achieve a higher daily gain *e.g.* by increasing the amount of concentrated feed at the level that the pigs would be able to receive a high amount of daily energy intake from a field.

7 Perspectives

The present study showed that there is a potential in growing free range organic pigs foraging JA due to high supply of their daily energy need. Therefore, it needs to be further investigated the amount of supplementary concentrate offered to pigs, in order to obtain a higher daily gain and ad the same time motivate the pigs to forage JA.

There might be some difficulties in incorporating JA into cropping system. JA lost tubers during the harvest cause big weed problem for the following crop in several seasons. This should be investigated more in the future so that this problem can be overcome.

In these studies, the pigs are introduced to field with whole plant, and the pigs do not use the above ground part of the plant efficiently in terms of energy intake. The yield from the top of the plant is high, and varies from 30-60 ton/ha (Heriksen & Bjorn 2003) and could very easily be used as forage, when are cut while the stems are green. On the other hand, early (late September) harvest of the top might decrease tubers yield. A better solution to our study could be to use the JA's above-ground plant part as a biomass source for energy generation. It could be harvested when the plants are dry.

In addition:

- It is necessary to make a market research and find out whether the consumers are willing to pay the extra price for product as such, in order to make the production profitable.

- It would be interesting to investigate how JAs affect the meat taste. This is probably very important for the consumers' motivation for paying an extra price for the pork.

- In the restricted system the surplus of kg N was relatively low, which can result in a low yield in the following crop. Higher stocking rate should be considered when the JA yield will be higher.

- It would also be relevant to measure the mineral nitrogen in the soil (N-min) to get an idea of the distribution of the nitrogen and the amount in different places.

- In order to find the accurate energy intake from JA, other methods should be investigated.

- It was not possible to run the experiment to the end due to heavy frost. The future research should consider a different period for the experiment. Maybe should be started in early spring.

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Appendixes

Appendix 1Soil type in Denmark

The relation between the division between the soil types used in ArcGIS and the Danish classification system JB number. In addition, the table shows the content of clay, silt, sand and organic matter in each of the different soil types (www.djf-geodata.dk).

<table>
<tr><th rowspan="2">Soil type</th><th rowspan="2">Texture definition</th><th rowspan="2">Sym bols</th><th rowspan="2">JB nr.</th><th colspan="5">Percent of mass</th></tr>
<tr><th>Clay under 2 µm</th><th>Silt 2-20 µm</th><th>Fine sand 20-2000 µm</th><th>Sand total 20-2000 µm</th><th>Organic content 58,7 %</th></tr>
<tr><td>1</td><td>Coarse sandy soil</td><td>GR.S.</td><td>1</td><td rowspan="2">0,5</td><td rowspan="2">0,2</td><td>0-50</td><td rowspan="2">75-100</td><td rowspan="10">Under 10</td></tr>
<tr><td>2</td><td>Fine sandy soil</td><td>F.S.</td><td>2</td><td>50-100</td></tr>
<tr><td rowspan="2">3</td><td rowspan="2">Clayey sandy soil</td><td>GR.L.S.</td><td>3</td><td rowspan="2">5-10</td><td rowspan="2">0-25</td><td>0-40</td><td rowspan="2">65-95</td></tr>
<tr><td>F.L.S.</td><td>4</td><td>40-95</td></tr>
<tr><td rowspan="2">4</td><td rowspan="2">Sandy clay soil</td><td>GR.S.L.</td><td>5</td><td rowspan="2">10-15</td><td rowspan="2">0-30</td><td>0-40</td><td rowspan="2">55-90</td></tr>
<tr><td>F.S.L.</td><td>6</td><td>40-90</td></tr>
<tr><td>5</td><td>Clay soil</td><td>L.</td><td>7</td><td>15-25</td><td>0-35</td><td></td><td>40-85</td></tr>
<tr><td rowspan="3">6</td><td rowspan="3">Heavy clay soil</td><td>SV.L.</td><td>8</td><td>25-45</td><td>0-45</td><td></td><td>10-75</td></tr>
<tr><td>M.SV.L.</td><td>9</td><td>45-100</td><td>0-50</td><td></td><td>0-55</td></tr>
<tr><td>SI.</td><td>10</td><td>0-50</td><td>20-100</td><td></td><td>0-80</td></tr>
<tr><td>7</td><td>Organic soil</td><td>HU.</td><td>11</td><td></td><td></td><td></td><td></td><td>Over 10</td></tr>
</table>

Appendix 2 Dates of starting and finishing the experiment in different paddocks.

Paddock	Start date	Date of finishing experiment	Days of experiment
1R[1)]	01/12/2011	09/01/2012	39
2L[2]	09/12/2011	18/01/2012	40
3R	16/12/2011	25/01/2012	40
4L	01/12/2011	09/01/2012	39
5R	09/12/2011	18/01/2012	40
6L	16/12/2011	25/01/2012	40

1) Restrictive

2) *Ad libitum*

Appendix 3 They way of calculating the costs of JA/m2

Source: Serup (2010).Okologikalkuler 2010 og 2011.

Costs of JA	DKK/ha
Winter wheat	
Income	
Grain	6845
Straw	945
Subsidies	750
Total income	**8540**
Outcome	
Seeds	800
Manure+slurry	560
Total outcome	**1360**
Gross margin 1	**7180**
Other costs	
Ploughing	600
Harrowing	510
Manure +slurry appl.	350
Mechan. weed control	140
Rolling	140
Harvest +sowing	350
Total other costs	2090
Gross margin 2	**5090**
Costs of JA tubers	3333.3
Mechanical operations	1000
Total costs of JA	9423.3
Total costs of JA/m2	**0.94**

Appendix 4 Faeces and urine recorded over 10 hours

Appendix 5 Faeces and urine recorded over 2 days.