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Integrating foraging and agroforestry into organic pig production - environmental and animal benefits

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PhD Dissertation
Department of Agroecology, Science and Technology
September 2018

INTEGRATING FORAGING AND AGROFORESTRY INTO ORGANIC PIG PRODUCTION - ENVIRONMENTAL AND ANIMAL BENEFITS

PhD Thesis · Science and Technology · 2018

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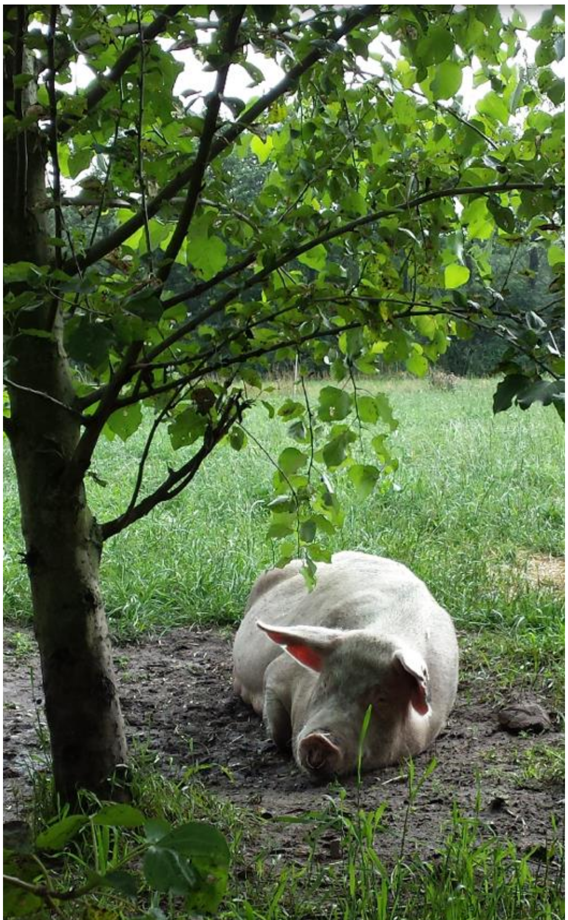

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Preface

The present PhD dissertation entitled “Integrating foraging and agroforestry into organic pig production - environmental and animal benefits” was submitted to the Graduate School of Science and Technology (GSST), Aarhus University, Denmark, for the degree of Doctor of Philosophy at the department of Agroecology, AU Foulum.

The PhD study was carried out in the period from May 2015 to June 2018 and was part of a larger research project pECOSYSTEM (Pig production in eco-efficient organic systems), which aims at improving environmental performance and animal health and welfare as well as mitigating climate changes by introduction of innovative production strategies at farm level.

The overall aim of the PhD project was to contribute to the development of new production and management strategies that leads to a more nutrient-efficient organic pig production and provide additional animal benefits.

The PhD study was based on modelling work and an on-farm experiment performed at a private organic pig farm in Denmark.

My hope is to contribute to creating awareness, interest and dialog between free-range and organic pig producers, key stakeholders within free-range and organic pig production as well as scientists and authorities, regarding the potential of introducing alternative production and management strategies into free-range pig production. The aim is to increase the outdoor free-range pig production and develop systems, which gain from integrating the animals into the farming system based on their capabilities. In my opinion, agroforestry in temperate regions is interesting and legitimate in terms of contributing to the development of future food systems, being multifunctional and producing a variety of products and public goods.

The PhD study received funding from GUDP (Green Development and Demonstration Programme), under the Danish Ministry of Food, Agriculture and Fisheries and from the Graduate School of Science and Technology (GSST), Aarhus University, Denmark.

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Summary

Outdoor organic pig production is associated with significant risk of nitrogen **(N)** leaching with a subsequent increased risk of polluting nearby surface and ground water sources. Contributing factors are high input of supplementary feed and a relatively high animal stocking density combined with pigs' heterogeneous deposition of urine and faeces within the paddock. In addition, pigs' rooting behaviour destroys the grass cover, which adds to the risk of nitrate leaching. In particular, risk of leaching severely increases during winter with periods of high rainfall and impaired grass growth. Based on concerns for the environment, snout ringing of sows is common practice. However, as pigs have a high motivation for rooting, this is a source of conflict between animal welfare and nutrient efficiency concerns according to the organic principles.

Therefore, based on pigs' species-specific and natural behaviour, the overall aim of the PhD project was to contribute to development of alternative production and management strategies leading to an improved environmental performance.

The alternative strategies undertaken were improved **foraging** and **agroforestry** in the range area in organic pig production. Agroforestry is the deliberate integration of trees into agricultural systems with livestock or crops. Three overall hypotheses were put forward, one focusing on the strategy of foraging and two focusing on the integration of agroforestry.

1. Improving pigs' foraging in the range area was expected to reduce greenhouse gas **(GHG)** emissions at farm level compared to current Danish organic practice with sows on pasture and growing pigs housed in stables with access to outdoor concrete yards. Furthermore, an organic production system with growing pigs in an optimised forage system was expected to reduce the N leaching at farm level compared to a system with growing pigs foraging on grass-clover, and was expected to improve overall farm environmental performance, also compared to the common practice.
2. An area with six poplar trees (20% coverage) in individual paddocks for lactating sows was expected to reduce the risk of N leaching in comparison to the pasture area.
3. Providing sows with a tree area was hypothesised to represent a more stimuli-rich environment than common practice and to be an attractive area during warm periods.

The strategy of improved foraging was investigated by modelling work based on key figures from Danish organic pig production, data from experimental and empirical on-farm studies. Subsequently, three scenarios of organic pig production systems were created:

1. Common Danish practice with sows on pasture and growing pigs housed indoors.
2. Sows and growing pigs foraging on grass-clover in the range area.

3. An improved system where sows and growing pigs forage on Jerusalem artichokes, lucerne and grass-clover.

The strategy of agroforestry was investigated by an experiment conducted at an organic pig farm in Denmark with poplar trees (*Populus sp.* 20% coverage) established at one end of the paddocks.

Foraging in the range area

In terms of reducing GHG emissions, the best performance with 3.12 kg CO_2 equivalents (eq) kg^{-1} live pig weight was obtained in the scenario where pigs were subjected to foraging on lucerne, Jerusalem artichokes and grass-clover. However, in terms of N leaching, this scenario showed the poorest performance with 110 kg N ha^{-1}, primarily due to the high level of N fixation in the lucerne crop. The scenario with pigs foraging on grass-clover had similar GHG emissions (3.68 kg CO_2 eq kg^{-1} live pig weight) and N leaching (100 kg N ha^{-1}) as the scenario representing the current practice.

Improved foraging in organic pig production is a feasible strategy to reduce GHG emissions, whereas obtaining a significant reduction in N leaching, requires optimisation in terms of providing high yielding crops with an appropriate nutrient composition for pigs. Improved foraging could favourably be combined with other strategies such as mobile systems, seasonal production (in the crop growth season) and a reduction in stocking density.

Poplar trees – environment

Soil samples indicated that poplar trees were more efficient in reducing N leaching than grass. Four weeks after sow occupation of paddocks, soil mineral N in a depth of 0-50 cm was comparable in the area with poplars and grass. However, in late winter/early spring, soil mineral N in a depth of 50-100 cm was lower in the area with poplar trees. This was supported by estimated N leaching, based on soil water samples, showing a 75% reduction in N leaching in the area with poplar trees compared to the area with grass. However, the system had a high nitrogen surplus with around 400 kg N ha^{-1} and therefore, on a paddock area basis, more trees, or other innovations, are needed to significantly reduce leaching. Furthermore, it is crucial to motivate sows to urinate and defecate in dedicated areas, preferably in the tree area. This involves optimising the spatial distribution of the resources (farrowing hut, feed and water).

Trees in paddocks means a reduced area for production of home-grown feed. Thus, for the farmer, the loss in feed production must be counterbalanced by an income from the trees in terms of products and benefits provided, including public goods or a premium for the pork produced. Importantly, the poplar trees were able to withstand sows' manipulations and recovered from the damages exerted by the sows.

Poplar trees – the animals
The sows preferred to rest in the area with poplar trees. Also, nursings outside the hut primarily took place in the tree area. In particular during winter, the sows used the trees for scratching. Together, the results indicated that the area with poplars were perceived to be more attractive e.g. due to the shade, shelter and protection provided. Although the area with poplar trees represented a more diverse environment, the sows did not respond by an increased general activity compared to sows without tree access.

Improved foraging and agroforestry are able to contribute to improving the environmental performance in organic pig production. Foraging and agroforestry may favourably be combined with other strategies such as a reduced stocking density, seasonal production, collaborations with producers of energy crops, and mobile systems.

Sammendrag (summary in Danish)

Økologisk produktion af grise på friland er forbundet med en forøget risiko for kvælstofudvaskning og dermed en forøget risiko for forurening af overflade- og grundvandsressourcer. Faktorer, der bidrager hertil, er et højt input af kraftfoder og relativt høje belægningsgrader kombineret med grises ulige afsætning af urin og fæces i folden. Desuden er grises rodeadfærd med til at ødelægge græsdækket i folden, hvilket øger risikoen for udvaskning. Især er risikoen for udvaskning høj i vinterperioden, som er kendetegnet ved høje mængder af nedbør samt reduceret græsvækst. På baggrund af de miljømæssige hensyn er det tilladt at tryne-ringe søer, hvilket er almindelig praksis i dansk frilandsproduktion. Da grise er udstyret med en stærk motivation for at rode, er dette en kilde til konflikt imellem hensynet til grisenes velfærd og hensynet til at opretholde en effektiv husholdning med næringsstoffer i overensstemmelse med de økologiske principper.

Med udgangspunkt i grises artsspecifikke og naturlige adfærdsmønstre var det overordnede formål med dette ph.d. projekt at bidrage til udvikling af alternative produktions- og managementstrategier som kan føre til at mindske miljøpåvirkningen af økologisk griseproduktion.

De alternative strategier som blev implementeret var forbedret fouragering og agroforestry i foldområdet. Agroforestry er en produktionsform hvor træer bevidst integreres i landbrugssystemer med husdyr eller afgrøder. Tre overordnede hypoteser blev fremsat, en relateret til forbedret fouragering og to relateret til integrering af agroforestry.

1. En forbedret fouragering hos grise i foldområdet forventes at føre til en reduktion i udledning af drivhusgasser på gård niveau sammenlignet med almindelig dansk praksis med søer på friland og slagtesvin på stald med adgang til betonudearealer.
   Derudover forventes økologiske produktionssystemer med forbedret fouragering hos slagtesvin at føre til en reducering af kvælstofudvaskningen på gårdniveau sammenlignet med et system med slagtesvin, som fouragerer på græs og forventet at føre til en forbedring af recirkuleringen af kvælstof på gårdniveau; også sammenlignet med nuværende praksis.
2. Et område med 6 poppeltræer (20% trædække) i individuelle folde med diegivende søer forventes at reducere kvælstofudvaskningen sammenlignet med græsområdet i folden.
3. Et område med træer i folde til diegivende søer forventes at repræsentere et miljø med flere stimuli sammenlignet med nuværende praksis, samtidig med at det er et attraktivt skyggeområde for søerne i perioder med høje temperaturer.

Effekten af en forbedret fouragering blev undersøgt gennem en modelleringsøvelse baseret på en syntese af nøgletal fra dansk økologisk griseproduktion, data fra eksperimentelle

studier samt gårdstudier. Efterfølgende blev der opstillet tre scenarier for økologisk griseproduktion:

1) Almindelig praksis med søer på friland og slagtesvin på stald med adgang til udearealer.
2) Søer og slagtesvin fouragerer på kløvergræs.
3) Et forbedret system, hvor søer og slagtesvin fouragerer på lucerne, jordskokker og kløvergræs.

Effekten af agroforestry blev undersøgt ved et eksperiment gennemført på en økologisk gård i Danmark med poppeltræer (*Populus sp.* 20% trædække) etableret i den ene ende af foldene.

Fouragering i foldområdet
Med hensyn til drivhusgasser performede det forbedrede system med fouragering på lucerne, jordskokker og kløvergræs bedst med 3.12 CO_2 eq per kg levende gris. Til gengæld havde dette system den største kvælstofudvaskning med 110 kg N ha^{-1} primært på grund af lucernens høje niveau af kvælstoffiksering. Scenariet, hvor grise fouragerede på kløvergræs havde samme kvælstofudvaskning som scenariet, der repræsenterede almindelig praksis med 3.68 kg CO_2 eq per kg levende gris og 100 kg N ha^{-1}.

Forbedret fouragering i økologisk griseproduktion er en mulig strategi i forhold til en reduceret drivhusgasproduktion, hvorimod en reducering i kvælstofudvaskningen vil kræve optimering med hensyn til at foreslå højtydende afgrøder med en passende næringsstofsammensætning til grise. En forbedret fouragering kan med fordel kombineres med andre strategier såsom mobile systemer, sæsonproduktion (i vækstsæsonen) og en reducering af belægningsgraden.

Poppeltræer – miljø
Jordprøverne indikerede, at poppeltræerne var mere effektive med hensyn til at reducere kvælstofudvaskningen sammenlignet med græs. Fire uger efter at pattegrisene og søerne var flyttet fra foldene, var mineralsk kvælstof i jorden i en dybde af 0-50 cm i området med henholdsvis træer og græs sammenlignelige. Men sent vinter/tidligt forår var mineralsk N i jorden i en dybde af 50-100 cm lavere i området med poppel træer. Dette blev understøttet af en estimeret kvælstofudvaskning, baseret bl.a. på prøver fra jordvand, som viste en reducering af kvælstofudvaskningen på 75% i området med poppeltræer sammenlignet med området med græs. Imidlertid havde systemet et højt estimeret kvælstofoverskud på omkring 400 kg N ha^{-1} og på basis af arealet i hele folden er der derfor brug for et større areal med træer eller andre tiltag for at reducere kvælstofudvaskningen yderligere. Derudover er det afgørende, at søerne motiveres til at gøde i specifikke områder; især i området med træer og dette omfatter en optimering af den rumlige fordeling af ressourcerne (hytte, foder og vand) i folden.

Træer i folde betyder at arealet til at producere foder på bliver reduceret. For landmanden betyder det et tab af hjemmeproduceret foder, som skal modsvares af dels en indkomst fra træerne og dels de goder der produceres, som inkluderer fælles goder, eller et ekstra tillæg for det producerede grisekød. Det er vigtigt, at træerne viste sig at være i stand til at modstå søernes interaktioner og at træskaderne var ikke voldsommere end at træerne var i stand til at komme sig.

Poppeltræer – dyrene

Søerne foretrak at ligge i området med poppeltræer. Ligeledes foregik hovedparten af diegivningerne uden for farehytten i området med træer. Især om vinteren anvendte søerne træerne til at klø sig på. Alt i alt tyder dette på, at søerne opfattede området med poppeltræer som værende attraktivt eksempelvis fordi området gav skygge, læ og beskyttelse. Selvom området med træer repræsenterede et mere forskelligartet miljø, så kvitterede søerne ikke med en general forøget aktivitet sammenlignet med søer, som ikke havde adgang til træer.

Forbedret fouragering og agroforestry er i stand til at bidrage med et forbedret miljøet i den økologiske griseproduktion. Fouragering og agroforestry kan med fordel kombineres med andre strategier såsom reduceret belægningsgrad, sæsonproduktion, mobile systemer og samarbejde med producenter af energiafgrøder.

List of included papers and manuscripts

Paper I
Jakobsen, M., T. Preda, A. G. Kongsted, J. E. Hermansen.
Increased foraging in outdoor organic pig production – modeling environmental consequences.
Status: Published in a special issue of 'Foods', November 2015.
https://doi.org/10.3390/foods4040622

Paper II
Jakobsen, M., J. E. Hermansen, H. M-L. Andersen, U. Jørgensen, R. Labouriau, A. G. Kongsted.
Elimination behaviour and soil mineral nitrogen load in an organic system with lactating sows – comparing pasture based systems with and without access to poplar (*Populus sp.*) trees.
Status: Revised version submitted September 2018 to 'Agroecology and Sustainable Food Systems'.

Paper III
Manevski, K., M. Jakobsen, A. G. Kongsted, P. Georgiadis, R. Labouriau, J. E. Hermansen, U. Jørgensen.
Effect on nitrate leaching of including poplar trees (*Populus sp.)* in free-range pig farming – a case study from a private organic farm in Denmark.
Status: Published in: 'Science of the Total Environment', July 2018.
https://doi.org/10.1016/j.scitotenv.2018.07.376

Paper IV
Jakobsen, M., H. M-L. Andersen, J. E. Hermansen, A. G. Kongsted. Sow behaviour and crop damages in organic pasture based systems with and without two rows of poplar (*Populus sp.)* trees.
Status: Draft.

Acknowledgements

Going through the different phases of this PhD project has been a professional as well as a personal journey - I feel grateful and privileged that I got the opportunity.

I sincerely thank my two supervisors Anne Grete Kongsted and John Erik Hermansen for their much appreciated support, guidance and constructive criticism and for making me feel welcome when knocking on their office doors.

A major part of this PhD project was founded on an experiment performed at a private organic pig farm in Denmark. I would like to thank the farmer for his enthusiasm, curiosity and interest in the project and for the collaboration, which also included the farm-workers, throughout the almost one year experimental period. Also, I would like to thank the sows and piglets for letting us get insight into their private lives.

The project benefitted profoundly from the work of two skilled technicians Kristine Riis Hansen and Orla Nielsen. I appreciate your perseverance, input and suggestions as well as your careful registrations and sense of detail in the recording process.

The effort put into Paper II and Paper III was based on cross sections collaboration in the Department of Agroecology, AU Foulum. Especially from the Section for Climate and Water but also from the Soil Fertility Section. My sincere thanks go to Kiril Manevski and Uffe Jørgensen for your help and collaboration and for exchanging knowledge within our different fields of work.

In many ways, I benefitted from a stay in the Soil Fertility Section, lasting one and a half months, in particular regarding my knowledge on nitrogen cycling in systems with pasture. Jim Rasmussen was a great guide into the world of nitrogen flows in the soil. I would like to thank everybody in the Soil Fertility Section as I really enjoyed the social environment in your group and the way you made me feel welcome.

Incorporation of trees into farming systems was completely new to me when I initiated this PhD project. Thus, it was of great value to get to see a real working silvo-pastoral system, the Dehesa in Spain with Iberian pigs and evergreen oak trees. Thanks to Dr. Vicente Rodríguez-Estévez at the Department of Animal Production, University of Cordoba, Spain, I was able to be part of the research activities from February until April 2017 and was introduced to several aspects of this delicate high value ecosystem. It was an inspiration to be part of the team performing behavioural observations of pregnant Iberian sows grazing.

I am grateful to have been part of the ever-changing System group – this definitely was the right place for me to be. A special thank you must go to Jesper Overgård Lehmann for patiently answering all my PhD questions and for our discussions on organic farming and many other things. During the last 7 months of my PhD, I was fortunate to have a very dear colleague Heidi Mai-Lis Andersen as my office mate. I really appreciated our discussions on pig behaviour and statistics as well as our collaboration on the paper related to the behaviour of sows. I would like to thank Teodora Dorca-Preda for our collaboration on the foraging paper, including your patience with me getting into the world of N balances. I would also like to thank Therese K. Mukendi for her help with text layout, including many of the figures in the thesis.

Sarah-Lina Aagaard Schild, Merete Studnitz, Lene Juul Pedersen and Heidi Mai-Lis Andersen constituted the piggy lunch group – meeting with you every second Wednesday was something I looked very much forward to and I enjoyed your company.

Mette Vaarst, thank you for being a role model as a researcher who is deeply dedicated to your work, which includes your qualities as a human being, truly interested in the well-being of others and in shaping a better world.

A special thanks has to go to Sarah-Lina Aagaard Schild for being my PhD allied in every possible way and for our mutual interest in and discussions on pigs and animal behaviour and lots of other stuff.

I truly owe a big thank you to Sophie van Vliet who was brave enough to take on the task of careful proofreading my thesis.

At last, I would like to acknowledge and thank my dear family and friends for caring and asking – all the way through.

Malene Jakobsen
Foulum, June 2018

Contents

Abbreviations

AU	animal unit (100 kg N excreted)
C	carbon
CF	carbon footprint
CP	crude protein
DKR	Danish kroner
DM	dry matter
iLUC	integrated land use change
LUC	land use change
GHG	greenhouse gases
ha	hectare
MJ	mega joule
ME	metabolisable energy
N	nitrogen

1. Introduction

1.1 Background

Within the past several decades, organic farming in Europe has developed from being a small scale production organized by groups of devoted pioneers into an agricultural production system recognised by the wider public and governments as a valid alternative to conventional agriculture (Kristiansen and Merfield, 2006). Mainly, this development into modern organic farming was fuelled by public concern for the consequences of the industrialised agriculture such as the welfare of livestock in the intensive production (Sørensen *et al.*, 2015), food scares and destruction of features in the farmed landscape (Kristiansen and Merfield, 2006). Today, the European Union supports organic farming with reference to supply to a specific market as well as provision of public goods such as environmental protection, animal welfare and development of rural areas (EU Regulation No. 834, 2007). In 2016, 13.5 million hectares were farmed organically in Europe by more than 370,000 producers and compared to 2015, organic land increased with almost one million hectares corresponding to an increase of 6.7% (Willer *et al.*, 2018). Still, the market is growing faster than the area, so production is not keeping up with consumer demand (Willer *et al.*, 2018).

On this background, obviously, it was important for pioneer organic livestock farmers to differentiate their production significantly from the intensive indoor production. Thus, in the beginning, Danish organic farmers with pigs practised outdoor free-range production, as it allows pigs to '*Live natural lives*' (Lund, 2006). However, as production increased and some farms specialized into producing organic pigs only, in practice is was challenging to keep all pigs outdoor. In addition, the detrimental consequences for the environment of outdoor pig production, in terms of nutrient leaching, became evident. Hence, growing pigs were moved to indoor housing with access to outdoor concrete yards and it became normal practice to snout-ring sows to prevent rooting, which destroys the grass cover and thereby increases the risk of nutrient leaching (Eriksen *et al.*, 2006a). As rooting is an exploratory behaviour of high priority for pigs (Studnitz *et al.*, 2007), it created a dilemma between animal welfare concerns on one hand and concern for the environmental on the other. Despite these production and management interventions, the current Danish organic pig production still faces profound environmental challenges as well as concerns for animal welfare.

In particular, the environmental challenges are related to production of outdoor free-range pigs all year round. As pigs are fed large amounts of concentrates, there is a significant input of nitrogen (N) to the paddock system. In combination with a relatively high stocking density (in Danish pig production, a stocking density of 2.8 animal units (AU), corresponding to 280 kg N excreted ha^{-1}, is allowed every second year (Poulsen, 2014)), pigs' non-random elimination behaviour (Stolba and Woodgush, 1989; Stern and Andresen, 2003) creates areas with N hotspots (Eriksen *et al.*, 2002; Watson *et al.*, 2003; Eriksen *et al.*, 2006b). Consequently, there is increased risk of N losses from the system and subsequently an increased risk of polluting adjacent water sources (Worthington and Danks, 1992; Eriksen and Kristensen, 2001; Williams *et al.*, 2005). This contradicts the organic Principle of Ecology, which states that resources must be recycled and managed efficiently to improve and maintain environmental quality (IFOAM, n.d.). Also, maintaining N within the farming system, is a prerequisite for sustaining a high self-sufficiency with livestock feed, thereby keeping the N cycle as closed as possible.

One way to improve the N recirculation within the farming system is to increase pigs' **foraging** in the range area, which has the potential to reduce the amount of N input to the system through purchased concentrate feed. Pigs ability for foraging, inherited from the wild boar (Stolba and Woodgush, 1989; Edwards, 2003) is well in line with the organic principles of recycling and efficient management of resources as well as providing animals with opportunities in accordance with their physiology, natural behaviour and well-being (IFOAM, n.d.). Studies on forage intake in pregnant sows show that they are able to take up around 40-65% of energy requirements from grass-clover (Ferre *et al.*, 2001; Sehested *et al.*, 2004; Fernández *et al.*, 2006). Growing pigs were able to ingest 60% of their daily energy requirements through Jerusalem artichokes in the study by Kongsted *et al.* (2013) and growing pigs restricted in protein have been estimated to ingest alfalfa corresponding to a daily dry matter (DM) intake of 470 g pig^{-1} day^{-1} (20% of total DM intake) (Jakobsen *et al.*, 2015). Iberian fattening pigs in the Spanish Dehesa system (from a live weight of ~110 kg), receiving no supplemental feed but with access to forage on acorns and grass, had a grass intake corresponding to 11% of daily DM intake (Rodriguez-Estevez *et al.*, 2009). However, growing pigs (50-60 kg) fed *ad libitum* with concentrates had a low intake of clover-grass corresponding to only 4% of daily organic matter intake in the study by Mowat *et al.* (2001). Edwards (2003) concluded from studies performed prior to 2003 that dry sows restricted in concentrates are able to ingest grazed herbage corresponding to approximately 2 kg DM day^{-1} covering 50% of maintenance energy requirements. For growing pigs fed *ad libitum,* the figures on daily forage intake are 0.1 kg DM, which covers less than 5% of requirements. This indicates that a reduction in concentrates increases the pigs' forage intake. An increase in forage intake reduces the input of concentrate feed into the paddock system and as a result, the N recirculation is improved. However, the overall environmental consequences at farm level remain to be understood.

Besides increased reliance on foraging, a relevant development path to consider may be to integrate trees in the production system in the form of **agroforestry**. Agroforestry is the deliberate integration of trees into agricultural systems with livestock or crops and specifically, intentional integration of trees into systems with livestock is referred to as silvo-pasture (Mosquera-Losada *et al.*, 2009) .

Integration of trees into paddock systems with pigs may be able to reduce N losses from the system. Poplars (*Populus sp.*) and willows (*Salix sp.*), often referred to as energy crops or short rotation coppice, are fast growing perennials and able to take up significant amounts of water and N (Dimitriou *et al.*, 2012; Jørgensen *et al.*, 2005; Pugesgaard *et al.*, 2015). This is related to energy crops having a permanent and long root system as well as a relatively long growing season. Thus, poplars and willows may take up N from deeper soil layers, which the grass roots do not reach and have an uptake in early spring when grass growth has not yet begun. However, it presupposes that pigs perform the majority of eliminations in the near vicinity of the energy crops. This has been supported by a previous experimental study with growing pigs in paddocks with willows, poplar trees and *Miscanthus*, (Horsted *et al.,* 2012; Jørgensen *et al.*, 2018). Furthermore, compared to grass, well established willow and poplar trees have an ability to withstand pigs' trampling and rooting behaviour as found in the study by (Horsted *et al.,* 2012). In addition, as trees reduce wind speed and solar radiation to the vegetation surface, this decreases ammonia evaporation (Jørgensen *et al.*, 2018) mainly coming from deposited urine (Jensen and Sommer, 2013). Furthermore, trees are expected to contribute to an increased carbon (C) sequestration both above and below ground (Eichhorn *et al.*, 2006; Jose, 2009).

Forest and nearby forest areas are the preferred habitats of the domestic pig's ancestor the wild boar (Barrett, 1982; Graves, 1984) and the domestic pig has retained many of the behaviours of the wild boar such as foraging (including rooting) (Stolba and Woodgush, 1984; Jensen, 1988; Stolba and Woodgush, 1989), nesting and wallowing (Bracke, 2011). Integration of trees into paddocks systems seem to create a more enriched and heterogeneous environment (Brownlow *et al.*, 2005) compared to the current relatively barren paddocks with pasture only and thus, may provide pigs with improved opportunities to perform species-specific and natural behaviour.

Another function of trees in pasture systems may be to provide animals with shelter and shade (Brownlow *et al.*, 2005; Wilson and Lovell, 2016). In the current pasture based system, pigs are exposed to a wide range of climatic conditions and the hut is the only possibility to seek shelter from wind, rain, snow and sun. Under Danish conditions, during a period of hot weather Schild *et al.* (2018a) recorded air temperatures up to 39.3 °C (median of 22.9°C across 24 hours) inside farrowing huts, which is somewhat higher compared to the thermal comfort zone of a lactating sow, which ranges from 12 to 22°C (Black *et al.*, 1993). In Denmark, outdoor free-range pigs must be supplied with a wallow when the mean temperature in the shade rises above 15°C (Anonymous, 2003), as pigs lacks functional sweat glands and are depending on external cooling facilities (Bracke, 2011). However, in particular at intermediate temperatures, trees provide sows with an alternative shaded area. In addition, a shaded area reduces water evaporation from mud after wallowing, which prolongs the effect of the mud, and protects the skin from sunburn. Hence, trees are expected to provide additional animal benefits compared to the current pasture system.

A few Danish organic pig farmers have planted trees in paddocks for sows, mainly poplar trees and willows. However, there are knowledge gaps when it comes to quantification of environmental performance and the effects regarding animal benefits in a system integrating pigs and trees.

1.2 Overall aim, objectives and hypotheses

The overall aim of the present PhD study was to contribute to the development of new production and management strategies leading to a more nutrient-efficient organic pig production that takes into account the species-specific and natural behaviour of pigs, while maintaining a competitive production. In order to do so,

the overall objectives were to *investigate*:

- Overall environmental effects of improved foraging in the range area.
- Environmental effects of introducing poplars (*Populus sp.*) into paddocks for lactating sows.
- Potential animal benefits of introducing poplar trees into paddocks for lactating sows.

Based on the objectives, the following overall hypotheses were identified to guide the work:

Hypothesis 1:
Organic production systems, which include sows' and growing pigs' foraging in the range area, will improve overall farm environmental performance in terms of reduced carbon footprint (CF). Organic production systems with growing pigs in an improved forage crop system will reduce nitrate leaching at farm level compared to a system with growing pigs foraging on grass-clover and will improve the overall farm environmental performance also compared to current practice

Hypothesis 2:
Including an area with poplar trees in individual paddocks for lactating sows will lead to an improved environmental performance, represented by a reduced risk of nitrate leaching compared to paddocks with pasture only.

Hypothesis 3:
An area with poplar trees in individual paddocks for lactating sows represents a more heterogeneous and stimuli-rich environment as well as an alternative shaded area during months of increased temperatures and thus, will provide sows with additional animal benefits compared to paddocks with pasture only.

The foundation of this PhD thesis is constituted by four scientific papers, which support the overall aim, objectives and hypotheses presented above.

In P**aper I,** the objective was to investigate the technical and environmental performance at farm level of pigs' improved foraging in the range area, as compared to a system with pigs foraging on grass-clover, and compared to the current Danish organic pig production system with sows on pasture all year round and growing pigs housed indoors with outdoor access. Thus, the paper addressed **hypothesis 1**.

The objectives of P**aper II** were to investigate site preference for sow elimination behaviour and to quantify soil inorganic nitrogen distribution and load in two pasture systems, with and without sow access to an area with poplar trees in individual paddocks (**hypothesis 2**).

The objective of P**aper III** was to quantify nitrate leaching in an area with poplar trees and an area with pasture in individual paddocks with lactating sows, involving three types of paddocks: 1. with sow access to trees, 2. without sow access to trees, 3. with only pasture. Like Paper II, the paper addressed **hypothesis 2**.

In P**aper IV**, the objective was to investigate behaviour in relation to activity level and site preferences across seasons in lactating sows in individual paddocks involving three types of paddocks: 1. with sow access to trees, 2. without sow access to trees, 3. with only pasture. In addition, the objective was to assess the level of damages to the poplar trees and vegetation cover exerted by the sows (**hypothesis 3**).

2. Organic pig production

2.1 Principles and regulations

In 2017, in Denmark, there were 232 certified organic pig farms (Ministry of Environment and Food of Denmark, 2018) and from 2016 to 2017 at least 180,000 organic pigs were raised and slaughtered in Denmark (The Danish Agricultural Agency, 2018). In comparison, in 2016, 32 million conventional piglets were produced and of these 18.3 million were raised and slaughtered in Denmark (Farming and Foods, 2017). Thus, currently, the organic pork production constitutes less than 1% of the total pig production. However, from 2015 to 2016, the retail sale and value of organic pork increased with 30 and 21%, respectively (Danish Statistics, organic retail sale, 2016). Also, the export of organic pork is increasing, from 2016 to 2017 with at least 5% (Friland, 2017a). In 2020, a production of 230,000 organic pigs is expected (The Danish Agricultural Agency, 2018). The increased sale is reflected in the payment as currently, organic pig farmers are paid almost three times as much per kg pork produced compared to conventional farmers, provided the quality supplements are obtained (May 2018, conventional: 8.90 DKR kg^{-1} pork, organic: 25.75 DKR kg^{-1} pork) (Friland, 2017a).

Principles

The International Federation of Organic Agriculture Movements (IFOAM) was formed in 1972 and today remains the only global non-governmental network for all organic organizations (IFOAM, n.d). In 2006, IFOAM presented the four *Basic Principles* of organic agriculture (Principles of Health, Ecology, Fairness and Care), each followed by a statement and an explanation. The Danish National association for organic farming, Organic Denmark, has adopted these four basic principles (Organic Denmark, 2015), which serve to give guidance to the development of standards, programs and positions (IFOAM, n.d.).

Regarding **nutrients**, the Principle of Ecology states that:

'Inputs should be reduced by reuse, recycling and efficient management of materials and energy in order to maintain and improve environmental quality and conserve resources'.

Hence, resources such as valuable nutrients (e.g. N) must be conserved and managed efficiently as they are prerequisites for the indispensable link between soil, crops and animals in the farming system. Nutrients must be handled with care so they are not lost from the farming system, with subsequent detrimental effects on the environment. Furthermore, nutrients leaving the farming system in products must be recycled back to the soil.

Regarding **resources**, the Principle of Fairness states that:

'Natural and environmental resources that are used for production and consumption should be managed in a way that is socially and ecologically just and should be held in trust for future generations'.

Thus, consumption of non-renewable resources such as oil, coal, and gas must be reduced and replaced with renewable resources as much as possible. This also addresses the concerns regarding greenhouse gasses (GHG) generated through production (methane from animals and nitrous oxide from soil bacteria), which contribute to global warming affecting the possibilities for future generations.

With regards to the **animals** in the farming system and the ecological systems, the Principle of Health states that:

'The health of individuals and communities cannot be separated from the health of ecosystems – healthy soils produce healthy crops that foster the health of animals and people'.

'Health is the wholeness and integrity of living systems. It is not simply the absence of illness, but the maintenance of physical, mental and ecological well-being. Immunity, resilience and regeneration are key characteristics of health'.

This refers to the close interdependency between soil, crops, and animals and to ecological systems in general, which inevitably are entwined in the farming system. The Principle of Health emphasizes the holistic approach of organic farming and concerns the ability of living beings and systems to withstand and be resilient towards disease and other disturbances. Hence, the main focus is prevention and the animals must be provided with conditions that foster physical and mental health, which in turn enable immunity and resilience.

With specific reference to the animals in the farming system, the Principle of Fairness states that:

'Animals should be provided with the conditions and opportunities of life that accord with their physiology, natural behaviour and well-being'.

On one hand, this links to the previous statement regarding provision of proper conditions and opportunities, which are prerequisites for healthy animals. However, it also claims that animals have the right to be treated in accordance with their physiology and be offered conditions that enable them to perform natural behaviour. Also, the statement acknowledges that animals are an important part of the farming system, in practice but also in terms of being sentient creatures that deserve special moral considerations (Vaarst *et al.*, 2004).

According to Lund (2006), the '*natural living*' approach towards animal welfare is the one that in the best possible way resembles organic farming's interpretation of animal welfare. The '*natural living*' approach can be interpreted as the '*animal rights view*' and the respect of the animal's integrity (Verhoog *et al*. 2004). It proposes that an animal's welfare depends on its possibilities to perform species-specific behaviour, which also means to live a natural life according to its genetics.

Regarding theories on human-nature and human-animal relations, Lund (2006) argues that the values and principles of organic farming respond to the same issues as the *ecocentric* theory, where populations, species, ecosystems and other features in nature have direct moral status. According to this theory, the individual animal is subordinate, thus, when defined at herd level, the '*natural living*' approach fits well into the *ecocentric* theory (Verhoog *et al*., 2004). However, Lund (2006) points out that there are different forms of *ecocentrism* where some allow focus on the individual animal.

The history and above described principles, values and underlying ethical theories of organic farming may not be known by individual farmers or involved stakeholders, who may well hold other moral concerns towards ecological systems and animals. Still, farmers, in their everyday practical farm life, are subjected to organic standards and regulations, developing across time and influenced by the organic principles and values.

Regulations

Organic pig production in Europe is subjected to EC regulation on organic farming with Council regulation (EC) No 834/2007 (EU Regulation No. 834, 2007) (Table 2.1) and Commission Regulation (EC) No 889/2008 (Commission Regulation No. 889, 2008) (Table 2.1). These can be found interpreted in the Danish law on organic farming LBK No 21 of 04/01/2017 (LBK No. 21, 2017) (Table 2.2). In addition, farmers are subjected to the EU Nitrate directive related to livestock manure (Anonymous, 2017b; EU Nitrate Directive, 1991) that stipulates a stocking density of 170 kg N ha^{1} year^{-1}. However, in Denmark the stipulated stocking density is lower with 140 kg ha^{1} year^{-1} (except for cattle production) (Dijk and Berge, 2009). Also, organic farmers with free-range pigs are subjected to the Danish law on keeping outdoor free-range pigs for agricultural purposes (LBK No. 51, 2017). In the EU regulation, it is stipulated that member states are allowed to implement stricter national rules provided that these also apply to non-organic production (Früh *et al*., 2014). However, private schemes are allowed, and Danish organic pig farmers have entered code of conduct along with various stakeholders (Anonymous, 2018) (Table 2.3).

Table 2.1. European rules and regulations on organic pig production (EU Nitrate Directive, 1991; Regulation No. 834, 2007; Commission Regulation No. 889, 2008 EU)

Stocking density	170 kg N ha^{-1} $year^{-1}$
Synthetic amino acids	Prohibited
Genetically modified organisms	Prohibited
Preventative treatment with chemically produced allopathic veterinary products or antibiotics	Prohibited
Tail docking	Prohibited
Cutting of teeth	Prohibited
Castration	Physical castration is allowed by applying adequate anaesthesia and/or analgesia only at the most appropriate age by qualified personnel
Lactation period	Minimum of 40 days
Housing	Sows must be kept in groups unless during the final stages of the gestation period and in the lactation period
Indoor area	Half of the floor area must be solid
Space allowance: indoor area (per pig)	
Lactating sows with piglets until 40 days	7.5 m^2
Weaners ≤ 30 kg	0.6 m^2
Growing pigs ≤ 50 kg	0.8 m^2
Growing pigs >50 kg and ≤ 85 kg	1.1 m^2
Growing pigs ≤ 110 kg	1.3 m^2
Growing pigs > 110 kg	1.5 m^2
Space allowance: outdoor area	
Lactating sows with piglets until 40 days	2.5 m^2
Weaners ≤ 30 kg	0.4 m^2
Growing pigs ≤ 50 kg	0.6 m^2
Growing pigs >50 kg and ≤ 85 kg	0.8 m^2
Growing pigs ≤ 110 kg	1.0 m^2
Growing pigs > 110 kg	1.2 m^2
Roughage	Permanent access to pasture or roughage. Roughage, fresh or dried or silage must be part of the daily feed ration
Protein feed	5% non-organic protein feed is allowed until 31 January 2018
On-farm produced feed	Minimum 20% of the feed must be home-grown or produced in the same area
Feed produced during the conversion period	On average, maximum 30% of the feed can be purchased conversion feed If the conversion feed is home-grown maximum 60% of the feed can be conversion feed.

Table 2.2. Danish rules and regulations related to organic pig production (Poulsen, 2014; [1]Anonymous, 2017b; LBK No. 21, 2017; [2]LBK No. 51, 2017)

[1]Stocking density on pasture	Maximum of 1.4 AU corresponding to 140 kg N ha^{-1} year^{-1} preferable for 12 months, followed by production of a N demanding crop. A stocking density of 2.8 AU, corresponding to 280 kg N excreted ha^{-1}, is allowed every second year. It is assumed that grass-clover is harvested for hay or silage and thereby removed from the area
	On a yearly basis, 20% of the feed must be produced on the farm itself or have Danish origin
Roughage	*Ad libitum*
Rooting material	*Ad libitum*
Shade	All animals must have access to shade
[2]Temperature regulation	All animals must have access to temperature regulation On pasture pigs ≥ 20 kg: access to wallow when the mean temperatures is >15°C in the shade
Lactating sows	
Snout-ringing	Is allowed
Piglets	
Interventions	Surgical castration is allowed within 2-7 days after birth by appropriate apply of anaesthetic and analgesic
Gestation and dry sows:	
Snout-ringing	Is allowed
Housing system	Minimum: indoor in groups with outdoor access Access to pasture from April 15th to November 1st (minimum 150 days a year) when the weather and soil conditions as well as the conditions of the sows allow it
Growing pigs	
Outdoor concrete yard	Minimum 50% of the outdoor concrete floor must be solid

Table 2.3. Additional rules according to code of conduct between producers and stakeholders within the Danish organic pig production (Anonymous, 2018)

Origin of animals	All animals must be born in Denmark
Feed	All feed must be of organic origin
Housing for lactating sows	Pasture all year round with access to farrowing huts
Paddock size: individual lactating sows	>300 m^2 sow^{-1}
Shade: lactating sows	During summer months, all animals must have access to shade. The hut is not considered a shaded area[1]. Shade can be offered through e.g. high vegetation[2]
Weaning age	On average minimum of 49 days
Cereals for piglets	Must be offered from a minimum of 4 weeks of age
Outdoor concrete yard for growing pigs	Minimum size: 20 m^2 Minimum of 10 m^2 for pigs up to 40 kg

[1]An exception is farrowing huts with an opening in the back corresponding to the size of the front entrance, thereby creating significant airflow.
[2]If an area of high vegetation is used for shade, the vegetation must be planted at the latest within the first plant season after conversion to organic farming.

2.2 In practice

In Danish organic pig production, it is normal practice to have two separate crop rotations, one devoted to paddocks for sows with grass-clover (approximately 20% of the rotation area (Larsen, 2000)) and another rotation to produce crops for feed. Typically, the rotation with sows is simple, exchanging between one or two years with cereals followed by one year with grass-clover for the paddocks. In the second rotation, crops like winter or spring barley, rye, oats and triticale, in addition to peas, field beans/fava beans, lupines, grass-clover and rape, are grown (Kongsted *et al.*, 2000). Normal practice is to cut the grass-clover fields for silage prior to fencing for paddocks.

Organic lactating sows and piglets are outdoors on grass-clover pastures all year round either in individual or common paddocks (Figure 2.1). According to the code of conduct, the paddock area must be minimum 300 m^2 (Anonymous, 2018). However, if the paddocks are used all year round, for lactating sows each paddock must be a minimum of 1500 m^2 corresponding to 280 kg N ha^{-1}. Piglets are able to move across paddocks and roam in the surrounding area. The field with sows is surrounded by a stationary fence to keep out predators, primarily foxes. Sows are moved to the farrowing field approximately a week prior to farrowing and the lactation period is on average seven weeks. From January 1st 2018, lactating sows must have access to shade (other than the hut, with one exception as stated in Table 2.3). Normally the sows are fed, watered, and checked once a day. In addition, when needed, the farrowing and gestation paddocks are revisited to give straw, water for wallowing and feed for piglets (Figure 2.1).

Fencing is labour intensive and therefore it is normal practice to shift paddocks once a year. Taking the length of the lactation period into account, six batches of sows occupy the farrowing field during a year. Each time a sow is moved into a paddock, the hut and feeding area must be moved to a new place in order to distribute the animal manure more evenly (Seges, 2016). Sows have access to insulated farrowing huts (on many farms an A-hut with a 4.2 m^2 floor area) provided with straw, which also serves as nest building material. During the first days after farrowing, on some farms a fender or a wooden board is used to prevent piglets from leaving the hut. During winter time, on many farms, the hut entrance is provided with a curtain (plastic or rubber) to keep the air temperature inside the hut as high as possible for the piglets and to keep the straw dry (Seges, 2016).

It is normal practice to castrate male piglets within 2-7 days after farrowing. Usually within the first few days after farrowing, cross fostering is performed. After a minimum of seven weeks lactation, piglets are moved to indoor housing. On some farms, weaners are kept on pasture in large groups for various periods of time and then moved to indoor housing when they weigh around 20-30 kg (Früh *et al.*, 2014) (Figure 2.1). Usually, weaned piglets are housed in large groups and with access to an outdoor concrete area (Figure 2.1). At around 20-30 kg, weaners are moved to pens for growing pigs also consisting of an indoor area with access to an outdoor concrete yard. In Denmark, pigs are sent for slaughter at a live weight of around 110 kg (Friland, 2017b).

After weaning, sows are moved to the mating unit. If the mating period lasts less than five days, they can be kept indoors without outdoor access. It is normal practice to cross sows with Danish Duroc boars (minimum of 25% Duroc) primarily due to the meat quality (Friland, 2017b). Mainly, sows are Danish Landrace – Danish Yorkshire crossbreeds. Normally, sows are mated through insemination but it is common practice to use a boar housed in the neighbouring pen or paddock for stimulation. Also, on some farms a boar is used to mate sows not conceiving through artificial insemination.

Pregnant sows are kept either on pasture in groups all year round or housed partly indoors in groups with access to pasture or outdoor concrete yards and partly outdoors as sows must have access to pasture from April 15th to November 1st (Figure 2.1). For systems on pasture, sows have access to common huts for shelter. In indoor systems, the sows are often housed in large groups on deep litter. Group size depends on the number of sows on individual farms and corresponding management procedures.

Figure 2.1. Organic pig production in Denmark. Top left: gestation field, Top right: farrowing field, Middle left: growing pigs in outdoor area, Middle right: growing pigs indoors, Bottom left: growing pigs in outdoor area, Bottom right: sow in wallow. Photos: Kristine Riis Hansen, Heidi Mai-Lis Andersen, Sarah-Lina Aagaard Schild, Malene Jakobsen.

3. Behaviour of the pig

The opportunity for livestock to perform species-specific and natural behaviour is an important aspect of organic farming. Species-specific behaviours are behaviours that are typical for the species and for the pig these would be behaviours such as rooting, wallowing and nest building. Natural behaviour is a relatively broad term and could be defined in many ways according to the purpose, but includes behaviours that an animal would perform under a wide range of natural conditions. In this context it is related to the animal's welfare and gives the animal pleasure and promotes its biological functioning. It is represented by behaviours that are common across species but important for the animal's welfare and includes behaviours such as locomotion, stretching, grooming, play, mating and resting (Bracke and Hopster, 2006).

Domesticated pigs in semi-natural environments show a rich pattern of behaviours resembling that of the wild boar and thus, do not seem to be affected by decades of breeding and intensive rearing conditions (Jensen, 1988; Stolba and Woodgush, 1984; Stolba and Woodgush, 1989; Wood-Gush *et al.*, 1990). Species-specific behaviours such as foraging (including rooting) (Stolba and Woodgush, 1989; Gustafsson *et al.*, 1999; Petersen, 1994) nest building (Jensen, 1986; Wischner *et al.*, 2009) and wallowing (Bracke, 2011) are readily seen performed by the domesticated pig. In order to optimise animal benefits and to be able to manipulate elimination behaviour it is important to gain insight into the behavioural patterns of pigs including wild boars and feral pigs and the affecting factors.

3.1 Natural habitat and species-specific behaviour of the pig

Natural habitat

Modern European domestic pigs (*Sus scrofa*) originated from the wild boar and the domestication of pigs took place independently in Asia and Europe 10,000 years ago (Larson *et al.*, 2005). The wild boar is an opportunistic omnivorous animal (Wilcox and Van Vuren, 2009) that along with feral pigs shows migratory behaviour and therefore are spread out across large parts of the world (Wood-Gush *et al.*, 1990). The flexibility in terms of diet explain their ability to thrive in various numbers of habitats (Schley and Roper, 2003).

Given natural conditions, studies on habitat preference of wild boars and feral pigs show that they prefer to reside in dense forest and areas with scrubs adjacent to water holes as well as forest close to rivers and streams or swamp and marshes. Areas with year round access to water and areas that remain moist throughout the year are sought (Graves, 1984; Abaigar *et al.*, 1994; Thurfjell *et al.*, 2009). Open areas with grassland adjacent to forest or bushes are preferred for activity (Graves, 1984) and areas with forest and dense vegetation are used for resting (Thurfjell *et al.*, 2009). Sows with piglets are more often seen in areas with forest compared to areas with no forest (Graves, 1984), which is probably related to the protection the vegetation offers against predators. Thus, occupation of a given habitat seems to be depending on food availability, soil moisture and cover for protection from climatic conditions but also predators and hunters (Graves, 1984; Dardaillon, 1986).

Daily rhythm

According to Graves (1984), daily activity patterns of wild boar and feral pigs depend on habitat, season, food availability, climatic conditions and predators. Away from civilization, wild boars have been observed foraging and travelling during daytime (Conley *et al.*, 1972) as cited in Graves (1984). However, when exposed to hunting, they will become nocturnal and rest and wallow during daytime (Stegeman, 1938). Kurz and Marchinton (1972) reported that feral pigs were day active from October to May but during summer, they became more active during night time, which was confirmed by Barrett (1982), who also studied feral pigs.

At increased temperatures during summer time, feral pigs will remain inactive during midday and at very hot days they are only active early morning and late afternoon (Graves, 1984). Wood-Gush *et al.* (1990) found that domesticated pigs in a semi-natural environment rested during the night in the hut provided and were active during daytime. Grazing activity showed a morning and an afternoon peak, whereas rooting was most often performed in the middle of the day. Similarly, in the study by Buckner *et al.* (1998), domesticated sows showed peaks of foraging behaviour at sunrise and sunset. In a pilot study of domesticated gilts and pregnant sows in a semi-natural area of 4 ha, during days of hot weather, typically from around 12.00-14.00, pigs were resting in the shade below trees on top of a small hill ridge (Jakobsen, 2013). Prior to that they grazed and after the midday rest they wallowed and then stayed in the area near the wallow and primarily rooted. Farmed wild boars also showed a peak grazing period before noon, approximately from 08.30-11.30 (on pasture between 08.30-16.30). Within these three hours they spent 62% of their time grazing compared to 42% in the remaining time on pasture (Rivero *et al.*, 2013).

Foraging behaviour

Foraging is part of pigs' explorative behaviour and pigs are highly motivated to explore to get information about the feed resources in the environment (Studnitz *et al.*, 2007; Olczak *et al.*, 2015). The motivation for foraging is influenced by factors of both internal and external origin (Kyriazakis, 2003) such as genotype (Kelly *et al.*, 2007), age (Edwards, 2003), preference for forage crop (Rachuonyo *et al.*, 2005) and supplemental feed (Day *et al.*, 1995; Danielsen *et al.*, 2000; Beattie and O'Connell, 2002; Stern and Andresen, 2003; Jakobsen *et al.*, 2015).

Under natural conditions, pigs will spent the vast majority of their active time searching for feed items in their surroundings (Studnitz *et al.*, 2007). In domestic pigs, already within the first few days after birth, piglets start rooting, biting, chewing and sniffing at objects

(Petersen, 1994). Rooting increases until week five and then decreases, whereas grazing increases. Under semi-natural conditions, foraging behaviour has been reported to amount to 52% (Stolba and Wood-Gush, 1989) and 54% (Rodriguez-Estevez *et al.*, 2009) of total observations. Management incentives such as strip-grazing affects foraging as found in the studies of growing pigs by Stern and Andresen (2003).

In the study by Edwards *et al.* (1993), the level of rooting by domesticated sows was related to the extent of hunger. In growing pigs, reductions in energy and crude protein (CP) compared to recommendations have shown to increase the level of rooting (Stern and Andresen, 2003; Jakobsen *et al.*, 2015). In wild boar, Welander (2000) found that the level of rooting increased in soils rich in nutrients and in village pigs in the highlands of Papua New Guinea, large amounts of earthworms in the soil stimulated rooting behaviour (Rose and Williams, 1983).

Also, feed intake is affected by climate. Feed intake decreases with increasing ambient temperatures (Edwards, 2003) and increases at temperatures below the thermo-neutral zone (Quiniou *et al.*, 2000). Andresen and Redbo (1999) found that growing pigs showed a decrease in grazing behaviour with increasing temperature. The level of rooting was not affected in a temperature range of 12-25°C, however, at a temperature above 20°C, rooting motivation was changed towards the wallowing and drinking area. In growing pigs, wind influenced time spent on rooting as the level decreased going from light, medium to strong wind (Kongsted *et al.*, 2013). In the Scottish highlands, wild boars were reported to prefer rooting during winter and autumn (76% of foraging time), and grazing during spring and summer (Sandom *et al.*, 2013). This is suggested to be due to the distribution of resources during the various seasons and the physical properties of the soil with a higher content of water during autumn and winter thereby making access easier. Furthermore, depth of rooting was related to the plant community as the wild boars rooted deeper in areas with bracken. This indicates that various plant communities attract different soil web communities.

Nest building

Around farrowing, wild boars and feral sows become solitary (Stegeman, 1938; Graves, 1984), which was also observed in the study by Stolba and Wood-Gush (1989) of domesticated pigs in a semi-natural environment. About 1-2 days prior to farrowing, the sow leaves the flock (Jensen, 1986; Stolba and Wood-Gush, 1989) and 4-6 hours seemed to be used for searching for an appropriate nesting site (Jensen, 1986). The behaviour of nest building is specific for the pig and the function is to provide piglets with shelter from rain and wind and comfort in terms of thermoregulation (Wischner *et al.*, 2009) as well as protection from potential predators (Olczak *et al.*, 2015). If given the conditions, domesticated sows will built nests resembling that of wild boars (Jensen, 1986). Mayer *et al.* (2002) investigated characteristics of farrowing nests in wild boar and reported that they were built in a hollow in the ground. Nesting materials differed but the sows used readily available plant species from the surroundings. Half of the nests were situated next to trees and all of them had overhead cover. The authors suggested that location of nest nearby trees or timber may serve as a defence function since the sows is then protected at the back. In the study by Jensen (1989) of domesticated sows in a semi-natural environment, sows preferred nesting sites with protection (beneath branches) and with an overview of the surroundings. Also, more protected sites were chosen during winter and a larger part of the nest material was made up of branches and twigs compared to summer. On this basis, the author suggested the nest building behaviour to be feed-back regulated by the protection offered from the environment around the nest. Similar observations were made by Mayer *et al.* (2002) as their findings also indicated that nest location and amount as well as type of material used for nesting was primarily affected by the climate and the surrounding environment.

Nests are also built by both genders for the purpose of resting (Wischner *et al.*, 2009). In the study of wild boar by Mayer *et al.* (2002), half of the nine beds had a depression made by the pigs, eight had a closed canopy cover and in four beds the understorey was dense or closed. Stegeman (1938) also reported that wild boars built protected beds with good cover and used materials such as leaves, evergreen needles and twigs (Graves, 1984). In the study by Wood-Gush *et al.* (1990) of domesticated pigs in a semi-natural environment, the pigs quickly got accustomed to sleeping in the hut provided with straw. As they had previously been sleeping on straw this may well have been the reason for using the hut and not building nests.

Thermoregulation and shelter use

Outdoor pigs are exposed to a wide variety of climatic conditions, which are expected to influence their behaviour (Buckner *et al.*, 1998). In piglets, the relation between body surface area and body mass is increased compared to adult pigs and therefore piglets, in particular, are susceptible to hypothermia. High temperatures represent the biggest challenge to adult pigs as they show reduced ability to transfer heat due to a small amount of sweat glands (Olczak *et al.*, 2015). Olczak *et al.* (2015) listed the responses of pigs subjected to high temperatures as increased respiration/panting, decreased activity and feed intake, increased water intake, limited contact with other pigs, lying on the side to expose as much of the body surface as possible, lying in cool humid places, shade seeking and wallowing (covering the body with mud). However, if the pig is exposed to either low or high temperatures during longer periods of time, the thermoreceptors adapt as compared to a sudden change in temperature (Swiergiel, 1997) as cited in Olczak *et al.* (2015).

When the ambient temperature increases, pigs seek shade (Heitman *et al.*, 1962; Blackshaw and Blackshaw, 1994; Olczak *et al.*, 2015). However, when offered a wallow they will reduce the amount of time spent in the shade (Heitman *et al.*, 1962). In the study by Buckner *et al.* (1998), sows in late gestation spent 49% of the observations outside the shelter (farrowing hut) and showed signs of heat stress during all seasons. Observations performed after dusk, at night and before dawn, indicated that sows spent the majority of time during darkness inside the huts. It may be that the hut is considered safer in terms of offering protection from predators. On the other hand, sows very close to farrowing were observed to lie outside the hut late in the evening and early morning. It may be that the sows considered the farrowing hut to be too hot. In the same study, the use of shelter increased during days of both cold, windy and wet weather. Also, the combination of low temperatures, high humidity and wind seem to increase pigs' use of shelter (Olczak *et al.*, 2015).

Pigs wallow primarily to cool down body temperature, protect the skin from sunburn and to remove ecto-parasites (Bracke, 2011). All year round, pigs will wallow also at temperatures below zero degrees but the behaviour is increased with increasing temperatures. At ambient temperatures of approximately 17-21°C adult pigs will start wallowing for cooling purposes (Heitman *et al.*, 1962; Stolba and Woodgush, 1989; Andresen and Redbo, 1999; Bracke, 2011). In the study by Buckner *et al.* (1998), during summer time late gestating sows were observed to spent a large proportion of their resting time in the wallow. In addition, during winter at two separate occasions sows in late gestation were seen wallowing. In growing pigs, Olsen *et al.* (2001) reported that they would use the wallow provided in the outdoor run also at air temperatures below zero degrees Celsius. Also, wild boars have been reported to break the ice to wallow (Stegeman, 1938) suggesting a different motivation than temperature regulation. Olsen *et al.* (2001) reported that growing pigs increased rubbing of the body with increasing temperatures and suggested it to be related to thermoregulatory behaviour. In the habitats of wild boars, wallows are often found in shaded, cool and wet areas (Stegeman, 1938), probably because the cover provides shade and thereby reduced temperatures but it may also be due to protection from predators. According to Bracke (2011), wallowing is possibly intrinsically motivated and thereby rewarding in itself, indicating the importance for animal welfare.

3.2 Elimination behaviour

Pigs' distribute their urinations and defecations non-randomly in the areas they occupy. This elimination pattern has been found in female wild boars (Ferretti *et al.*, 2015), in domesticated pigs roaming a semi-natural area (Stolba and Wood-Gush, 1989), in domesticated sows on pasture (Watson *et al.*, 2003) and in free-range growing pigs on pasture (Stern and Andresen, 2003; Horsted *et al.,* 2012). The result is nutrient hotspots that increases the risk of N losses, which is exacerbated if the vegetation cover is destroyed and there are no roots to absorb the mineral N (Eriksen *et al.*, 2006a). In outdoor systems on pasture, regular movement of huts as well as the feeding and drinking area leads to a more even distribution of nutrients in the paddock (Eriksen and Kristensen, 2001; Eriksen *et al.*, 2006a; Quintern and Sundrum, 2006). This indicates that it might be possible to some extent to manipulate the elimination behaviour of pigs.

Piglets

Already at an early age, piglets move away from the nest to eliminate. Stangel and Jensen (1991) observed sows and piglets in a semi-natural environment and found that piglets already one day after farrowing went away from the sow and most of them also outside the nest to urinate and defecate. Piglets in farrowing huts on pasture have also been observed to move away to eliminate already eight hours after farrowing (Dellmeier and Friend, 1986). Also, this was the case in the study by Petherick (1983) with sows and piglets housed indoors in large straw-bedded pens, where piglets less than 24h of age moved to the edge of the straw bed to excrete.

Piglets are susceptible to hypothermia, in particular during their first days of life (Edwards, 2002). Thus, from an evolutionary point of view it would be important for piglets to avoid eliminating and resting in the same area (Petherick, 1983), also to minimize the risk of transmission of infections and parasites (Damm and Pedersen, 2000). In the study by Stangel and Jensen (1991), piglets moved further away from the nest to urinate and defecate as they got older, which was confirmed in an observational study of 12 wild boar piglets in an enclosure (Buchenauer *et al.*, 1982). Stangel and Jensen (1991) described the piglets' tendency to leave the sow and the nest for eliminations as spontaneous. In indoor systems, piglets were observed to eliminate in specific areas from two days of age (Petherick, 1983), five days (Buchenauer *et al.*, 1982) and six days (Whatson, 1985). According to Whatson (1985), the piglets simply avoided eliminating in the resting area in contrast to Buchenauer *et al.* (1982) and Petherick (1983) who stated that piglets selected out special places or areas to eliminate and by doing that they kept the resting area clean.

Furthermore, Stangel and Jensen (1991) found that piglets only started to follow the sows to areas adjacent to the nest at four days of age, suggesting that the behaviour is not learned from the sow, which was confirmed in the study by Whatson (1985) of indoor sows and piglets.

Number of eliminations

Regarding the number of eliminations, for individually housed lactating sows, Andersen and Pedersen (2011) recorded 3.3 urinations and 2.0 defecations. For pregnant sows in an organic indoor system with access to an outdoor yard and pasture, the average number of eliminations was higher with 4.8 urinations and 4.0 defecations (Ivanova-Peneva *et al.*, 2006). Almost similar figures were found for female wild boars with a mean number of defecations pig^{-1} day^{-1} of 3.8 to 4.3 (Ferretti *et al.*, 2015). In gilts housed indoors in pens and observed during a period of 23 hours prior to farrowing, on average they urinated and defecated 7.9 and 6.4 times, respectively (Damm and Pedersen, 2000). This high frequency is common prior to parturition, as the weight of the enlarged uterus puts pressure on the intestines and the bladder (Hartsock and Barczewski, 1997). For growing pigs (housed indoors with access to outdoor runs) with a mean weight of 45 kg and 70 kg at the start and end of the experiment, respectively, Guo *et al.* (2015) on average observed 17.9 eliminations pig^{-1} day^{-1}. Aarnink *et al.* (1996) observed indoor housed growing pigs from a mean weight of 26 and 112 kg at the start and end of the experiment and found a considerably lower number of eliminations with on average 4.3 urinations and 4.2 defecations pig^{-1} day^{-1}, respectively. The authors found no difference in the number of urinations and defecations between female and male growing pigs.

Effect of resources

As stated previously, moving the huts, feed and water in outdoor free-range system have shown to lead to a more uniform distribution of nutrients, indicating that pigs change their elimination behaviour according to the location of these resources.

Pigs roaming a semi-natural area primarily defecated uphill at least five meter from the nest and no further away than 15 m when leaving the nest in the morning (Stolba and Wood-Gush, 1989). Similar findings were obtained in the study of outdoor growing pigs with zones of grass, willow and *Miscanthus* by Horsted *et al.* (2012) where on average only 2% of eliminations were performed in the zone with the hut. Organic growing pigs in a mobile housing system with access to grazing areas defecated 1-15 m away from the hut (Salomon *et al.*, 2007). This was closer to the hut compared to the pigs in the semi-natural area in the study by Stolba and Wood-Gush (1989) but may be a reflection of the more confined housing conditions in the former. Another suggestion may be that the pigs perceived the hut with straw as a clear defined boundary from the pasture area. Salomon *et al.* (2007) reported that in none of the mobile pens the pigs defecated close to the feed troughs, drinking water and wallow. Also, in the study by Watson *et al.* (2003), pregnant outdoor sows did not urinate and defecate near the hut, feeding area and water trough. The pigs did receive supplemental feed once a day in the study by Stolba and Wood-Gush (1989) but the location was not defined. Thus, it was not possible to state how close to the feeding area the pigs defecated. In the study by Horsted *et al.* (2012) approximately 10% of the observed eliminations were performed in the zone with feed, water and wallow. However, it was not reported how close to resources eliminations were performed.

In their observations of growing pigs given 50 m^2 of new pasture each morning, where pigs were also fed, Stern and Andresen (2003) found that 41% of urinations and 50% of defecations were performed in this area. The results indicate that access to new land may be a way to distribute nutrients more evenly. However, it was somehow unexpected that the pigs eliminated in the same area as they were fed. In the study by Horsted *et al.* (2012) where pigs had access to zones with willow and *Mischantus*, on average 49% of eliminations were performed in the zone with willow situated closest to the feeding area. In comparison, the zones with grass received about 2% of eliminations. In the study by Stolba and Wood-Gush (1989), during daytime away from the hut, the pigs defecated in wide paths, running though bushes with gorse. The results from these two studies indicate that tall vegetation stimulates the pigs to perform eliminations. In the case of the latter study, another explanation could simply be that the pigs were active at that time and eliminated while transporting themselves from one area to another. The willow zone in the former study was situated between the hut and the feeding area. Thus, the pigs had to pass the willow zone going from the hut towards the feeding area. This may be part of the explanation as to why the pigs primarily eliminated in the willow zone. Similar findings were reported by Salomon *et al.* (2007) and Benfalk *et al.* (2005) (similar study). Areas covered with manure in the mobile system extended towards the feeding area as the pigs urinated and defecated on their way from the hut to the feeding area.

In the study by Watson *et al.* (2003), a larger amount of eliminations compared to expected was performed along the fence of the paddock. As one of the explanations for this elimination pattern, the authors suggested relation to territoriality. According to Graves (1984), wild boars make use of e.g. marking in interactions with other pigs. However, the author also stated that the home range of feral pigs was not defended as a territory. Also, Stolba and Wood-Gush (1989) suggested that domesticated pigs showed marking behaviour by smelling the trunk of a tree followed by stroking with the occipital region of the head. In studies of wild boar and feral pigs, most often, the term home range is used. From the available literature, it seems as if pigs will fight for access to resources such as feed and water (Wood-Gush *et al.*, 1990) and to some extent also wallowing (Bracke, 2011), rather than defend a territory.

In summary, wild boars and feral pigs prefer to reside in and near forest and dense vegetation and they seem to adapt their daily rhythm according to habitat and food availability, climatic conditions and predators. Studies of outdoor domestic pigs suggest that in terms of foraging, there is a peak activity in the morning and late afternoon or at sunset. Foraging is part of pigs' explorative behaviour and as pigs get information about the feed resources in the environment they are highly motivated to perform the behaviour and use a large amount of the day exploring. Foraging is affected by internal and external factors and studies indicate that foraging is stimulated by the type and amount of feed items available below the soil surface (rooting). Also, management incentives such as strip grazing and protein restriction have shown to increase foraging.

Under natural conditions, a few days prior to farrowing the sow will leave the group and build a nest. The location of the nest and the amount and type of material used seem to be affected primarily by the climatic conditions and the protection offered by the environment. Nests are also built by both genders for resting purposes. Typically, nests built by wild boars and feral pigs have some kind of protection from branches hanging down or from a dense understorey.

Pigs seek shade at increased temperatures but will use the wallow for thermoregulation at temperatures of approximately 17-21°C. Besides wallowing for cooling down body temperature, pigs will wallow to protect the body from sunburn and to control ecto-parasites. This may be the reason why wallowing is seen throughout all seasons. Possibly wallowing is rewarding in itself stating the importance for animal welfare. Pigs also seek shelter from the outdoor climatic elements, in particular the combination of cold, windy and wet weather.

Studies show that pigs distribute their eliminations non-randomly. Already a few days after birth piglets move away from the nest to eliminate. Studies in outdoor pigs suggest that the behaviour is innate rather than learned. In outdoor systems, moving the hut, feeding place and water have shown to result in a more uniform distribution of nutrients, suggesting that pigs perform eliminations according to the location of resources and prefer not to eliminate in the near vicinity of the resources. Also, in studies of outdoor pigs, the area between the hut and the feeding place is primarily used for eliminations. This indicates that is it possible to some extent to manipulate the behaviour in particular by the location and distribution of resources in the paddock.

4. Nutrient management

Currently, in Danish organic pig production, the breeding material is the same as in conventional production. These sows are highly prolific and therefore need significant amounts of concentrate feed during lactation, which demands optimization of feed production at farm level. Minimizing N losses is of major importance as this is one of the challenges in organic pig production. Increasing crop yields means an increased self-sufficiency with fodder and a reduced import of nutrients into the farming system, thereby potentially decreasing the risk of nutrient losses.

The organic Principle of Health states that the use of food additives should be avoided as this may have adverse effects on health (IFOAM, n.d.). Thus, it is not allowed to supply concentrate feed with artificial amino acids (Anonymous, 2017a). This is a challenge in organic pig production as it is difficult to optimize feed rations in terms of the limiting essential amino acids e.g. lysine and threonine with cost-efficient organic feedstuffs. In order to supply sufficient amounts of essential amino acids, typically, rations contain excess CP compared to the needs of the animals.

As stated previously, organic pigs are outdoors all year round or indoors with access to outdoor areas and have more space to roam. Thus, the climatic conditions are much less controlled compared to conventional indoor production (Edwards, 2003). However, organic pigs are fed according to norms for conventional pigs. In Northern Europe, a rule of thumb has been to feed 10-15% extra compared to conventional norms to make up for the energy used for thermoregulation and exercise (Edwards, 2003). The challenge is that the energy requirements of organic pigs are not yet known and are met by feeding increased amounts of concentrates, leading to an overload of protein even though the animals are only in need of extra energy. The excess N not utilized by the animal is excreted to the environment, primarily in the urine but also in faeces. The N in urea from the urine is quickly hydrolysed to ammonia, due to the enzyme urease present in most soils (Sommer *et al.*, 2004).

The N load in the system depends on the stocking density in paddocks. According to legislation, a maximum stocking density of 2.8 AU ha^{-1} (280 kg N ha^{-1}) is permitted every second year if the area is kept free from pigs the following 12 months and a N demanding crops is sown (Poulsen, 2014). This relatively high stocking density along with the non-random elimination behaviour of pigs creates nutrient hotspots with an increased risk of N losses from the paddocks, in particular during seasons (autumn, winter) with high precipitation and insignificant nutrient uptake by the grass.

4.1 Nitrogen flows in a paddock system with animal manure

The paddocks with pigs can be considered a system at field level from where N flows in and out through biological processes (Figure 4.1). Apart from the sources of N going into the system through e.g. feed as well as the N sources going out of the system via weaned piglets, various biological and chemical reactions between the system and the surroundings as well as within the system (internal N flows) contribute to the N cycling of the system (Whalen and Sampedro, 2010). In turn, together with the farming practices, these interactions and processes reveal potential risk areas of N losses.

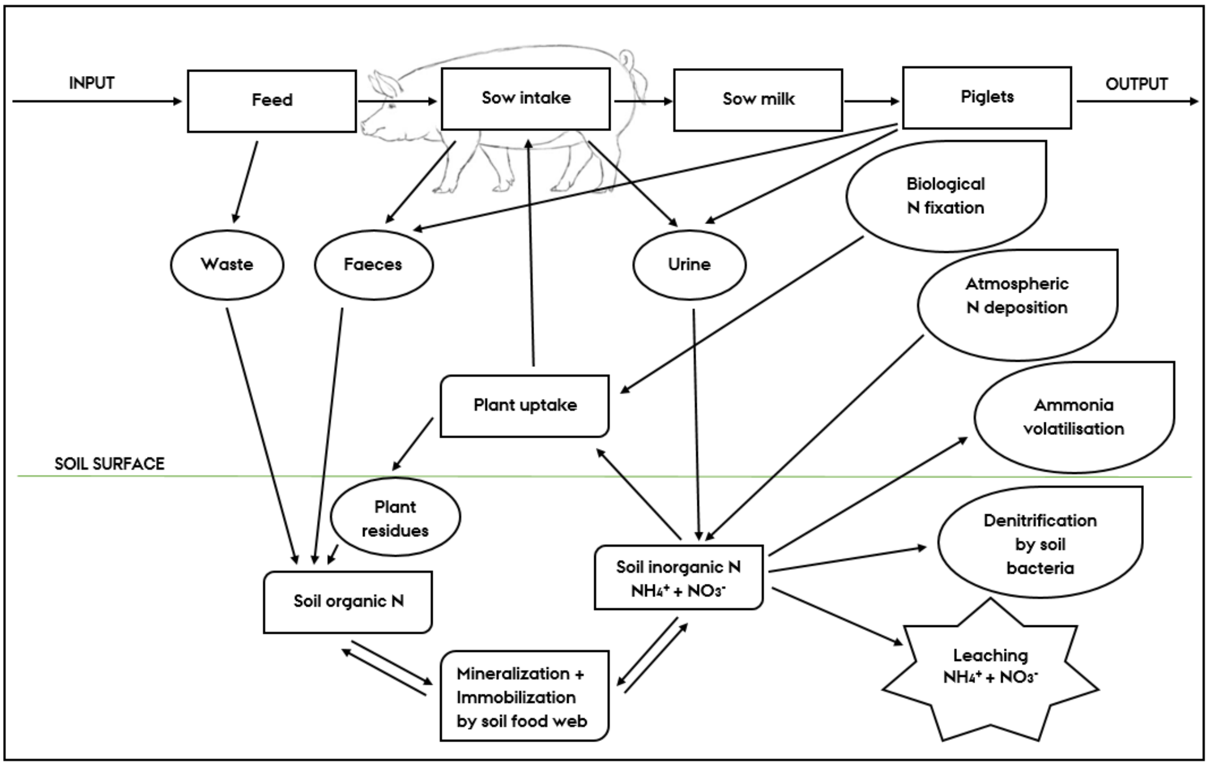


Figure 4.1. Nitrogen input and output and flows in a pasture based paddock system with lactating sows. Modified after Worthington and Danks (1992). The grass-clover fields are harvested (removal of N) for silage prior to insertion of sows in paddock. Also, there is an input from purchased straw although minor compared to N in purchased feed.

The below description of N sources and flows related to Figure 4.1 is based on Whalen and Sampedro (2010) unless stated otherwise.

Nitrogen input and output

Primarily, N entering the pasture system comes from the CP in purchased concentrate feed. In addition, there are contributions of N from straw (purchased or produced on the farm) for the farrowing huts and a minor contribution from seeds (grass and clover). Part of the N in feed is converted into protein in the production of milk, serving as feed for the piglets, which are weaned after seven weeks and then leave the paddock system and part of the N is used for sow maintenance. The rest is deposited as urine and manure and together with wasted concentrate feed built into the soil organic N pool.

Atmospheric deposition

Atmospheric N is deposited into the system as wet deposition (deposited with rain) and dry deposition (the direct deposition of particles and gasses). Ammonium (NH_4^+) is transported in acid cloud droplets and then deposited as wet or dry deposition. Also, ammonia (NH_3) is transported and deposited but closer to the source compared to ammonium (NH_4^+) (Sommer *et al.*, 2004).

Nitrogen fixation

The N cycle includes the important gaseous component dinitrogen (N_2) that makes up approximately 79% of atmospheric air. However, N is only available to plants if N fixating organisms convert dinitrogen to a form available for plant uptake. This process is taking place primarily through symbiosis of leguminous plants (e.g. clover) with *Rhizobium* bacteria located in root nodules. A minor contribution comes from fixation of N through *Azotobacter* bacteria. The level of N fixation depends on N availability in the soil in addition to the presence of any other species competing for soil N.

Urine and faeces

In addition to intake of concentrates, sows are grazing. Some of the N from the plant material, as well as N from the concentrate feed, is deposited as urine and faeces directly on the ground. Nitrogen in faeces enters the soil organic N pool through the soil microorganisms and is not ready for uptake until the processes of mobilisation and mineralisation have taken place. Primarily, urine contains urea and the amount depends on the CP concentration in the feed. Urea is relatively quickly hydrolysed to ammonia (NH_3) through urease, an enzyme readily available in the soil. Ammonia is a gas and therefore undergoes volatilisation, which is then lost from the system. Also, ammonia reacts with hydrogen and is converted to ammonium that potentially can be taken up by plants or leached.

Mobilisation/Mineralisation

On a continuous basis, there is a decay of plant material from the grass-clover vegetation (leaves, and roots), which is built into the soil organic matter N pool. The soil food web (soil organisms, including bacteria) breaks down the organic matter. After mobilisation and depolymerisation (breakdown into proteins and amino acids), N is eventually mineralised into the inorganic form ammonium (NH_4^+). Part of the ammonium is lost through volatilisation (NH_3). However, as the nitrification process is rapid (conversion of ammonium-N into nitrate-N (NO_3^-) through an intermediate product nitrite (NO_2^-)), the ammonium concentration in the soil is relatively low. Ammonium and nitrate are both readily available for uptake by plants and soil organisms (assimilation).

The main environmental factors affecting the mineralisation process are soil moisture, (between 50-80% of field capacity is considered optimal) temperature (between 25-35°C is optimal for the activity of microorganisms) and pH (pH values between 6.5-8.0 are most optimal for bacteria and pH values between 5.5-6.5 are most optimal for fungi). In natural ecosystems, soil inorganic N pools are typically less than 1 mg N kg^{-1} soil and in fertilized agricultural soils less than 100 mg N kg^{-1} soil.

Dinitrification

Nitrate enters the soil water solution and the majority is probably taken up by plants and by the soil food web (assimilated). In addition, some nitrate undergoes denitrification by soil denitrifying microorganisms and thus, is converted into nitrous oxide (N_2O) (potent GHG) and the vast majority is then converted to dinitrogen (N_2) under anaerobic conditions. Also, dinitrogen is produced during the nitrification process where ammonium is converted to nitrate by nitrifying soil bacteria. After rainfall or irrigation when the soil becomes waterlogged and anaerobic conditions prevail, the process of denitrification is the most important under grasslands and forests. The nitrification process is speeded up at increased soil temperatures in combination with water saturation.

Nitrogen leaching

Leaching is a process where N is transported down the soil profile, below the root zone and lost to the surroundings with excess water. Predominantly, N leaching is influenced by crop type and local factors such as soil type, initial N content in the soil, N application and climate, primarily time and amount of rainfall. It is important to stress that in a temperate climate there is a seasonal leaching as plants do not absorb nutrients during winter where growth is impaired due to low temperatures. Also, in Northern Europe, precipitation is high during autumn and winter contributing to an increased leaching. Ammonium (NH_4^+) and nitrate (NO_3^-) are water soluble and can be lost through leaching. As nitrate is an anion it is easily leached compared to ammonium, which is a cation. The surface of clay minerals and humus is negatively loaded and therefore cations such as ammonium adhere to the surface whereas nitrate does not and is therefore much more mobile in the soil.

In Denmark, sandy soils cover approximately 50% of the agricultural area, and often sandy soils are preferred for free-range pig production (Eriksen *et al.*, 2006a; Eriksen *et al.*, 2006b), supposedly due to less mud problems caused by traffic with machines and pigs (Jørgensen *et al.*, 2018) and the reduced water holding capacity compared to clayey soils (Watson *et al.*, 2003; Tahir and Marschner, 2017). The combination of high rainfall during autumn and winter and coarse soils such as sandy soils may lead to a relatively high proportion of N being leached (Eriksen and Kristensen, 2001).

4.2 Nitrogen balances in systems with outdoor free-range pigs

The N balance method is used to account for the N flow within a system. It relies on the principle that N can always be accounted for in the system, as there is always a “balance” between input and output. The calculations imply quantification of N input and output. The difference between these two (N input – N output) represents the N surplus or N balance and is considered to be the amount not utilised within the system: the losses to the atmosphere (e.g. N2O, NH3), soil N changes and potential N leached.

Nitrogen balances can be calculated at farm, field and herd level and for each system the balance is defined as the difference between the inputs to the system and the outputs (Knudsen *et al.*, 2006). At farm level, the N balance for a livestock system is based on inputs such as feed, manure, straw, seed, N deposition, N fixation minus the output such as live animals and culled animals. The N leaching from the system can be estimated by calculating the atmospheric emissions and the soil N changes and deducting these from the balance. At field level, the balance is based on the inputs to the field such as manure, seed, N deposition and N fixation minus the output such as crops. Emissions are calculated from the crop residues and if there are livestock in fields, from the emissions from deposited manure. At herd level the N balance is inputs such as feed, forage and straw (purchased or from the fields) minus the output such as manure (to the fields) and the losses are emissions from stable and storage (Figure 4.2).

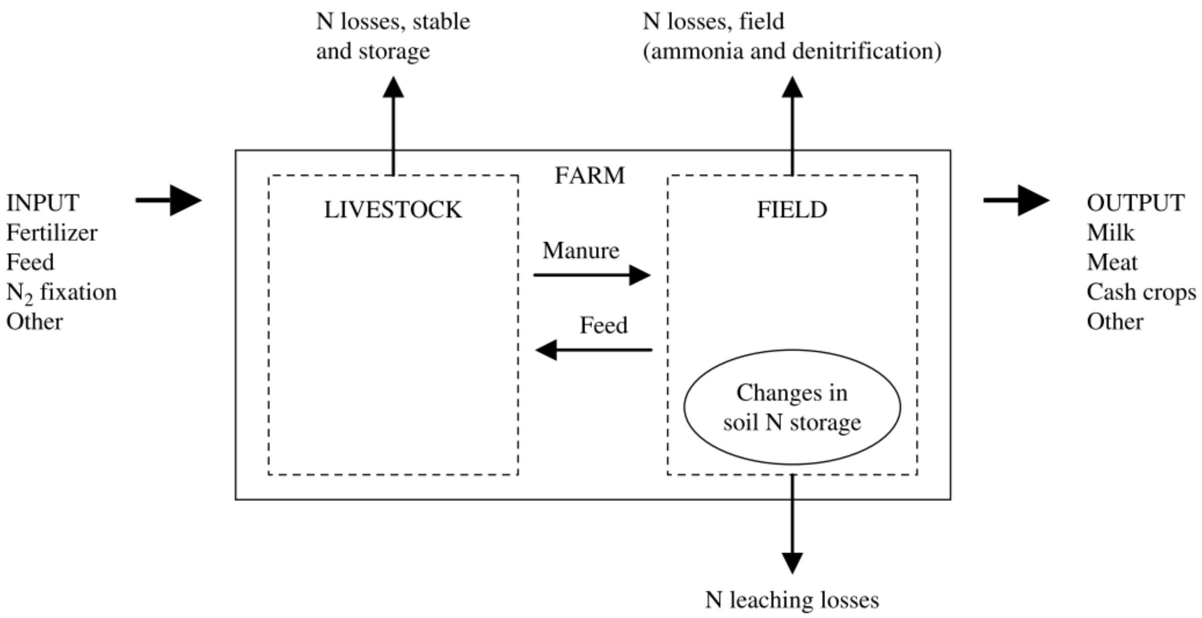


Figure 4.2. The main N flows used in the nitrogen balance, from Knudsen *et al.* (2006).

High field N surpluses have been reported in studies related to free-range and organic pig production. Estimated surpluses ranged from 500 to 608 kg N ha^{-1} in fields with lactating sows (Worthington and Danks, 1992; Eriksen and Kristensen, 2001; Eriksen *et al.*, 2002; Eriksen *et al.*, 2006b), from 186 to 195 in fields with pregnant sows (Eriksen *et al.*, 2006b), and from 265 to 576 kg N ha^{-1} in fields with dry sows (Williams *et al.*, 2000), depending on stocking density. For comparison, in the arable control field estimated N surplus was 27 kg N ha^{-1}.

Estimated N surpluses in studies with growing-finishing pigs fed *ad libitum* up to 80 kg were 507 kg N ha^{-1} in the study by Eriksen *et al.* (2006a). With restricted feeding, the N surplus was 388 kg N ha^{-1}, indicating the effect of reducing feed level. In a recent study with growing pigs in paddocks with stripes of willows, *Miscanthus* and poplar trees, the estimated N surpluses were 626 and 185 kg N at high (117 m^2 pig^{-1}) and low (367 m^2 pig^{-1}) stocking density, respectively (Jørgensen *et al.*, 2018), stating the effect stocking density has on the potential risk of leaching.

Soil nitrogen load and distribution

As mentioned previously, pigs' non-random elimination behaviour creates N 'hotspots', which have been identified in several studies where soil sampling and subsequent measurements of soil mineral N in paddocks with sows have been included (Eriksen and Kristensen, 2001; Eriksen *et al.*, 2002; Watson *et al.*, 2003; Eriksen *et al.*, 2006b). In the study by Watson *et al.* (2003), pregnant sows' preferred areas for urinations and defecations showed soil nitrate and ammonium levels of 204 ± 60 kg N ha^{-1} and 56 ± 21 kg N ha^{-1}, respectively (animal density of 35 sows ha^{-1} ~290 m^2 sow^{-1}). On the contrary, N levels in less preferred areas were much reduced with 80 ± 23 kg nitrate ha^{-1} and 13 ± 0.5 kg ammonium ha^{-1}.

In paddocks with lactating sows, the level of soil mineral N prior to insertion of sows (spring) has been measured to range from 0.7 to 21.3 mg N kg^{-1} soil (soil depth 0-20 cm) (Eriksen and Kristensen, 2001), corresponding to 4.9-149 kg N ha^{-1}. After six months with sows (in October), levels had increased significantly with on average 43 mg N kg^{-1} soil corresponding to 305 kg N ha^{-1} (recalculations from mg N kg^{-1} soil to kg N ha^{-1} were performed according to Rubæk and Sørensen (2011)). Some point values were very high with 162 mg N kg^{-1} soil (1134 kg N ha^{-1}). The highest levels were found closest to the feeding area. In the following spring (March), the mean level of ammonium and nitrate were 6.4 mg N kg^{-1} soil (45 kg N ha^{-1}), indicating a significant loss of nutrients throughout the winter period.

Nitrogen leaching

In terms of N leaching, Williams *et al.* (2005) measured 137 kg N ha^{-1} during winter after one year of stocking in a system with pregnant sows on established grass (12 sows ha^{-1} or 830 m^2 sow^{-1}). In comparison, leaching in the arable control was much less with 38 kg N ha^{-1}. The study showed the effect of stocking density and vegetation cover, as nitrate leaching was also measured in paddocks with 25 sows ha^{-1} on stubble and in paddocks with 18 sows ha^{-1} on stubble undersown with grass. Nitrate leaching in these two systems were somewhat higher with 235 and 198 kg N ha^{-1}, respectively, compared to the best practice system with sows on established grass. Losses of nitrate through leaching corresponded to 41-52% of the estimated N surplus. In a study with lactating sows (32 sows ha^{-1}), N leaching was considerably higher with on average 320 kg N ha^{-1} over the 18 months measuring period (Eriksen *et al*., 2002) and with 500 kg N ha^{-1} 10 m from the feeding area. During the period of grazing, N leaching was 25-30 kg N ha^{-1} but considerably higher during autumn and winter. In comparison, leaching outside paddocks was 100 kg N ha^{-1} as a mean across the measuring period.

Figures on N balances and measured N losses evident from various experimental studies of free-range and organic pig production are relatively high. However, they differ both within and across studies in terms of stocking density and season, indicating the possible effects management incentives (reduced stocking density and seasonal production) may have reducing N losses from the system. Also, meeting the specific energy requirements of organic pigs without increasing the amount of CP in the feed ration thus, composing it of optimal organic feedstuffs regarding essential amino acids, will improve the systems' environmental performance.

5. Agroforestry

The practice of agroforestry is one of the oldest and most widely used across the world. Until at least the Middle Ages it was general custom in Europe to clear abandon forest, then burn the slash and afterwards grow crops in the cleared areas and sow or plant trees prior to, along with or after crop cultivation (Nair, 1993). During the 19th and 20th century, traditional agroforestry practices declined in Europe, some of the predominant reasons being introduction of artificial fertilisers in most parts of Europe and intensification of agriculture with a focus on specialisation and monoculture. Also, field sizes became larger in the process of merging smaller farms into larger units whereby field boundary trees and individual trees within fields were removed. (Eichhorn *et al.*, 2006; Nerlich *et al.*, 2013).

5.1 The concept of agroforestry

Agroforestry is an integrated way of farming where humans deliberately combine agricultural elements such as crops and or livestock with trees and or other types of woody vegetation (Mosquera-Losada *et al.*, 2009). Integration of agriculture and forestry has been practiced for centuries but it was not until the seventies and early eighties that the term agroforestry was coined (Smith *et al.*, 2013). A scientific and commonly accepted definition of agroforestry was put forward in the early 1980´ties by Lundgren and Raintree (1983):

'Agroforestry is a collective name for land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately used on the same land management unit as agricultural crops and/or animals, either on the same form of spatial arrangement or temporal sequence. In agroforestry systems there are both ecological and economical interactions between the different components'.

The approach to agroforestry is multifunctional and the central hypothesis is that through resource complementarity (the trees acquire water, light and nutrients that the crops or animals would otherwise not use), there is an increase in productivity compared to cropping the components in monoculture (Cannell *et al.*, 1996). Complementarity also includes the capability of trees to produce environmental benefits, ecosystem services and products.

According to Nair (1993), agroforestry systems can be classified according to four major criteria based on the type of system components, the function of the system, ecology and socio-economics.

With regards to the 'Type of system components' classification:

- Crops integrated with trees (including shrubs/trees and trees) are referred to as *silvo-arable systems* or *agri-silvi-culture*,

- Integration of trees with livestock as *silvo-pastoral* systems,
- Trees integrated with both crops and livestock/pasture as *agro-silvo-pastoral* systems
- 'Others' refers to e.g. aquaculture farming with trees.

Environmental benefits and ecosystem services provided by agroforestry systems include e.g. reduced nutrient runoff, C sequestration (above and below ground), biodiversity conservation (e.g. wildlife habitats and species, connection of habitats by corridors), pollination and seed dispersal, enhanced soil fertility (e.g. N fixation, recycling of nutrients, increased organic matter), erosion control, water recharge, modification of the microclimate (temperature, humidity, wind speed) clean water and air (Jose, 2009; Broom *et al.*, 2013; Smith *et al.*, 2013; Dollinger and Jose, 2018). In addition, agroforestry landscapes add to the recreational and aesthetic values in addition to providing cultural protection (Jose, 2009; Smith *et al.*, 2012). Furthermore, agroforestry supplies products such as timber, biomass, livestock, fodder and forage for livestock, fibre, fruits, nuts, mushrooms and herbal medicine (Smith *et al.*, 2012; Wilson and Lovell, 2016). The products can be divided on the basis of providing revenue on a short, medium and long term basis, respectively. Also, environmental benefits and services provided by agroforestry occur across a range of spatial scales such as the farm (local), regional and global scale as described by Jose (2009).

The combination of trees with forage and livestock production can be referred to as *silvo-pasture* or *silvo-pastoral* systems. In Europe, silvo-pastoral systems have been one of the main agroforestry practices used in past and present time (Mosquera-Losada *et al.*, 2005). In North-Western Germany, Britain and Denmark, silvo-pasture was introduced around 6.000 years ago (Bergmeier *et al.*, 2010). Silvo-pasture can include forest grazing, woodland grazing and grazing in areas with open forest trees. In the latter, the density of trees is low and grazing animals would be livestock or wild animals. In the two former systems, the focus is on the forestry and the density of trees is high or the system is natural forests (Mosquera-Losada *et al.*, 2009). Additionally, grazed orchards (sheep, hens, cows) and systems with woodland chickens (den Herder *et al.*, 2017).

5.2 Systems integrating pigs and trees in a temperate climate

In Europe, there is a long tradition for mast-feeding or pannage, which is an agroforestry practice where pigs forage on acorn and beech mast in oak (*Quercus sp.*) and beech (*Fagus sylvatica*) woodlands as well as fallen fruit in orchards in autumn (Smith, 2010). During the Middle ages and until modern times, in various parts of Europe, mast-feeding was economically viable for farmers and a way to fatten their pigs on common land (Luick, 2009; Wealleans, 2013). In the UK, the practice to turn pigs out into woodland dates back to Roman times (Hislop and Claridge, 2000). In Southern Germany, the income for rural people to a high degree depended on giving out rights for grazing of pigs in common woods (Luick, 2009). During the 16th to 18th centuries, in Denmark, mast feeding of pigs from oak and beech (oldensvin) was common with relatively large flocks of pigs (Bruun and Fritzboger, 2002). Also, trees situated in pastures and fallow fields, were used for mast. Pigs were transported over long distances to arrive to the larger forest areas. (Bruun and Fritzboger, 2002). Today, pannage is almost non-existing in Northern Europe. Although, in the New Forest National park in the United Kingdom, up to 600 pigs for a minimum of 60 days during autumn forage on acorns, beech mast and chestnuts (Rodriguez-Estevez *et al.*, 2009).

Via the LUCAS database, den Herder *et al.* (2017) mapped and quantified the current distribution of agroforestry, including livestock agroforestry, in the European Union (Eurostat, 2015). A total of 15.4 million ha are used for agroforestry corresponding to 8.8% of the utilized agricultural area and 3.6% of the total territorial area. Silvo-pasture or livestock agroforestry is the most prominent of agroforestry practices comprising 15.1 million ha corresponding to 3.5% of the total territorial area (Figure 5.1). In absolute terms, the largest extend of livestock agroforestry can be found in Spain (5.5 million ha), Greece (1.6 million ha), France (1.6 million ha), Italy (1.3 million ha) and Portugal (1.1 million ha).

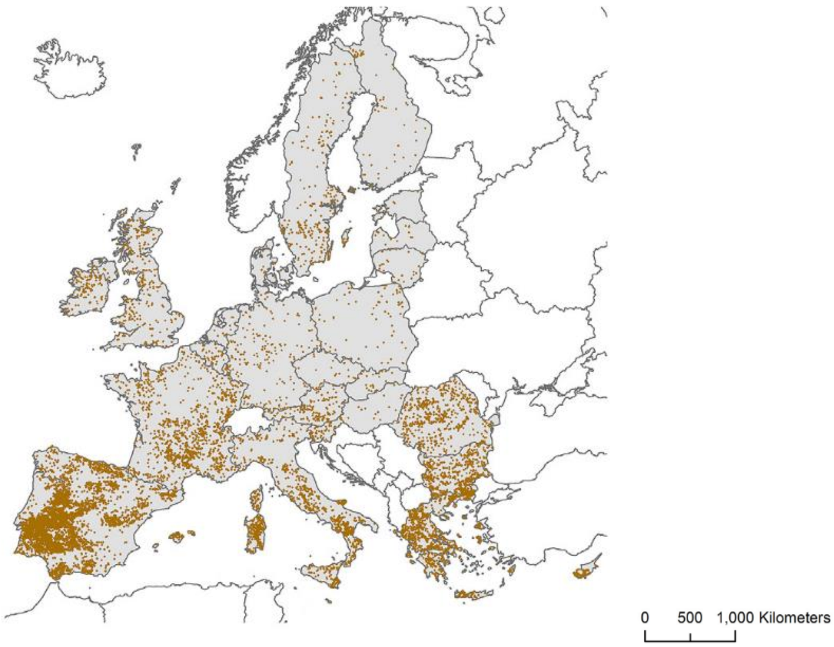


Figure 5.1. Distribution of livestock agroforestry across Europe based on the LUCAS database (Eurostat, 2015), modified after den Herder *et al.* (2017).

Currently, the Dehesa (Figure 5.2) is the largest surviving mast feeding system in the world (Wealleans, 2013) and one of the most predominant agroforestry systems in Europe (Moreno and Pulido, 2009). The Spanish Dehesa or the Portuguese Montado is a traditional but updated Mediterranean agro-silvo-pastoral system that originated from the clearing of evergreen woodlands and there is evidence of their existence 6000 years ago (Rodriguez-Estevez *et al.*, 2009). The Dehesa is an open woodland with a tree density of 20-50 trees ha^{-1} (Rodríguez-Estévez *et al.*, 2012). It is well suited for extensive livestock grazing as the land is shallow (rarely > 50 cm) and has stony and poor, usually acid, soils (Moreno and Cáceres, 2015; Moreno and Pulido, 2009). Regional robust livestock breeds in particular Iberian pigs but also sheep, goats, cattle and horses are integrated with oak woodlands (cork oak (*Quercus suber L*) and/or holm evergreen oak (*Quercus rotundifolia L*)), the latter being the dominant species in the Dehesa (Kaonga, 2012). In comparison to the Dehesa, the main tree species in the Portuguese Montado is cork oak (*Quercus suber L*). All year round, livestock benefits from the shade effect of scattered oak canopies (Joffre *et al.*, 1999).

Figure 5.2. The Spanish 'Dehesa': Iberian pigs integrated with oak woodlands. Photo: Malene Jakobsen.

The Dehesa and Montado are primarily known for the production of fine Iberian ham from the Iberian pig foraging on acorns during the montenera or pannage season from October until February at a stocking density of 0.4-0.6 livestock units ha^{-1} (Olea and San Miguel-Ayanz, 2006). Pigs are turned out onto the Dehesa or Montado at approximately 8-12 months of age where they weigh around 60-80 kg. They feed on acorns and graze without any supplemental feed. All pigs are snout-ringed in order to prevent rooting behaviour. At 140-160 kg they are slaughtered. Depending on the time of birth the pig will experience one or maybe two mast periods. After weaning and prior to being turned out onto the Dehesa, pigs are fed concentrate feed (Rodríguez-Estévez *et al.*, 2012).

In addition to animal products, cork, firewood and charcoal are being produced (Smith, 2010). Furthermore, the system has cultural value, is rich in biodiversity and home to endangered species such as the Iberian lynx (*Lynx pardina*), imperial eagle (*Aquila adalberti*), and black vulture (*Aegipius monachus*), (Kaonga, 2012). Today, legislation has made it possible to intensify the production by increasing the stocking density and by clearing trees without replacement, hence, making the Dehesa susceptible to degradation (Moreno and Pulido, 2009; Rodríguez-Estévez *et al.*, 2012).

5.3 Agroforestry and potential animal benefits

Protection from wind
Dense windbreaks are important for protection of livestock against wind (Isebrands and Richardson, 2014), particularly in combination with low temperatures, creating a chilling effect. Positive effects of windbreaks on animal health and welfare as well as production parameters have been validated primarily in large land areas with extreme temperatures such as the northern Great Plains of the U.S, the Canadian Prairie, and southern Australia (Brandle *et al.*, 2004). Producers from these areas report an increase in survival of new-born lambs and calves as well as a reduction in feed costs.

In landscapes that are predominantly flat and open such as in Denmark, windbreaks are suggested to contribute to an improved microclimate in pig paddocks during autumn and winter when relatively low temperatures and strong winds prevail. At times with windy weather, the difference in temperature between sheltered and unsheltered areas may be as large as 15°C (McArthur, 1991). If pigs are supplying their daily energy and nutrient intake by foraging in the range area, windbreaks may be important as pigs have been reported to prefer to stay inside huts on windy days (Kongsted *et al.*, 2013). Air temperatures around medium dense windbreaks will be several degrees warmer than temperatures in the open (Brandle *et al.*, 2004), which may be positive for animal welfare during cold periods but have negative effects during periods of increased temperatures. Also, windbreaks affect the distribution of snow, which is suggested to have positive effects on piglet survival.

In temperate regions, poplars and willows are typically planted as shelterbelts and hedgerows (windbreaks) (Isebrands and Richardson, 2014). Shelterbelts are rows of trees planted around the farm and fields and typically they are planted and cut in order for the branches to interweave whereby walls are created (Mosquera-Losada *et al.*, 2009). The aim is to alter wind flow as well as microclimate around fields and to protect animals and crops from wind and drifting snow. Coppice practices can be used to create different structures in tree rows e.g. a dense multi-stemmed windbreak or widely spaced porous windbreaks. During winter, poplars have an increased wind porosity compared to summer, with a reduction of more than

70% in wind when trees are foliated compared to 25% when trees are defoliated (Isebrands and Richardson, 2014).

Shade

The shaded area below the tree canopy is suggested to provide an area for pigs to thermoregulate at intermediate temperatures as trees have a cooling effect by heat absorption from the leaves. In a recent Danish study it was found that during summer, pregnant and lactating sows situated in a tree area in individual paddocks had lower respiration rate (30 breaths per 60 seconds) than sows situated within the farrowing hut (46 breaths per 60 seconds) (Jakobsen *et al.*, 2017).

Another potential animal welfare challenge related to increased temperatures is sunburn. A Danish pilot study performed in lactating sows suggested a high incidence of sunburn, in particular severe sunburns on the ears (peeled skin and wounds) (Jakobsen *et al.*, 2017). Tree canopies offer pigs protection against the sun and according to Isebrands and Richardson (2014), windbreaks that are tall and more spread out are preferable for generating shade during summer.

Diversified micro environment

Paddocks with pasture are very much in contrast to the preferred habitat of wild and feral pigs, who prefer areas adjacent to dense forest and areas with scrubs. Also, as stated previously, pigs spend a relatively large amount of time during the day exploring their surroundings. Thus, introducing trees into paddocks with pasture is suggested to provide the pigs with a more enriched and heterogeneously environment and thereby provide the opportunity and stimuli to perform natural behaviour (Brownlow, 1994; Brownlow *et al.*, 2005). However, in the study of Horsted *et al. (*2012) with growing pigs in paddocks with zones of willow, *Miscanthus* and grass, pigs rested more than half of the day and activities such as rooting, grazing and manipulating willow and *Miscanthus* together accounted for only 24.4% of all recorded behaviours. Only 4.7% of the observational time, pigs were recorded to manipulate willows and *Miscanthus*. This is somewhat less compared to the amount of grazing and rooting of pigs in a semi-natural environment reported by Stolba and Woodgush (1989), which constituted 52% of all the recorded behaviours. Also, foraging activity was reduced compared to the study of Iberian pigs foraging on acorns and grazing, which accounted for 71 and 61% of observations time for year one and two, respectively. Although, the stocking density was higher in the study by Horsted *et al.* (2012) compared to the other studies and the Iberian pigs did not receive any supplemental feed.

Skin care

Grooming is a comfort behaviour and as the pig is not able to reach all of its body parts it is depending on external elements to rub and scratch body parts against. According to Bracke (2011), scratching or rubbing the body is the most frequent reported behaviour performed after wallowing. For pigs in semi-natural or natural environments, trees (Stegeman, 1938; Stolba and Woodgush, 1989; Van Putten, 2000), bushes (Van Putten, 2000) posts (Rose and Williams, 1983) and rocks (Van Putten, 2000) are used for scratching and rubbing. In paddocks consisting of pasture only, the hut is the only object, which can be used for scratching and rubbing. The corners of the hut may be the best possibility as the front, back and sides are normally smooth surfaces. Trees are suggested to be suitable objects for grooming, in particular as the surface of the tree trunk is relatively rough compared to the hut and therefore more easily offers the pig relief.

Watercolour painting by Birte Mølgaard

5.4 Energy crops - characteristics and potential environmental benefits

Energy crops, short rotation coppice or short rotation woody crops are fast-growing tree species cultivated to produce high yields of biomass for production of energy. Coppice refers to the ability of some tree species to regrow after being cut down. Perennial energy crops include species such as alder, ash, southern beech, birch, eucalyptus, poplars, willows, paulownia, paper mulberry, Australian blackwood and sycamore (Dimitriou and Rutz, 2015). In Europe, poplars and willows (members of the *Salicaceae* family) are typically used and therefore the focus is on these two species.

Characteristics

In temperate regions, poplars is one of the highest yielding tree species extensively cultivated in agricultural systems. Apart from fast growth and high yield, some of the positive characteristics of poplars are the adaptation to soil and climate, good rooting capacity, high ability for coppice and large genetic variation. Some of the less favourable characteristics are the high susceptibility to diseases as well as a high demand for light and water. However, in temperate regions during winter time with high precipitation and thus, high soil water percolation, paddock system with pigs can benefit from the high water use from willows as potential risk of N leaching is then reduced. Willows are from the genus *Salix*, derived from the Celtic *sallies* where *sal* means *near* and *lis* means *water*, which refers to the moisture requirement for seed germination rather than a high requirement for water after establishment (Dillen *et al.*, 2011).

Compared to annual agricultural crops e.g. wheat, perennials such as willows and poplars have a permanent and deep rooting system that can take up mineralised N (Jørgensen *et al.*, 2013) below the root zone of annual crops. In addition, perennials have higher evapotranspiration and as a consequence reduced drainage from the rooting zone, thus, contributing to a lower level of N mineralization (Pugesgaard *et al.*, 2015). According to the study by Crow and Houston (2004), root growth of poplars and willows is affected by factors such as plant variety, site conditions and coppice cycle. They found a root depth of up to 1.3 m and reported other studies finding root depths up to 3 m. Regular cutting appeared to slow the development of roots and poplars had more roots on well-drained sandy soils compared to willow.

Environment – nitrogen

From a study of poplar trees, it was reported that four years after establishment (with coppice in the third year), nitrate leaching was reduced from 13 to 1.5-8 kg N ha^{-1} $year^{-1}$. Within the four years, N losses were reduced with 80 and 40% with or without fertilization, respectively (Diaz-Pines *et al.*, 2017). During autumn, prior to defoliation, poplar trees accumulate large amounts of storage protein in the bark. This is kept as a reserve and is ready for use when the trees begins the growth cycle again during spring (Vancleve and Apel, 1993; Millard and Grelet, 2010). Within the first season of establishment, Cooke and Weih (2005) found that about 50% of the total N in the tree was deposited in the leaves. In mature poplars, more N was deposited in roots and stems that have a higher proportion of biomass compared to leaves.

During a three years growing period Pugesgaard *et al.* (2015) compared N leaching in willow (newly established and old = 12 years) with N leaching in grass-clover and winter wheat and found a similar level in willow (7 kg N ha^{-1} $year^{-1}$) and grass-clover (5 kg N ha^{-1} $year^{-1}$) and that was somewhat lower compared to winter wheat (37 kg N ha^{-1} $year^{-1}$), stating a positive effect of willow compared to annual crops. In young willow, during the first winter after establishment, N leaching was 53.9 kg N ha^{-1}, whereas after three growth periods, the leaching was reduced to 0.3 kg N ha^{-1}. The reduction in N leaching could be expected as the roots were much less developed during the first winter. For the old willow, there was a large variation between plots, which is normal in older plantations. Also, in the study by Jørgensen *et al.* (2005), N leaching was high (100 mg L^{-1} soil water) from willow grown on coarse sandy soil during the first year after establishment and thus, there was no positive effect of fertilisation within the first year. During the second year after establishment, nitrate levels in soil water dropped significantly to levels lower than 50 mg L^{-1}. In areas with willow, over a production period of 20 years, an estimated mean leaching of 10-30 kg N ha^{-1} $year^{-1}$ on sandy soils in Denmark is expected (Jørgensen, 2005). For clay soils, the expected reduction in N leaching by establishment of energy crops is 34 kg N ha^{-1} $year^{-1}$ and for sandy soils 51 kg N ha^{-1} $year^{-1}$ (Eriksen *et al.*, 2014).

Eco-system services

In terms of effects on soil properties, biodiversity, and C sequestration, poplars are less beneficial in comparison to set-aside land and permanent extensive grassland, whereas the opposite is the case when replacing arable crops with poplars (Dillen *et al.*, 2011). In the study by Diaz-Pines *et al.* (2017), soil organic C showed an accumulation rate of 0.4 Mg ha^{-1} $year^{-1}$ five years after establishment of poplars. In terms of biodiversity, according to Larsen *et al.* (2015), energy crops are in general favourable compared to annual agricultural crops. This is due to the fact that the rotation period of energy crops is longer compared to that of annual crops. Also, energy crops provide improved soil protection, increased variation in the landscape and there is less disturbance during the growth period. Reduced tillage and increased levels of organic material from dead leaves increase the species variety and amount of earthworms. In comparison to set-aside land, there is no difference in the species variety of small mammals, whereas the number of bird species is higher in areas with energy crops. However, when areas with energy crops are compared to deciduous forest, meadow and bogs, the species variety of small mammals is lower (Larsen *et al.*, 2015).

6. Own research

The overall aim of the thesis was to contribute to the development of alternative production and management strategies leading to a more nutrient-efficient organic pig production based on the animals' opportunities to perform species-specific and natural behaviour.

The overall objectives were to investigate:

1. Farm level environmental effects of improved foraging in the range area.
2. Environmental effects of introducing poplars into paddocks for lactating sows.
3. Potential animal benefits of introducing poplars into paddocks for lactating sows.

The thesis comprises four papers, which are linked to investigate the overall aim and objectives and to confirm or deny the issued hypotheses as presented in chapter 1.

Paper I was based on a modelling exercise in which key figures on organic pig production, empirical data from on farm studies, data from experimental studies as well as emission factors were brought together to set up scenarios for three organic pig production systems in terms of the technical and environmental performance at farm level. The methodological approach of **Paper II to IV** is very different from paper I, as these papers are relying on one large experiment performed at a private organic pig farm in Denmark. The experiment was conducted from May 2015 until March 2016 and included recording and collecting a wide range of data such as behavioural observations of sows, soil samples, soil water samples and visual estimation of faeces distribution and load, tree damages and vegetation cover.

6.1 Materials and methods: Foraging (modelling – Paper I)

The objective of paper I was to investigate the technical and environmental performance at farm level of outdoor free-range sows and growing pigs foraging in the range area compared to the current organic production system with sows on grass-clover pastures and growing pigs housed in stables with outdoor access.

The hypotheses:

- Improved foraging in the range area will reduce greenhouse gas emissions (GHG) compared to a system with sows and growing pigs foraging on grass-clover and compared to the current Danish organic practice with sows on pasture and growing pigs in stables
- Organic production systems with growing pigs in an improved forage crop system will reduce nitrate leaching at farm level compared to a system with growing pigs foraging on grass-clover and improve overall farm environmental performance also compared to the current practice.

Firstly, the technical performance of three scenarios for Danish organic pig production systems was modelled (Figure 6.1). Scenario 1 or the reference scenario represented the current practice with sows on pasture and growing pigs housed in stables (*indoor finishing*). Scenario 2 and 3 represented the alternative scenarios where sows and growing pigs were foraging in the range area. In scenario 2, pigs were foraging on grass-clover (*free-range: grass-clover*), whereas in scenario 3 efforts were done to construct a cropping system that allowed a maximum intake by foraging considering the type of feed and availability over the year. This scenario included lucerne, Jerusalem artichokes and grass-clover (*free-range: alternative crops*)

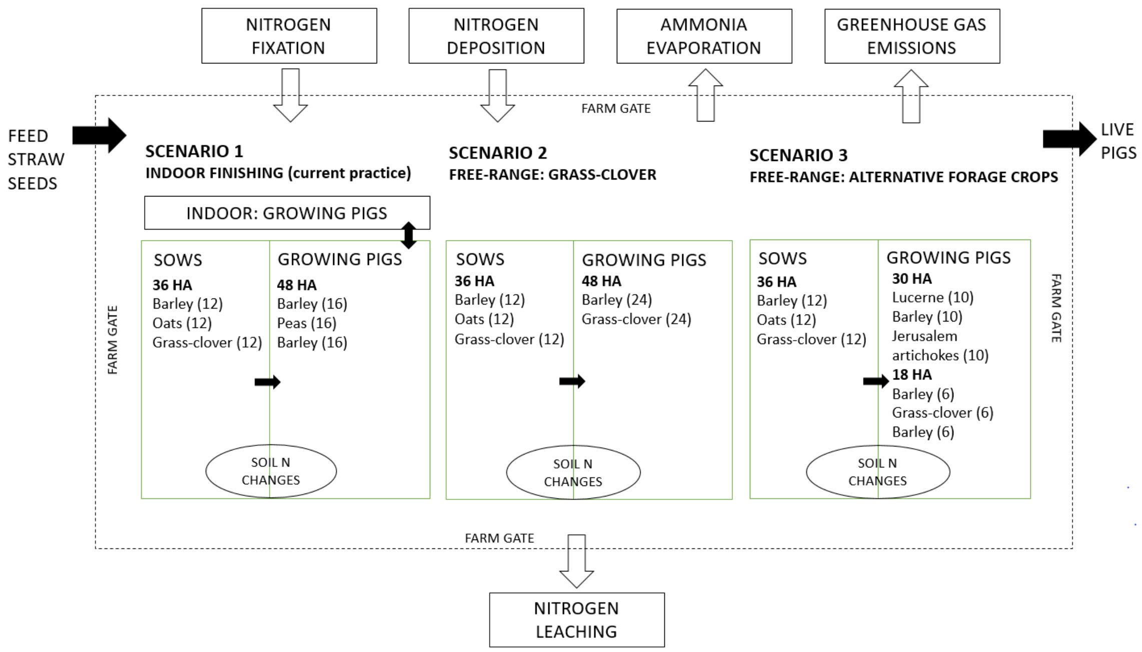


Figure 6.1. Schematic overview of the issues investigated in paper I: Nitrogen balance at farm level, nitrogen leaching and greenhouse gas emissions modelled in three scenarios of organic pig production.

Technical performance

The technical performance of the three scenarios provided the basis for calculating the environmental performance. The basis of all three scenarios was 100 annual sows with production of 1925 finishers and 84 ha based on a stocking density of 1.4 livestock units ha^{-1} $year^{-1}$, corresponding to 140 kg N ha^{-1}.

The sow system was similar in all three scenarios with outdoor free-range pregnant and lactating sows and indoor housing during insemination. Piglets were weaned at seven weeks of age. In the *indoor finishing* scenario weaners were moved indoors and housed in smaller groups until 30 kg and then moved to larger groups until slaughter at 110 kg. In the two free-range scenarios weaners and growing pigs were housed outdoors in paddocks until slaughter at 110 kg.

In all three scenarios, the crop rotation for sows constituted 36 ha and 48 ha for growing pigs (Table 6.1). In the *free-range: alternative crops* scenario gilts and pregnant sows had access to Jerusalem artichokes. The size of the paddock area was based on legislation on stocking density according to Danish environmental regulations (2.8 livestock units ha^{-1} every second year, corresponding to 280 kg N ha^{-1}). Hence for pregnant and lactating sows, a minimum of 10 ha was required.

In the *indoor finishing* scenario, the oats produced in the crop rotation for sows (12 ha) were allocated to gilts, dry sows and pregnant sows. The crop rotation for growing pigs consisted of 16 ha of barley, 16 ha of peas and 16 ha of barley. The produced barley and peas were allocated to growing pigs.

In the *free-range: grass-clover* scenario, half of the crop rotation was cultivated with barley (24 ha) and the other half with grass-clover (24 ha). The growing pigs were foraging on the 24 ha of grass-clover, divided into four paddocks comprising of 6 ha each.

In the *free-range: alternative crops* scenario, the 48 ha for growing pigs were divided into two crop rotations. One rotation consisted of 30 ha: Lucerne (5 ha), lucerne (5 ha), barley (5), barley (5), Jerusalem artichokes (5) and Jerusalem artichokes (5). The second rotation comprised 18 ha with 6 ha of barley, followed by 6 ha of grass-clover and after that 6 ha of barley. During winter, growing pigs were supplemented with lucerne silage. In March, April, September, October and November, growing pigs were foraging on Jerusalem artichokes. During May and June, growing pigs were foraging on grass-clover and during July and August on lucerne. In both free-range scenarios, the total production of barley was allocated to the growing pigs.

In all three scenarios, pastures for lactating sows (2.5 ha) were not assumed to contribute in terms of grazing or production of silage. For pregnant sows 2.5 ha of pastures were estimated to produce 18,300 Mega joule (MJ) metabolisable energy (ME) ha^{-1}. Also, the 5 ha grazed after harvest for silage were estimated to produce 18,300 MJ ME ha^{-1} and the 5 ha for silage 30,500 MJ ME ha^{-1}.

Table 6.1. Production characteristics for three modelled organic pig production systems

	Sow herd	Growing pigs		
Production characteristics:	All systems	Current practice[1]	Free-range: grass-clover[2]	Free-range: alternative crops[3]
Crop rotation, ha				
Barley	12	32	24	22
Oats	12			
Peas		16		
Grass-clover	12		24	6
Lucerne				10
Jerusalem artichokes				10
Total hectares	36	48	48	48
Yield, kg DM ha^{-1}				
Barley	3,825	3,825	3,825	3,825
Oats	3,825			
Peas		2,556		
Grass-clover	4,920		4,094	2326
(thereof grazed)	(1,630)		(1,356)	(2,326)
Lucerne,				6,531
(thereof grazed)				(1,454)
Jerusalem artichokes				6,667
Average yield, kg DM ha^{-1}	4,190	3,402	3,960	4,793

[1]Indoor finishing: Sows on pasture and growing pigs housed in stables with outdoor concrete areas.
[2]Free-range: grass-clover: Sows and growing pigs forage in grass-clover paddocks.
[3]Free-range: alternative crops: Sows and growing pigs forage on grass-clover, lucerne, and Jerusalem artichokes.

I all three scenarios, sows returned to the same field every third year. In the *free-range* scenarios with foraging, pigs were moved in the crop rotation throughout the year according to availability of forage crops. To optimize foraging, pigs were subjected to strip-grazing.

To get a more precise estimate of the amount of N going into the farming system through the feed in the three scenarios, the nutrient (CP) content in organic feed mixtures available at Danish feed mills was used and not the nutrient requirements. Also, when formulating feed rations, protein sources were based on crops grown in Denmark or Northern Europe as much as possible. Concentrate feed for lactating sows and weaners was purchased as these groups are the most demanding in terms of essential amino-acids. Feed composition was based on Danish norms for conventional pigs in terms of the recommended level of digestible CP per MJ ME.

For sows, the energy consumption was based on norms for conventional sows plus 15% related to thermoregulation and increased activity. For growing pigs, energy and protein consumption was based on norms for conventional pigs. On top of this, for the *indoor* *finishing* scenario, 7% energy was added to meet requirements for thermoregulation and increased activity.

In the two *free-range* scenarios, 20% energy was added on top of the norm for conventional pigs to accommodate requirements for thermoregulation and increased activity related to foraging.

In the *indoor finishing* scenario, growing pigs were allocated roughage corresponding to 3% of the energy content of the daily feed ration. It was assumed that weaners were not able to utilise energy and nutrients in the forage. For non-lactating sows roughage comprised 22% of the energy in the daily feed ration.

For non-lactating sows, in the *free-range: grass-clover* scenario, 36% of the energy in the daily feed ration consisted of forage, whereas in the *free-range: alternative crops* scenario, the figure was 60%. For both *free-range* scenarios, growing pigs (30-50 kg) were estimated to utilise forage corresponding to 3.7 MJ ME kg^{-1} weight gain (up to 18% on a DM basis) and for finishers (50-110) 8.5 MJ ME kg^{-1} weight gain (up to 22% on a DM basis), assuming there was no significant impact on daily gain.

Environmental performance

For each of the three scenarios, the environmental performance of the systems was modelled in terms of GHG emissions and N leaching.

Nitrogen balance – potential nitrate leaching

Nitrogen balances were calculated at farm level as the difference between the N input to the system (purchased in feed, straw, seeds, biological N fixation and deposition) and N output from the system (live pigs, culled sows and dead animals). Nitrogen emissions and changes in soil N were deducted from the N surplus to estimate potential N leaching. Calculations of N emissions were based on emission factors from the literature and adjustments to the current systems.

Greenhouse gas emissions

Three categories of GHG emissions were included:

1. Energy use in fields and stables, soil carbon changes, land use changes (LUC): Carbon dioxide (CO_2)
2. From feed production: Nitrous oxide (N_2O)
3. Manure management + enteric fermentation of ingested fibres: Methane (CH_4)

6.2 Materials and methods: Silvo-pasture (on-farm experiment)

As the three studies related to paper II–IV were all performed with similar materials (same fields and animals), these are presented in a separate section. Afterwards, each individual study is presented in terms of objectives and hypotheses together with a summery related to the specific methodology implemented and the recordings obtained.

Paper II-IV were based on three experimental studies performed on a private organic pig farm situated in Brørup, Southern Denmark (55°34'38" N, 8°59'36" E) in the period from May 2015 until March 2016. This site has a coarse sandy soil with on average 4% clay, 5% silt, 90% sand and 1% organic matter in the top soil (0-25 cm). All three studies were focused on the effects of introducing an area with poplar trees into individual paddocks (grass-clover pastures) with lactating sows.

The **overall objective** was to investigate potential environmental and animal benefits of poplar trees and the overall **hypothesis** was that including an area with poplar trees would reduce N leaching and provide additional animal benefits compared to paddocks with only pasture (Figure 6.2).

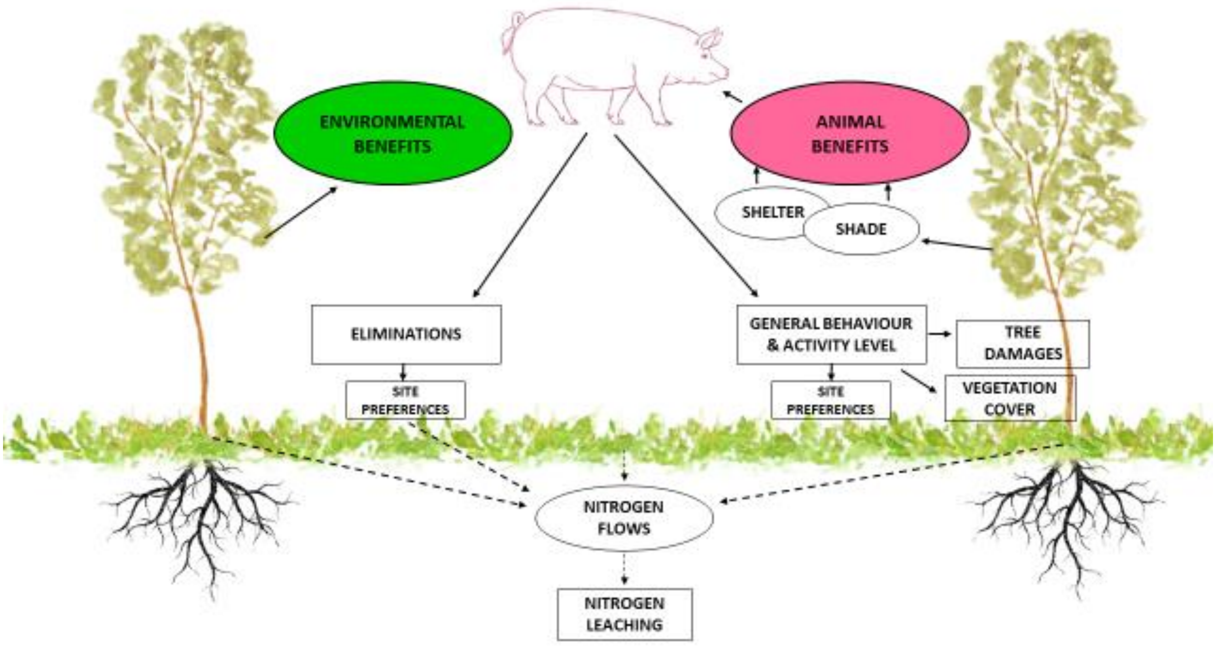


Figure 6.2. An illustration of the links between the elements included in paper II-IV, where the effects of including poplar trees into paddocks with lactating sows were investigated in terms of environmental and animal benefits.

Experimental sow paddocks

The experiment began in May 2015 and ended March 2016. On May 15 2015, the first of four batches of sows were inserted into three types of individual paddocks representing the main treatments.

- Paddocks (330 m^2) with access to an area with trees (AT) (Field 1 & 2)
- Paddocks (270 m^2) without access to trees (NAT: trees fenced off) (Field 1 & 2)
- Paddocks (324 m^2) with no trees and pasture only (NT) (Field 3)

The paddocks with trees were grouped into seven blocks along the row of paddocks situated next to each other (South → North direction) and the two treatments, with access to trees (AT) and without access to trees (AT) were randomly allocated within each of the seven blocks. Each of the seven paddocks representing the treatment with no trees (NT) was blocked along the row of paddocks situated next to each other (West → East direction).

The experimental paddocks were situated in three different field locations (Figure 6.3). The paddocks with only pasture represented the current practice in Danish organic pig production. The paddocks with trees were situated right next to each other and were separated by one strand of electric wire. In paddocks without access to trees, the tree area was fenced off also with one strand of electric wire. In all three types of paddocks, piglets were able to move freely between and outside paddocks, including the tree area where some sows did not have access.

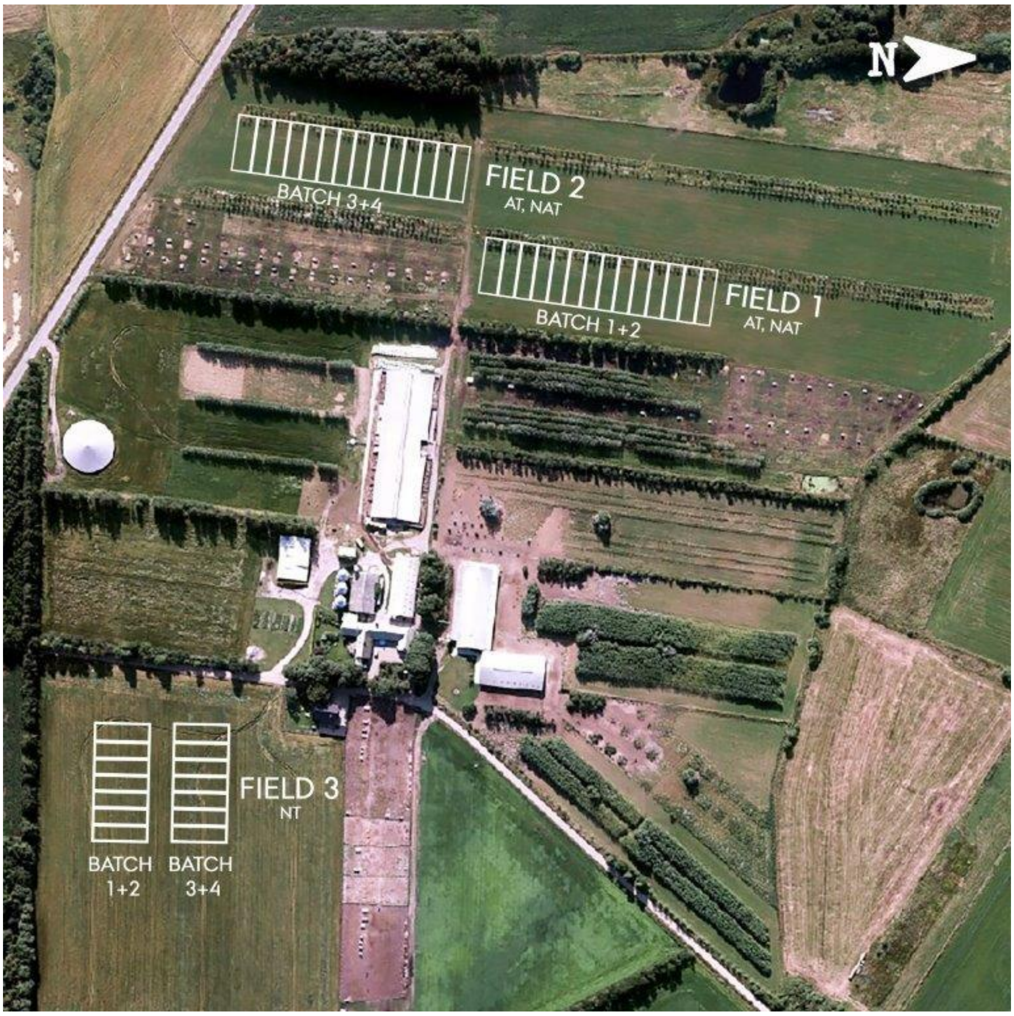
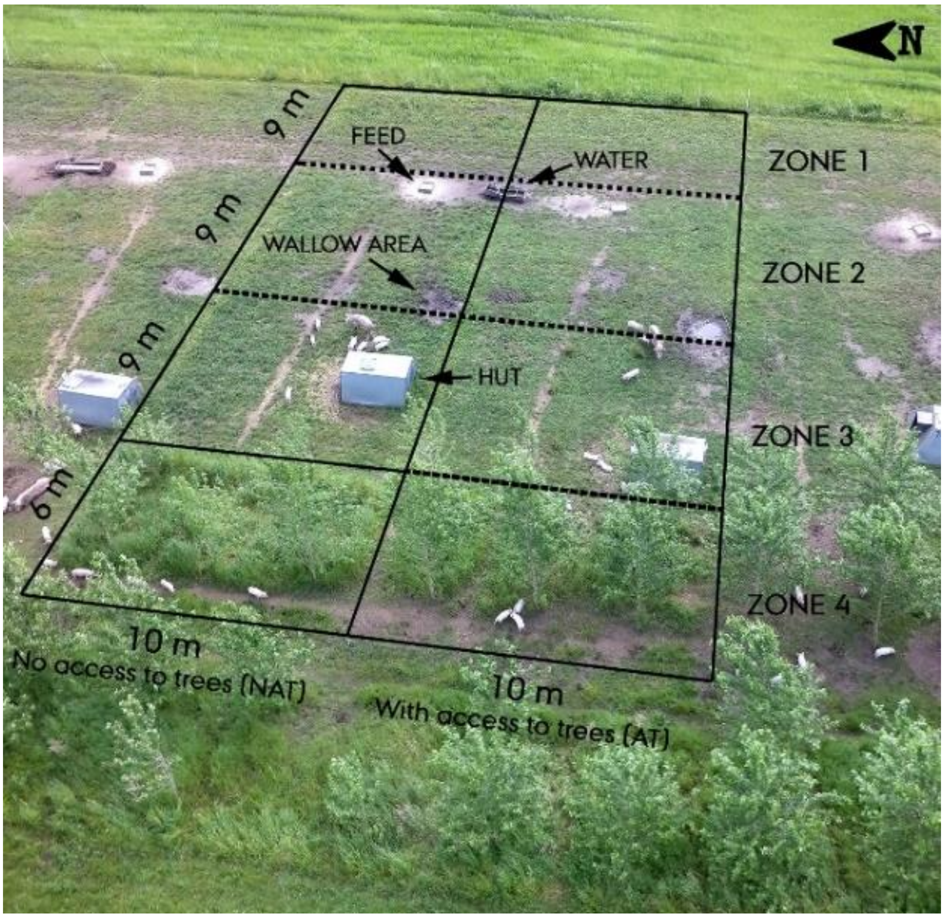


Figure 6.3. Overview of the location of experimental paddocks on a private organic pig farm in Denmark. Paddocks with and without tree access (AT, NAT) were located on Field 1 and 2. Paddocks with no trees (NT) were located on Field 3.

The area with poplar trees measured 10 x 6 m and constituted 20% of the total paddock area. Optimally, each area with trees included six poplars with an inter- and between row distance of approximately 3 m. In Field 1, each paddock on average contained 5 trees for the AT and NAT treatment. In Field 2, the figures were 4.6 and 3.3 trees per paddock for the AT and NAT treatments, respectively. In Field 1, the height of the poplars was on average 6 m. The distance from the trees to the electric fence was approximately 2 m. The poplar trees were clones OP42 (*P. maximowiczii*) × (*P. trichocarpa*). They had been planted in 2011 at a density of 1000 stems ha^{-1} and thus, at the beginning of the experimental period in May 2015 they were four years of age. The trees had not been pruned nor received any animal manure prior to the experimental period.

The individual paddocks were divided into zones. Paddocks with trees were divided into four zones and paddocks with only pasture were divided into three zones (Figure 6.4).

Each sow and her piglets occupied one experimental paddock. They had access to an A-framed hut with a floor area of 4.2 m^2, an entrance in the front (0.5 m x 0.7 m) and an opening for ventilation (16 cm x 26 cm) situated at the rear (16 cm from the roof). The farrowing huts were supplied with straw prior to insertion of sows and straw was provided during the lactation period as needed. The hut was situated in zone three next to the area with poplars (zone four). Each sow had an individual feed trough measuring 0.6 x 0.6 m located in zone 2. Two neighbouring sows shared one water trough measuring 1 x 0.4 x 0.2 m located in zone 2. A total of four batches of sows occupied the paddocks during the experimental period. Each time a new batch of sows was inserted into the paddocks, the hut, feed and water trough were relocated and the straw mats left on the field. However, all resources were situated in the same zone throughout the experimental period. During summer, all sows had access to an individual wallow measuring approximately 1 m^2 located in zone 2.



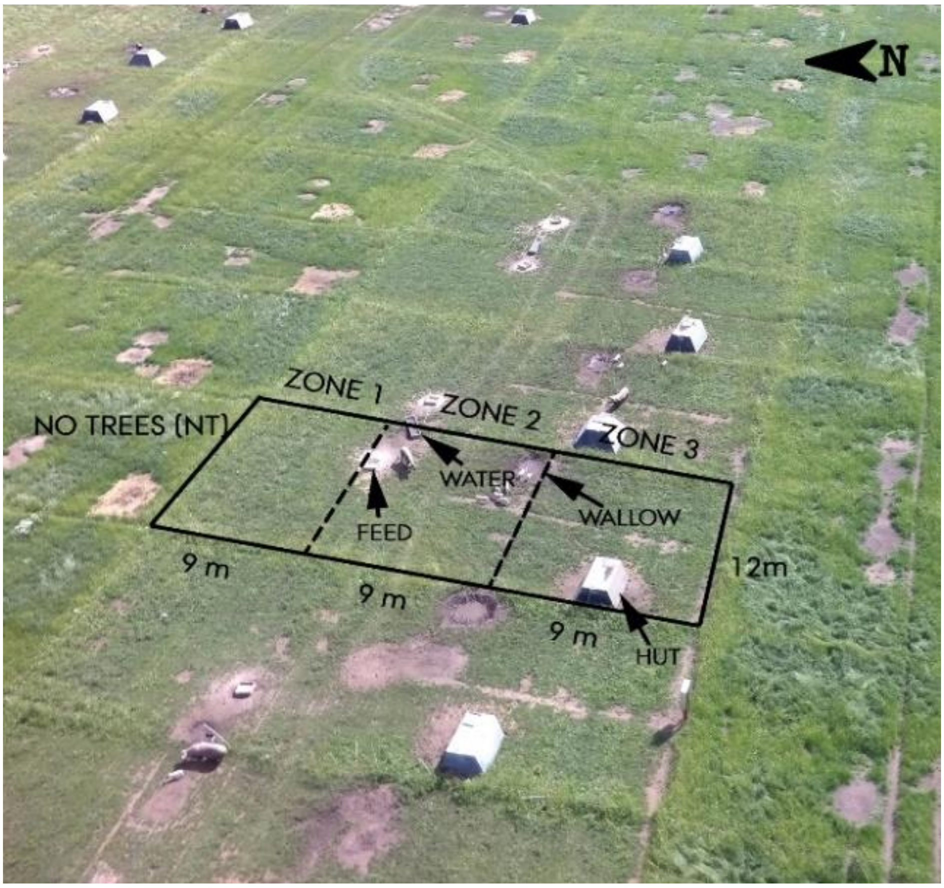


Figure 6.4 Experimental paddocks for lactating sows. Top: Paddocks with and without sow access to poplars (AT, NAT: trees fenced off), bottom: Paddocks with no trees (NT).

Animals

In total, four consecutive batches of sows comprising 84 multiparous (mean parity 2.9) snout ringed Landrace x Yorkshire sows were included in the experiment. Five to seven days prior to expected farrowing the sows were inserted into the paddocks. The lactation period lasted seven weeks and afterwards the piglets were weaned and moved to indoor housing and the sows moved to the indoor insemination facilities. At weaning, the piglets were weighed and the number of piglets recorded for each type of treatment.

Temporally, paddocks were occupied by sow batch:

- 1: May 15 - July 9 2015 (Field 1 and Field 3)
- 2: August 7 - October 1 2015 (Field 1 and Field 3)
- 3: October 30 - December 23 2015 (Field 2 and Field 3)
- 4: January 22 - March 17 2016 (Field 2 and Field 3)

It is important to mention that in Field 3 with pasture only, paddocks allocated to sow batch 1 and 2 were situated in one location in Field 3 and for sow batch 3 and 4 the paddocks were situated just opposite (Figure 6.3). In between the four batches of sows there was a period of three weeks without sows in paddocks.

Each batch consisted of 21 sows that were stratified into seven groups by parity. Afterwards every group of sows was allocated to the tree types of paddocks (AT, NAT, NT).

Feeding

Once a day between 07.00 and 12.00 the sows were fed a standard feed mixture with 14.3% CP and 13.2 MJ ME per kg feed. Throughout the experimental period, the farmer recorded the allocated feed based on five different classes: 1 ~ 3 kg, 2 ~ 6 kg, 3 ~ 9 kg, 4 ~ 14 kg, 5 ~ 19 kg for each feeding and every sow. Every second week during the lactation period, a control of the five classes was performed and corrections were made if any deviations occurred. On average, each sow was allocated 9.0, 7.3, 8.6 and 6.3 kg in batch 1, 2, 3 and 4, respectively.

6.2.1 Sow elimination behaviour and soil mineral nitrogen (Paper II)

In the study related to paper II the **objectives** were to investigate:

1) Site preferences for elimination behaviour in lactating sows
2) Soil mineral N load and spatial distribution in individual paddocks with (AT) and without (NAT) access to poplar trees.

It was **hypothesised** that:

1) Sows' elimination behaviour was primarily performed in the area with poplar trees
2) The level of soil inorganic N was higher in the area with poplar trees than in the paddock area with grass.

Paddocks with and without access to trees (AT, NAT) were occupied with a total of 56 Landrace x Yorkshire multiparous sows.

Sow elimination behaviour

Sows' urination and defecation behaviour was recorded as all occurrences behaviour along with the location of the behaviour. In AT paddocks, the location was related to zone 1, 2, 3 and 4 and for NAT paddocks zone 1, 2 and 3. In addition, it was recorded if a sow eliminated within 1 m from the feed and water and within 1 m from the paddock fence, defined as any of the sow's body parts being within the area.

The sows were observed one day during the week of farrowing and one day during week 3, 5 and 7 of the lactation period. Observations were performed either Mondays, Tuesdays or Wednesdays. The observations began at 9.00 and ended at 19.20 during summer (batch 1 and 2) or at sunset, around 16.30 during winter (batch 3 and 4). During the experimental period, observations were carried out by three experienced observers situated outside the paddocks (next to zone 1). Each observer recorded the behaviour of two neighbouring sows (one block).

Each observation day was divided into four observation periods: 1. 09.00 – 11.10, 2. 11.50 – 14.00, 3. 14.30 – 16.40 and 4. 17.10 – 19.20. In each observation period, the first block was randomized and the following blocks were observed in numerical order (South → North direction). The two sows in a block were observed for five minutes before moving on to the neighbouring block. During each observation day, every sow was observed for 60, 60, 45 and 55 minutes in batch 1, 2, 3 and 4, respectively.

Faeces location and load

At the day of weaning, for each batch of sows two trained persons evaluated the location and load of faeces visually (% of area covered) in each paddock divided into rectangles of 1.0 x 1.5 m (zone 1-3) and 1.0 x 1.0 m in zone 4 (poplars). For each rectangle in the grid, the load of faeces was scored according to seven levels: 0.0 = no faeces, 0.5 = 10%, 1.0 = 20%, 1.5 = 30%, 2.0 = 40%, 2.5 = 50%, 3 = 60%. For each of the two types of paddocks, an average of the faeces load was calculated for every rectangle across the four sow batches.

Soil sampling

To evaluate the level of mineral N in the soil and by that the potential N leaching, soil samples were collected in paddocks in Field 1 occupied by sow batch 1 and 2. Samples were collected October 26-28 2015 and March 29-31 2016 corresponding to three and 25 weeks after the occupation of sows and piglets, respectively (Figure 6.5). After batch 2 the paddocks were kept empty and were not cultivated.

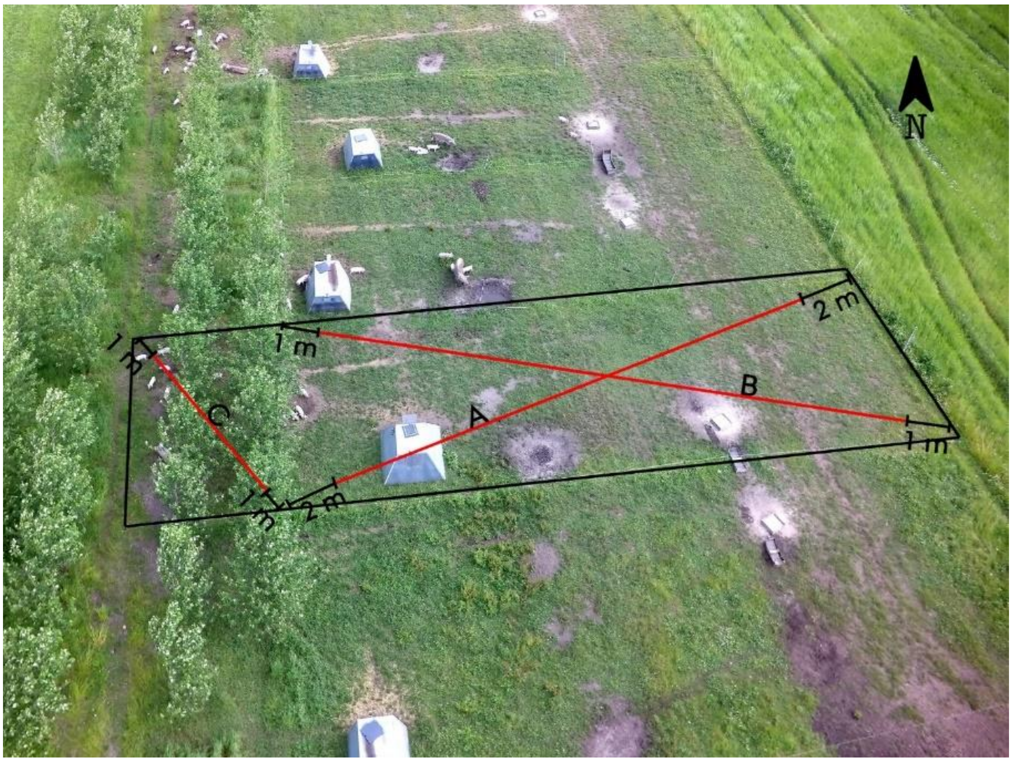


Figure 6.5. The red lines indicate locations of soil sampling: 16 samples (A=6, B=10) in the pasture area and 6 samples (C) in the poplar area in three paddocks with access to trees (AT) and in three paddocks without access to trees (NAT). Distance between samples: A=4 m (sample 3 to 4 = 9 m), B=3 m, C=2 m.

For each type of paddock, three paddocks were randomly chosen in which samples were collected at 16 and 6 grid points in the pasture and poplar area, respectively in two depths: 0-50 cm and 50-100 cm. Prior to analysis for mineral N the 16 soil samples collected in the grass area and the 6 soil samples collected in the paddock area were pooled, respectively.

Recordings - spatial variation of soil mineral N

To investigate the spatial variation of soil mineral N within each of the two types of paddocks, one paddock for each type was randomly chosen and soil samples collected in 42 and 18 grid points in the pasture and poplar area, respectively (Figure 6.6). The samples were collected in October 26-28 2015 and March 29-31 2016 in a depth of 0-50 cm and 50-100 cm.

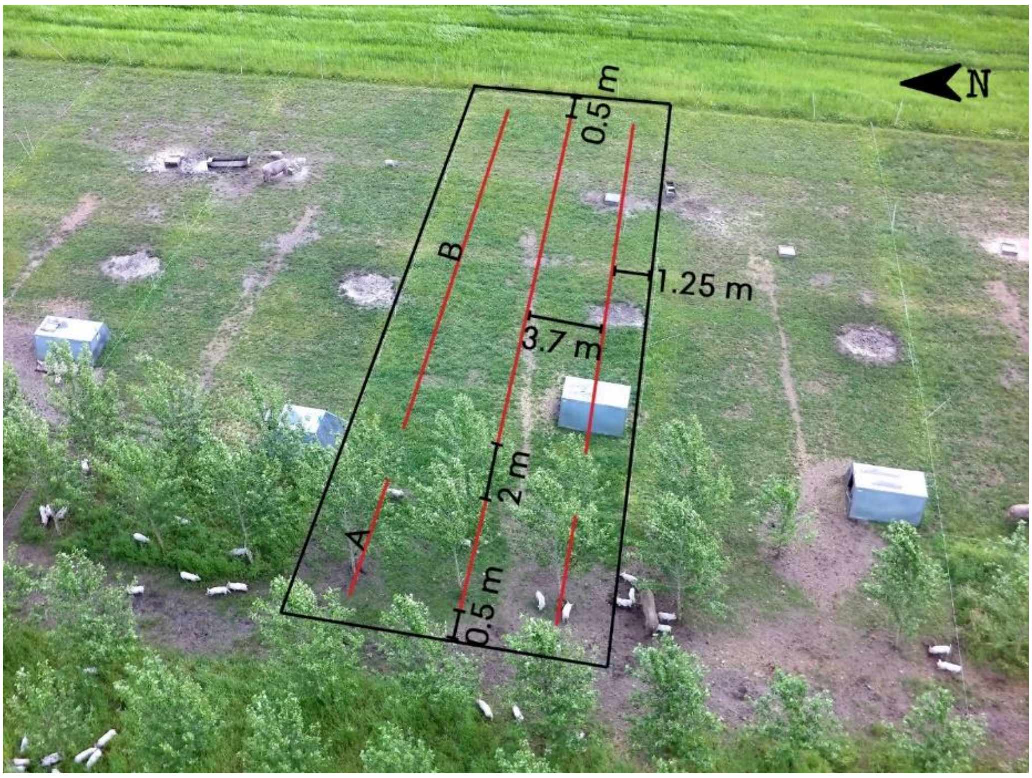


Figure 6.6. The red lines indicate locations of soil sampling: 18 samples in the poplar area (A=6 samples) and 42 samples in the pasture area (B=14 samples) in one paddock with access to trees (AT) and in one paddock without access to trees (NAT: trees fenced off). Distance between samples: A=1 m and B=2 m.

6.2.2 Nitrogen leaching (Paper III)

The **objective** of paper III was to:

1) Quantify nitrate leaching in the poplar and grass area, respectively, in the three paddock treatments.
2) Calculate N balances at field level in the three paddock treatments.

It was **hypothesised** that N leaching was reduced in areas with poplar trees compared to areas with grass.

Nitrogen leaching was determined by measurements of soil water nitrate concentrations and two process-based models (*CoupModel* and *Daisy* model).

The experiment included paddocks located in Field 1 (AT: 7 paddocks, NAT: 7 paddocks) and Field 3 (NT: 7 paddocks) occupied by sow batch 1 and 2 (in total 42 sows).

As input to the modelling in order to quantify N leaching, the following were recorded:

Soil water content

Volumetric soil water content was measured with time domain reflectometry (TDR) along with a calibration method developed for Danish soils. Within each treatment, TDR probes were installed in four paddocks in the area with trees and in the area with pasture (Figure

6.7). The TDR probes were installed in depths of 0.25 m, 0.50 m and 1.00 m. From August 2015 until May 2016, soil water content was measured two to three times a month. In the paddocks with pasture only (NT), soil water content was measured until April 2016.

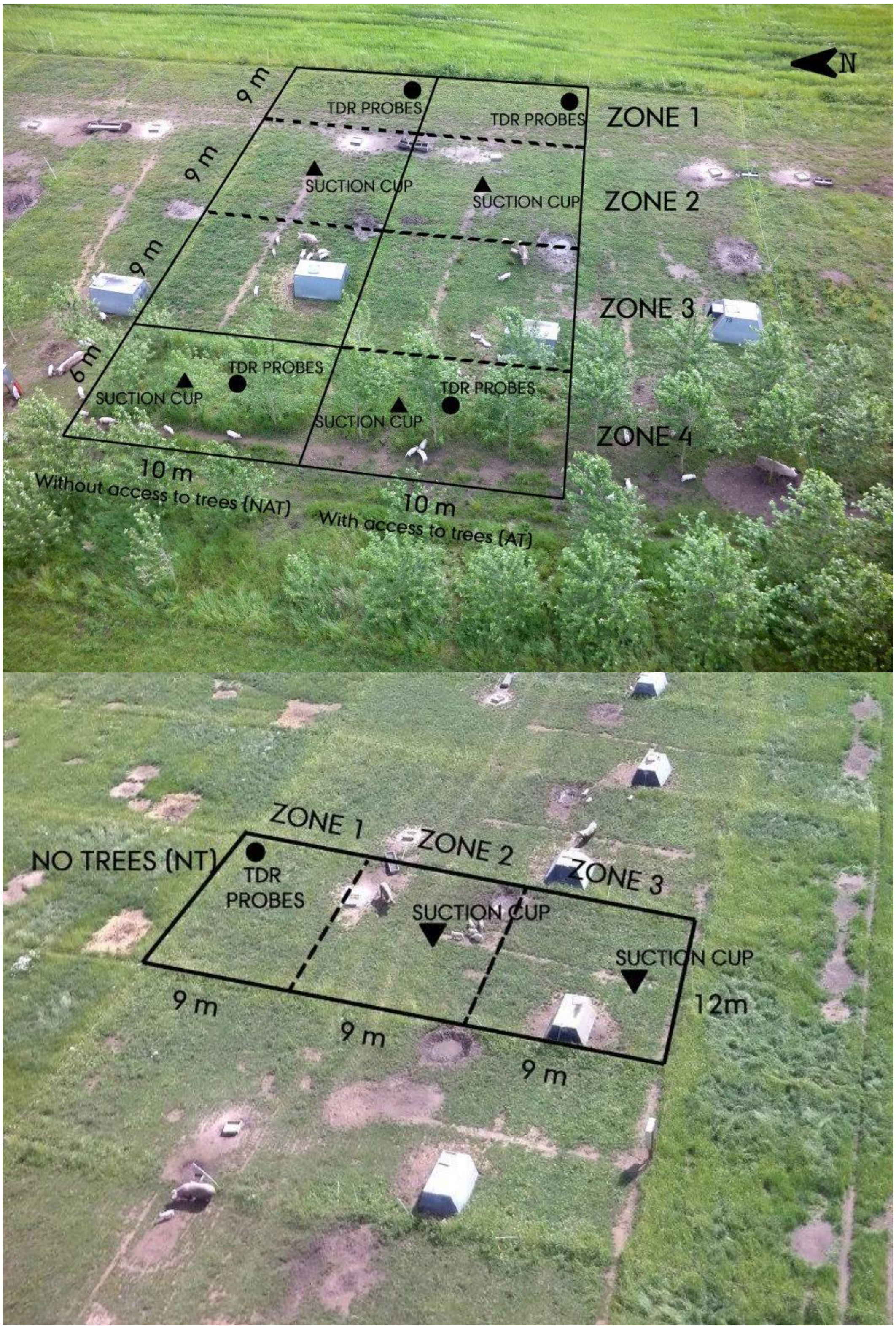


Figure 6.7. Location of suction cups and TDR probes in individual paddocks with lactating sows. AT: with access to a poplar area, AT: without access (trees fenced off), NT: no trees.

Soil water nitrate content
Soil water samples were collected at a depth of 1.0 m in ceramic suction cups installed in each paddock in the middle of the pasture area and in the middle of the area with poplar trees (Figure 6.7). Samples were collected every second to third week from June 2015 until April 2016.

Climate
For the entire period from January 2014 until December 2016, data on air temperature (°C), solar radiation (W m^{-2}), wind speed (m s^{-1}), relative humidity (%) and precipitation (mm) were obtained.

Poplar trees and plant cover
The input related to poplar trees and grass-clover vegetation included data on leaf interception capacity (poplars 0.1 mm, grass-clover 0.1 mm), minimum transpiration resistance (poplars 30 s m^{-1}, grass-clover 1.0 s m^{-1}) and root depth (poplars 1.0 m, grass-clover 1.0 m). The leaf area index (LAI) for grass-clover was estimated based on visual estimation of grass-clover cover. For the poplar trees, LAI was based partly on visual estimations at the experimental site and partly from aerial photos. In addition, the number of trees and tree height was recorded. Plant cover in paddocks (grass-clover) was estimated every two weeks during the lactation period. Thus, for each sow batch, plant cover was recorded four times. For each zone in every paddock, percentage plant cover (percentage of area with grass and clover, respectively) and percentage area rooted was estimated. In each zone percentage plant cover and rooted summed up to a 100%.

Modelling soil drainage
Soil water balances were modelled with two models, the *CoupModel* and the *Daisy* model. To minimize potential bias induced by using a single model and or by the person performing the modelling, two models were used. The water balance for the two models included water fluxes at the soil surface and in the soil. Soil surface fluxes included precipitation and evapotranspiration and fluxes in the soil included deep percolation (water loss) or capillary rise (water gain).

For each model the simulated daily drainage was used to calculate N leaching from the area with poplar trees and the area with pasture in the AT and NAT treatment and in the NT treatment. Modelled daily N leaching, evapotranspiration and drainage were accumulated to annual figures (April 1 2015 – March 31 2016).

Nitrogen balance
Nitrogen balances were estimated at paddock level in each of the three treatments as the difference between inputs to the paddocks (feed, straw, N fixation, N deposition) and output

(weaned piglets). The feed input was based on the farmer's estimated daily input to individual sows across the experimental period and the output (weaned piglets) was based on the number and weight of piglets at weaning (measured per treatment) and the amount of N in piglets.

Watercolour painting by Birte Mølgaard

6.2.3 Sow behaviour (Paper IV)

The overall **objective** of paper IV was to investigate the effect of inclusion of an area with poplar trees in individual paddocks on sow behaviour.

The **hypotheses**:

1) An area with poplar trees provides a more enriched and heterogeneous environment and therefore sows with access to an area with trees will show an increased level of activity compared to sows with no access to trees.
2) An area with poplar trees provides a more enriched and heterogeneous environment and therefore sows with access to an area with trees will show an increased level of foraging compared to sows with no access to trees.
3) The trees provide shade in the vegetative season and thus, during periods of increased temperature, sows with access to an area with poplar trees will spend more time outside the farrowing hut compared to sows without access to trees.

4) As the trees provide an area with shade, during periods of increased temperatures, sows with access to trees will be lying more in the area with trees compared to the other zones in the paddock.
5) The level of damage to the poplar trees and the vegetation exerted by the sows is not devastating.

The study included all three types of paddocks (AT, NAT, AT) occupied by four batches with 21 sows in each. The recording of plant cover in paddocks began May 29 2015 and ended March 17 2016. The recording of tree damages began June 11 2015 and ended June 1 2016.

Behavioural observations
The behavioural observations began May 18 2015 (sow batch 1) and ended March 17 2016, (batch 4). Behavioural elements occurring regularly (Table 6.2) were recorded by scan sampling at one minute intervals. Behaviours occurring irregularly or seldom were recorded as '*all occurrences'* (Table 6.3). As the paddocks were situated in different fields and the observations had to be performed simultaneously in the fields with trees (AT, NAT) and the fields with no trees (NT), on each observation day there were two observers. The observation methodology was similar to the one described in chapter 6.2.1 below the section named '*Sow elimination behaviour*'.

Table 6.2 Ethogram used during scan sampled observations of sow behaviour

Behaviour	Definition
Eating concentrates[1]	Snout in the feed trough, either eating concentrates or searching (sniffing, licking) for leftovers. Lifting the head from the feed trough and chewing. Eating leftovers right beside the feed trough
Grazing[1]	Pulling/biting grass or other forage items with the mouth. Chewing and or swallowing grass or other forage items
Rooting[1]	The snout is in the soil with shovelling and forward headed movements along or into the soil. The back can be relaxed or arched
Walking and standing[1]	Upright and at least one leg is moving or upright with all four legs in contact with the ground
Other or unknown activities	E.g. social interaction or activity not recognized
In hut[1]	The whole body is inside the hut. Might be standing with the head outside the hut
Sternal recumbency	Body lying immobile in ventral position on sternum with forelegs either tucked under the body or stretched out and hind legs either tucked under the body or visible to one side. Eyes might be open or closed. Head might be moving
Lateral recumbency	Body lying immobile in lateral position on the side with legs (either front or hind legs or all four legs) tucked up towards the body or stretched out to the side. Eyes open or closed. Head might be moving
Sternal recumbency in shade	Similar to definition of 'sternal recumbency' but with at least 50% of the body in shade
Lateral recumbency in shade	Similar to definition of 'lateral recumbency' but with at least 50% of the body in shade

[1]Definitions according to Horsted *et al.* (2012) and Jakobsen *et al.* (2015).

Table 6.3. Ethogram used during continuous observations of sow behaviour

Behaviour	Definition
Drinking (water trough or wallow water)	The snout is in the water trough and touches the water. Slurping sounds might be heard.
Wallowing[1]	Digging with one front leg, rooting, standing with at least one leg in the wallow or lying in the wallow pool
Scratching, hut	Any body part is rubbed against the hut
Scratching, trees	Any body part is rubbed against a tree
Biting, any part of tree	Any part of the tree is in contact with the inside of the mouth
Chewing stones	A stone is visible inside the mouth or sounds are heard from the movement of a stone inside the mouth.

[1]Definition according to Bracke (2011).

Poplar trees

Any damage to poplar trees in each of the 14 paddocks was recorded every two weeks during the lactation period. However, for sow batch 1 recordings were only performed three times during the lactation period. For each sow batch the last recording was performed on the day of weaning. As sow batch 1 and 2 occupied paddocks in Field 1 the recording period in this location lasted from June 11 until October 1 2015. Likewise, as sow batch 3 and 4 occupied paddocks in Field 2, the recording period in this location went from November 2 until March

17 2016. In addition, in Field 1, one recording was performed June 1 2016 in order to see to which degree the trees had recovered from the previous damages. From the weaning of piglets in batch 2 on October 1 2015 until June 1 2016, the areas with trees in Field 1 had not been occupied with sows.

For each poplar tree, up to a height of 1.1 m from the ground, the number of branches on the tree was recorded. Also, the amount of bark removed, up to a height of 1.1 m from the ground was recorded on an arbitrary scale: 0: no bark removed, 1: 1%, 2: 2-5%, 3: 6-10%, 4: 11-20%, 5: 21-30%, 6: 31-40%, 7: 41-60%, 8: 61-80%, 9: 81-90% and 10: 100%. In addition, the circumference of each poplar trees was measured in Field 1 on May 29 2015 prior to insertion of sow batch 1 and again after two growing seasons on November 29 2016. The difference in circumference was used as an indicator of poplar growth. Similar measurements were performed in Field 2 on October 29 2015 prior to insertion of sow batch 3 and again after one growing season on November 29 2016.

Plant cover

Plant cover was estimated as described in section 6.2.2 related to paper III below the sub-headline '*Poplar trees and plant cover*'.

Climate

Recordings of daily air temperature (°C), precipitation (mm) and wind speed (m s^{-1}) were obtained from a meteorological station located approximately two km from the experimental site. In addition, during days of behavioural observations, air temperatures were recorded at the beginning of each of the four observational periods by use of a thermometer located in a tree row opposite the experimental paddocks.

7. Results

The overall aim of the PhD project was to contribute to the development of a more nutrient-efficient organic pig production, based on the pigs' species-specific behaviour, by integrating the management and production strategies foraging and poplar trees, respectively, into the paddock range area. On this basis, the three overall objectives were to *investigate*:

- Environmental effects of improved foraging in the range area at farm level.
- Environmental effects of introducing poplar trees into paddocks with lactating sows.
- Potential animal benefits of introducing poplar trees into paddocks with lactating sows.

7.1 Environmental benefits

7.1.1 Impacts of improved foraging at farm scale

In terms of improved environmental performance at farm level, the positive impact of foraging is based on an assumed reduction in purchased feed, whereby the N recirculation within the system is improved and GHG emissions reduced. This leads to a reduced risk of N losses to the surrounding environment. Also, maintaining N in the farming system is vital for increasing yields of home-grown crops.

To investigate this hypothesis, three scenarios were elaborated: 1) The current practice in Danish organic pig production with sows on pasture and growing-finishing pigs housed indoors with access to outdoor runs. 2) Sows and growing pigs kept on grassland and foraging on grass-clover. 3) Sows and growing pigs in an improved foraging system with lucerne, Jerusalem artichokes and grass-clover and with a reduction in supplementary feed to stimulate forage intake.

In the two free-range scenarios with foraging, crops yields were higher compared to the *current practice* scenario and the crop yields in the *alternative crops* scenario, with inclusion of lucerne and Jerusalem artichokes, were higher compared to the scenario based on grass-clover. The latter represented the scenario where pigs were foraging on grass-clover, a well-known crop present in crop rotations with pigs but with limited yields. In the *alternative crops* scenario, lucerne and Jerusalem artichokes were introduced as new crops due to the high yields and with regards to lucerne having a favourable protein and lysine content for pigs (Weltin *et al.*, 2014). In addition, in the *alternative crops* scenario, foraging was possible over a longer period of the year due to Jerusalem artichokes compared to the *grass-clover* scenario.

Nitrogen leaching

Even though it was possible to reduce input of protein feed (N) at farm level and maintaining the pig production, it was evident that the estimated potential N leaching in the three scenarios was not reduced (Table 7.1). In fact, the *alternative crops* scenario had a somewhat higher potential N leaching compared to the *current practice*, which showed similar performance as the *grass-clover* scenario.

There are two main reasons for this simulated result. Firstly, there is much lower ammonia emissions from the manure when pigs are on pasture than when kept in stables with outdoor concrete areas, and in order to have appropriate crops available for foraging, the share of on-farm N fixating crops had to be increased. This lead to higher levels of mineral N in the soil prone to leaching, which an estimated higher soil C and N sequestration in the *alternative* scenarios was not able to counteract. Furthermore, in the *alternative* scenarios, the lower input of purchased feed was not able to counteract the higher use of feed due to thermoregulation and higher level of activity compared to the *current practice* scenario.

Table 7.1 Nitrogen balance at farm level (kg N ha^{-1}) in three scenarios of organic pig production. Negative and positive values with regards to soil N sequestration are related to depletion and build up, respectively.

	[1]Indoor finishing	[2]Free-range: grass–clover	[3]Free-range: alternative crops
Input:			
Imported feed	164	145	140
Seed	3	1	2
Straw	1	2	2
N fixation	31	38	51
N deposition	16	16	16
Total input	214	202	210
Output:			
Live pigs	68	68	68
Culled sows	3	3	3
Dead animals	0	0	0
Total output	72	72	72
Balance	**143**	**130**	**139**
N losses:			
Ammonia	49	24	20
Denitrification	3	6	6
Soil N sequestration	−8	4	4
N leaching	**99**	**100**	**110**
Indirect denitrification from leaching	1	1	1.1

[1]Indoor finishing: Sows on pasture and growing-finishing pigs housed indoors.
[2]Free-range: grass-clover: Sows on pasture and growing-finishing pigs foraging on grass-clover.
[3]Free-range: alternative crops: Sows on pasture and growing-finishing pigs foraging on lucerne, grass-clover and Jerusalem artichokes.

Greenhouse gas emissions

In terms of estimated potential GHG emissions per kg pig produced, both with and without including soil C emissions and indirect Land Use Change (iLUC), the *alternative crops* scenario showed improved performance compared to the other two scenarios with similar emissions (Table 7.2). Primarily, the GHG emissions in the *alternative crops* scenario were due to lower emissions related to home-produced feed, lower soil C emissions related to a lower import of protein-rich feed and lower emissions from iLUC due to less imported feed, compared to the two other scenarios. The similar GHG emissions between the *current practice* scenario and the *grass-clover* scenario was the net result of higher GHG emissions from production of home-grown feed and higher enteric fermentation in the *grass-clover* scenario, whereas GHG emissions related to soil C from home-produced feed were much higher in the *current practice* scenario.

Table 7.2. Greenhouse gas emissions (GHG) (kg CO_2 equivalents kg^{-1} live pig weight) in three scenarios of organic pig production. Land use is defined as m^2 $year^{-1}$

Contributor	[1]Indoor finishing	[2]Free-range: grass-clover	[3]Free-range: alternative crops
I Home-produced feed:			
• Nitrous oxide (N_2O)	0.46	0.84	0.75
• Methane (CH_4) from manure management	0.41	0.05	0.04
• Energy use (field operations)	0.14	0.20	0.15
Total	1.01	1.09	0.94
II Imported feed from production of feed[4]	0.96	1.07	0.84
III Enteric fermentation	0.14	0.24	0.22
IV Energy use from production	0.06	0.00	0.00
Total (I+II+III+IV)	2.17	2.4	2.00
V Soil C emissions from			
• Imported feed	0.21	0.21	0.16
• Home-produced feed	0.15	-0.08	-0.03
Total	0.36	0.13	0.13
VI. Indirect Land Use Change	1.16	1.15	0.99
Total GHG emissions	**3.69**	**3.68**	**3.12**
Land use (m^2 $year^{-1}$)	8.11	8.05	6.90

[1]Indoor finishing: Sows on pasture and growing-finishing pigs housed indoors.
[2]Free-range: grass-clover: Sows on pasture and growing-finishing pigs foraging on grass-clover.
[3]Free-range: alternative crops: Sows on pasture and growing-finishing pigs foraging on lucerne, grass-clover and Jerusalem artichokes.
[4]Refers to all categories of emissions related to production of feed (emissions of nitrous oxide, methane and carbon dioxide).

7.1.2 Effects of silvo-pasture

The risk of N leaching is particularly high during winter and early spring when grass growth is impaired and the risk is reinforced with high precipitation, as is often the case at this time of the year in Northern Europe, and with reduced vegetation cover. Poplar trees with a permanent and long root system as well as a relatively long growing season, were suggested to take up part of the N from deeper soil layers, not reached by grass roots. Compared to grass, poplar trees may take up N in early spring when grass growth has not yet begun. However, it requires that the sows perform the majority of eliminations near the poplar trees.

According to behavioural observations, the sows did not perform the majority of eliminations in the poplar zone (zone 4) or near the poplar zone (zone 3: hut) (Figure 7.1). In paddocks with access to poplars, sows preferred to urinate in zone 1, the zone furthest away from the poplar zone. In paddocks without access to the poplar zone, there was no difference between zones preferred for urinations. However, most urinations (numerically) were performed in zone 1. Also, sows did not prefer to defecate in the zone with poplars or zone 3 next to the poplar zone. Rather, in both treatments, the defecation pattern was random.

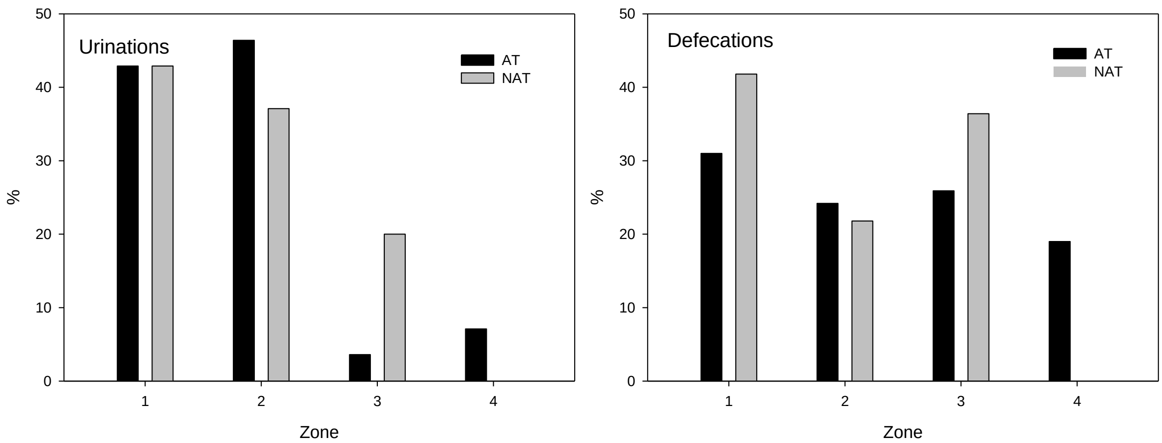


Figure 7.1. Urinations and defecations in zones within individual paddocks occupied by lactating sows with access (AT) and without access (NAT: trees fenced off) to an area with poplars. Values for each zone are percentages of total observed urinations and defecations, respectively. Relative area: zone 1 (grass): 28%, zone 2 (including feed, water, wallow): 28%, zone 3 (including hut): 26%, zone 4 (poplars): 18%.

Faeces location and load

Visual estimation of faeces location and load within paddocks showed a somewhat different picture compared to observations of defecation behaviour. In both treatments, the defecation pattern was non-random (Figure 7.2). Clearly, the sows avoided defecating around the hut, feed and wallow area. A relatively large amount of faeces was located along the paddock fence opposite the farrowing hut. In AT paddocks, faeces was located in almost all areas of the poplar zone (zone 4) but with varying loads ranging from 10-50% being covered. The difference between the visual estimations of faeces and the behavioural observations of defecations is suggested to be due to lack of additional zones around the resources (hut, feed, and wallow) when eliminations was recorded. The division into 3 (NAT) and 4 (AT) almost equally sized zones did not take the location of resources into account.

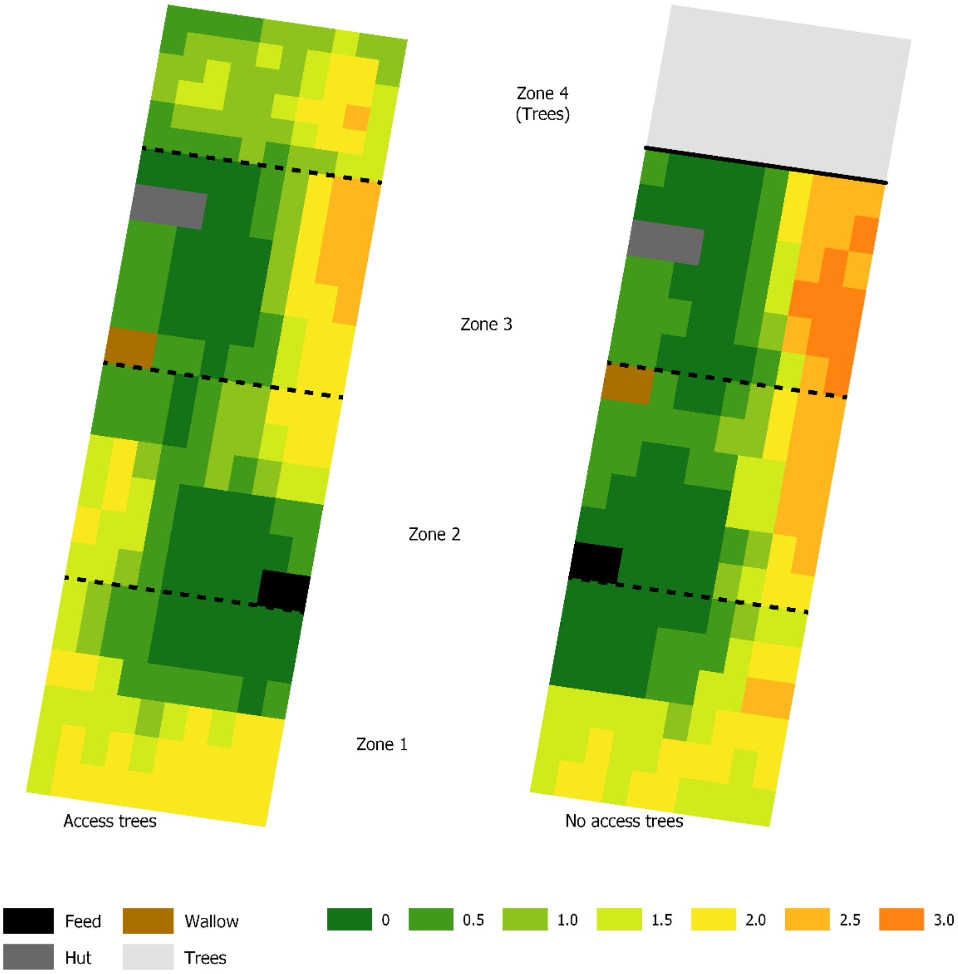


Figure 7.2. Faeces location and load in zones in individual paddocks occupied by lactating sows with access (AT) and without access to an area with trees (NAT: trees fenced off) on average across four consecutive sow batches. Load was visually estimated as percentage of each rectangle covered: 0.0: no manure; 0.5: 10%, 1.0: 20%, 1.5: 30%, 2.0: 40%, 2.5: 50%, 3.0: 60%.

Soil mineral nitrogen - spatial distribution

According to the spatial distribution of total soil mineral N (ammonium and nitrate) at the end of October (depth 0-50 cm) in a single paddock within each treatment (four weeks after weaning of batch 2), a high level was located in zone 3 around the hut in both treatments (Figure 7.3). In addition, in the paddock with access to poplars (zone 4), the level was high in the part of the poplar zone facing towards zone 3 (hut). In the NAT paddock, total mineral N was also high in the area around the feed. Hence, these results were somewhat different compared to the behavioural observations and the visual estimation of faeces, although in the poplar zone the visual estimations of faeces and soil mineral N to some extend agree.

The results must be interpreted with caution as only one paddock within each treatment was investigated. However, it does display the large variation in mineral N load within individual paddocks similar to the visual estimations of faeces. Also, it shows that mineral N levels were high in a few soil samples.

The fact that areas with a high mineral N was not in accordance with observed eliminations and the visual estimations of faeces, is suggested to be due to the behavioural observations being recorded every second week for all four sow batches from May 2015 to March 2016. Also, as the behavioural observations began at 09:00, probably some morning urinations performed in zone 3, where the hut was located, were missed. The visual estimations represented only faeces and are presented as an average across four sow batches, whereas soil mineral N represented the continuous load of urine and faeces deposited by sow batch 1 and 2 minus uptake by crops from May until the end of October. The high mineral N located around the feeding place may partly be related to waste of concentrates.

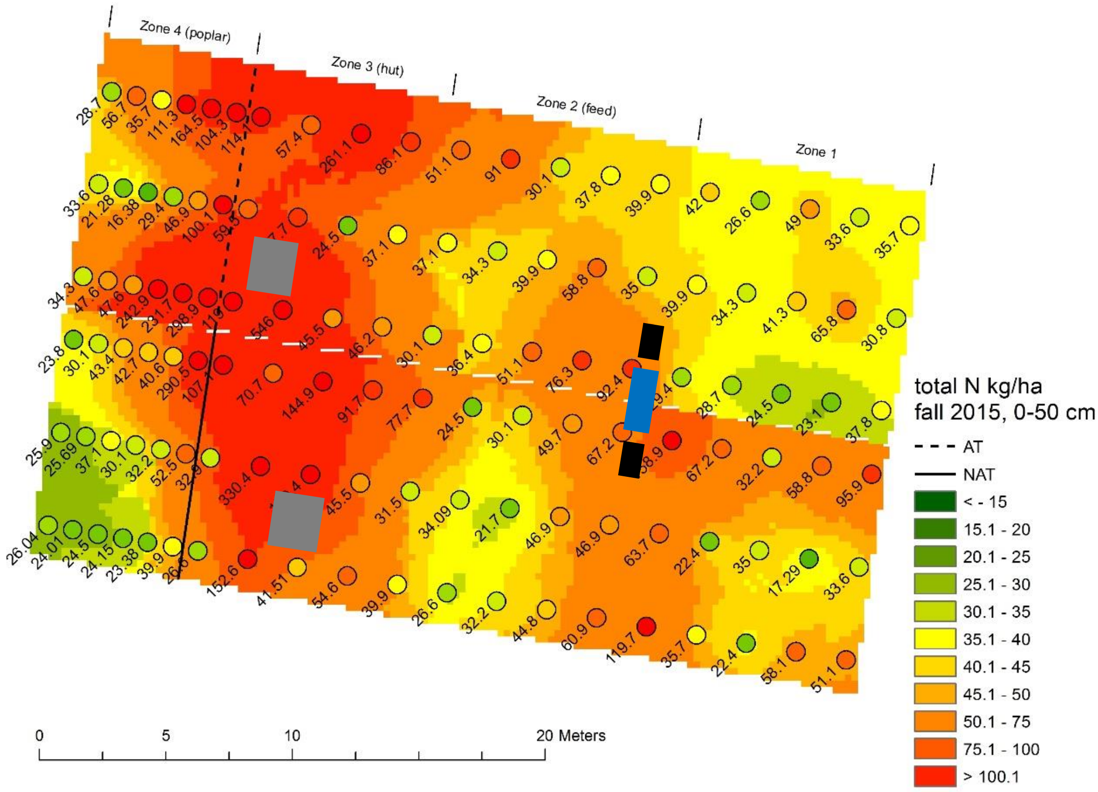


Figure 7.3. Total mineral nitrogen (ammonium and nitrate) in soil samples (42 in the pasture area and 18 samples in the poplar area) collected at the end of October 2015 in a depth of 0-50 cm in two individual paddocks with lactating sows. AT: paddocks with access to poplar area. NAT: paddock without access to poplar trees (tree area fenced off).

Soil mineral nitrogen – pooled samples

Soil mineral N in the grass area and the poplar area were based on 16 pooled soil samples in the grass area (zone 1, 2 and 3) and 6 pooled samples in the poplar area (zone 4), collected in three paddocks from the AT and NAT treatment, respectively. The soil samples were collected at the end of October 2015 and at the end of March 2016 in a depth of 0-50 and 50-100 cm, respectively.

Soil mineral N contents at the end of October represented the N load during the period with sows minus the uptake by crops. The difference in mineral N from October to March represented the amount of N possibly leached (no pigs and soil cultivation within that period).

The level of total mineral soil N (depth 0-50 cm) in the grass area at the end of October did not differ between the AT and NAT treatment, even though the stocking density in the NAT treatment was higher than in the AT treatment (Table 7.3). At the end of October, there was no difference in the levels of nitrate between the grass and the poplar area in the AT treatment, whereas ammonium levels were higher in the grass area compared to the poplar area. In the NAT treatment, total mineral N was much lower in the poplar area compared to the grass area, which was expected as the trees were fenced off. At the end of March, however, there was no difference in soil mineral N between the grass and the poplar area within each treatment.

In both treatments, soil mineral N was lower at the end of March compared to the end of October in the grass and poplar area, respectively. The exception was the poplar area in the NAT treatment with no difference as the sows did not have access.

In October, mineral nitrate levels (depth 50-100 cm) were similar for the grass and the poplar area in the AT treatment and the grass area in the NAT treatment, whereas nitrate was much lower in the poplar area without access to poplars. In March, however, the nitrate levels were much lower compared to October, except for the tree area, which was fenced off.

As total soil mineral N in a depth of 0-50 cm was similar for the poplar area and the grass area in paddocks with access to the tree area and nitrate in a depth of 50-100 cm in the poplar area with access to trees was higher compared to the level of nitrate in the poplar area without access, this suggested that during the growth period, the poplar trees did not take up more of soil available N than grass. However, the lower soil nitrate content in a depth of 50-100 cm in the area with poplars compared to the area with grass at the end of March, suggested that the poplar trees were taking up nitrate more efficiently than grass in deeper soil layers during winter and early spring.

Table 7.3 Effect of season (end of October 2015, end of March 2016), area (grass, trees) and treatment: access to poplars (AT) and without access to poplars (NAT: trees fenced of) on mean mineral N load (nitrate, ammonium and total mineral nitrogen, kg ha^{-1}). Based on pooled soil samples (16 and 6 points in the pasture and tree area, respectively) collected in a depth of 0-50 cm and 50-100 cm from three paddocks within each treatment. Least square means are shown. Values within columns with different superscript letters are different ($p \leq 0.05$), standard errors (parenthesis)

Sampling time	Treatment	Area	Soil depth 0-50 cm			Soil depth 50-100 cm
			Nitrate	Ammonium	Total	Nitrate
October 2015	*AT*	Grass	42.5^{a} (10.1)	35.5^{a} (6.0)	77.9^{a} (13.6)	19.3^{a} (2.3)
		Trees	49.2^{a}(13.4)	18.7^{c} (3.0)	67.9^{a} (13.4)	14.7^{a} (2.1)
	NAT	Grass	34.8^{a} (8.8)	32.6^{a} (5.5)	67.4^{a} (11.7)	18.7^{a} (2.2)
		Trees	4.5^{d} (5.5)	14.7^{bc} (2.4)	19.2^{b} (5.3)	2.7^{b} (0.9)
March 2016	*AT*	Grass	11.9^{c} (2.9)	10.0^{b} (1.7)	21.9^{b} (3.8)	7.2^{c} (1.0)
		Trees	6.6^{cd} (2.0)	14.7^{bc} (3.0)	21.3^{b} (4.7)	2.7^{b} (0.4)
	NAT	Grass	13.5^{c} (3.4)	11.7^{b} (1.9)	25.2^{b} (4.5)	6.3^{c} (0.9)
		Trees	3.2^{d} (1.6)	13.8^{b} (2.2)	17.0^{b} (3.3)	2.7^{b} (0.5)

Modelled nitrate leaching

Taken as a weighted average of the poplar and the grass area in paddocks in the three treatments, N leaching was lowest in paddocks without access to poplars (NAT) with 101 kg N ha^{-1} (Table 7.4). Nitrate leaching in paddocks with tree access (AT) (176 kg N ha^{-1}) was almost similar to the level found in NT paddocks (control) with 206 kg N ha^{-1}.

Table 7.4 Nitrogen balances at field level (kg N ha^{-1}) in three paddock treatments with lactating sows and seven weeks lactation. AT: access to an area with trees, NAT without access to trees (trees fenced off), NT: only pasture (representing current practice on Danish organic pig farms). Estimated N leaching calculated as a weighted average of the poplar and the grass area (Table 7.5)

	AT	NAT	NT
Input:			
Feed	576	564	600
Straw	5	5	5
N fixation (clover)	30	30	30
N deposition	16	16	16
Total input	627	615	651
Output:			
Weaned piglets	191	219	183
Balance	**436**	**396**	**468**
N efficiency (%)[a]	30	36	28
N losses:			
Ammonia	90	88	93
Denitrification	10	9	11
NO_x-N	12	12	13
N_2-N	30	28	32
N leaching	**176**	**101**	**206**
Soil N balance	118	157	113

[a]Calculated as ratio of the output to total input.

Total soil mineral N load at the end of October (0-50 cm) in paddocks with access to poplars was similar for the poplar area and the grass area. However, the modelled nitrate leaching showed a much lower leaching in the poplar area compared to the grass area, suggesting that the poplar trees did take up soil water nitrate. In comparison, in the grass-clover/control area in paddocks with no trees (NT), nitrate leaching was much higher (*CoupModel*: 321, *Daisy*: 257 kg N ha^{-1}) (Table 7.5). This may be related to the relatively short distance between the hut and the suction cup in the NT treatment compared to the other two treatments.

Opposite, in the grass-clover area in paddocks with no trees (NT), nitrate leaching was lower compared to the grass-clover/control area within the same treatment and the grass-clover area in paddocks with access to trees (AT) (*CoupModel*). A reduction in nitrate leaching was obtained by approximately 20% tree cover. However, on a paddock basis, this was not sufficient and therefore additional management and production strategies could be implemented to reduce leaching further.

Table 7.5 Modelled nitrate leaching (kg N ha^{-1}) in individual paddocks with lactating sows subjected to three types of treatments (7 paddocks in each treatment, suction cups: 1 m depth): AT: sow access to an area with poplars, NAT: without access to poplars (trees fenced off) and NT: no trees (grass-clover pasture representing the control). Two process based models were used to calculate nitrate leaching (*CoupModel and Daisy*). Mean values within columns with different superscript letters are different ($p \leq 0.05$), 95% confidence interval in brackets

Treatment	Area	Vegetation	*CoupModel*	*Daisy*
AT	Poplar	Poplar	70 (19-121)^{ab}	71 (20.5-122)^{ab}
NAT		Poplar	32 (1-82)^{a}	32 (1-82)^{a}
NT, control	Grass-clover/control	Grass-clover	321 (224-419)^{c}	257 (172-342)^{c}
AT	Grass-clover	Grass-clover	317 (222-412)^{c}	253 (175-331)^{cd}
NAT		Grass-clover	197 (125-270)^{bc}	153 (90-217)^{bcd}
NT, control		Grass-clover	154 (98-210)^{b}	123 (70-175)^{abd}

In summary

Observations of elimination behaviour, visual estimation of faeces location and soil mineral N represented different ways of obtaining information about the N load in the paddocks. Urination behaviour of sows in paddocks with poplar access (NAT) was non-random, whereas urination behaviour of sows in paddocks without sow access to trees (NAT) as well as defecation behaviour in both paddock treatments (AT and NAT) was random. The observational results are suggested to have been affected by the lack of additional zones in accordance with paddock resources. Also, the morning urinations were probably missed as the observations started at 09:00.

Unlike the behavioural observations, the visual estimations of faeces location clearly showed a non-random pattern with no faeces around the resources and with faeces located in the poplar area. In accordance, soil mineral N load showed a non-random distribution, across the individual paddock. High levels of soil mineral N in the poplar area in the paddock with access to poplars (AT) confirmed that the sows performed eliminations in the area with poplar trees.

Levels of mineral nitrate in pooled soil samples collected in March in the grass and the poplar areas in paddocks with and without access to trees, suggested that the poplar trees did take up more nitrate in a depth of 50-100 cm in late winter and early spring compared to grass. The modelling of nitrate leaching showed a reduced leaching (75%) in the poplar area with access to trees compared to the grass area.

7.2 Animal benefits

Giving animals the opportunity to perform species-specific and natural behaviour is important in organic farming as it provides the basis for both physical and mental health, which foster immunity and resilience. With regards to pigs, species-specific behaviours are foraging (rooting and grazing), wallowing and nest-building. Natural behaviours are locomotion, resting, stretching, grooming, playing and mating. Behaviours that are expected to give the animal pleasure and promote the animal's biological functioning (Bracke and Hopster, 2006).

As the domestic pig has retained many of the behavioural traits of the wild boar, which prefers forest and nearby forest areas as its habitat, it is important to resemble such an environment to the extent possible. Introduction of an area with poplar trees into sow paddocks contributes to a more heterogeneous and stimuli-rich environment compared to the current practice with pure pasture.

Based on this, it was decided to investigate the following behaviours: activity in general, foraging, nursing outside the farrowing hut and grooming defined as scratching on the farrowing hut and poplar trees. In addition, 'outside hut' as an indirect measure of the attraction of the range area. When outside the hut the preferred area for activity, grazing and resting as an indication of the attractiveness of the various paddock zones and the effect of temperature as an indication of the use of the trees as an alternative shaded area. As pigs are highly motivated to explore, interactions with the trees were also investigated in terms of biting branches or the tree trunk and chewing on leaves. In addition, it was decided to look into stone chewing as chewing different objects is seen in snout-ringed pigs and functions as a substitute for rooting (Studnitz *et al.*, 2003). Chewing is part of the pig's explorative behaviour along with sniffing, rooting, nudging and biting and is a way for the pig to become familiar with its environment (Studnitz *et al.*, 2007). Hence, it was hypothesised that sows with access to trees as explorative objects would chew stones less compared to sows within the other paddock treatments.

Behaviour - scan sampling

Figure 7.4, 7.5 and 7.6 show the distribution of 'active', 'grazing' and 'out of hut' in the three treatments for each observation day (indicated by date at the x-axis) within batch 1, 2, 3 and 4, respectively. With a few exceptions, across each batch of sows, activity level, foraging and time spent out of the hut followed the same trend for each treatment on observation days. Sows with tree access (AT) were provided with a more heterogeneous environment, but compared to the NAT and NT treatments, they were not more active, foraging more or spent more time outside the hut. Also, there was no effect of the age of piglets and climate. Rooting was observed at a very low level indicating that snout-ringing was effective, which was also reflected in the high percentage of grass cover, except in batch 4 (January-March). The only areas sows were able to keep free from vegetation consistently during the whole observation period were the areas with suction cups and tubes for collection of soil water. This was due to the relatively short time from installation of suction cups until insertion of sows and thus, the areas was not covered with vegetation at the beginning of the experiment. Relatively low temperatures prevailed during the summer of 2015 with the highest daily mean temperature being 21.6 °C (Figure 7.7), which is suggested to be one of the reasons for no effect seen.

Within all three treatments sows were most active in zone 2 where the feed trough was located (Figure 7.8). As the sows on seven out of 16 observation days were fed after the beginning of behavioural observations, this is likely to have been the explanation. The second most preferred zone for activity was zone 1 without paddock resources (except from grass) which was the most preferred zone for grazing. In paddocks with tree access (AT), the tree zone (zone 4) was the least preferred for activity and grazing but the most preferred for lying. Furthermore, sows without trees access (NAT) preferred to lie in zone 3, the zone next to the poplars and sows in paddocks with no trees (NT) preferred zone 2 with the feed. The data set based on observations of lying was too small to test for effect of climate. Hence, it can only be speculated that the sows used the tree area for thermoregulation and maybe the sows considered it a more protected area compared to the pasture area. That sows without tree access (NAT) preferred to lie in zone 3, may be due to the trees providing shade during part of the day and being considered a protected area. However, the sows may as well have been lying next to the hut (located in zone 3) as the hut was also providing some shade during the day.

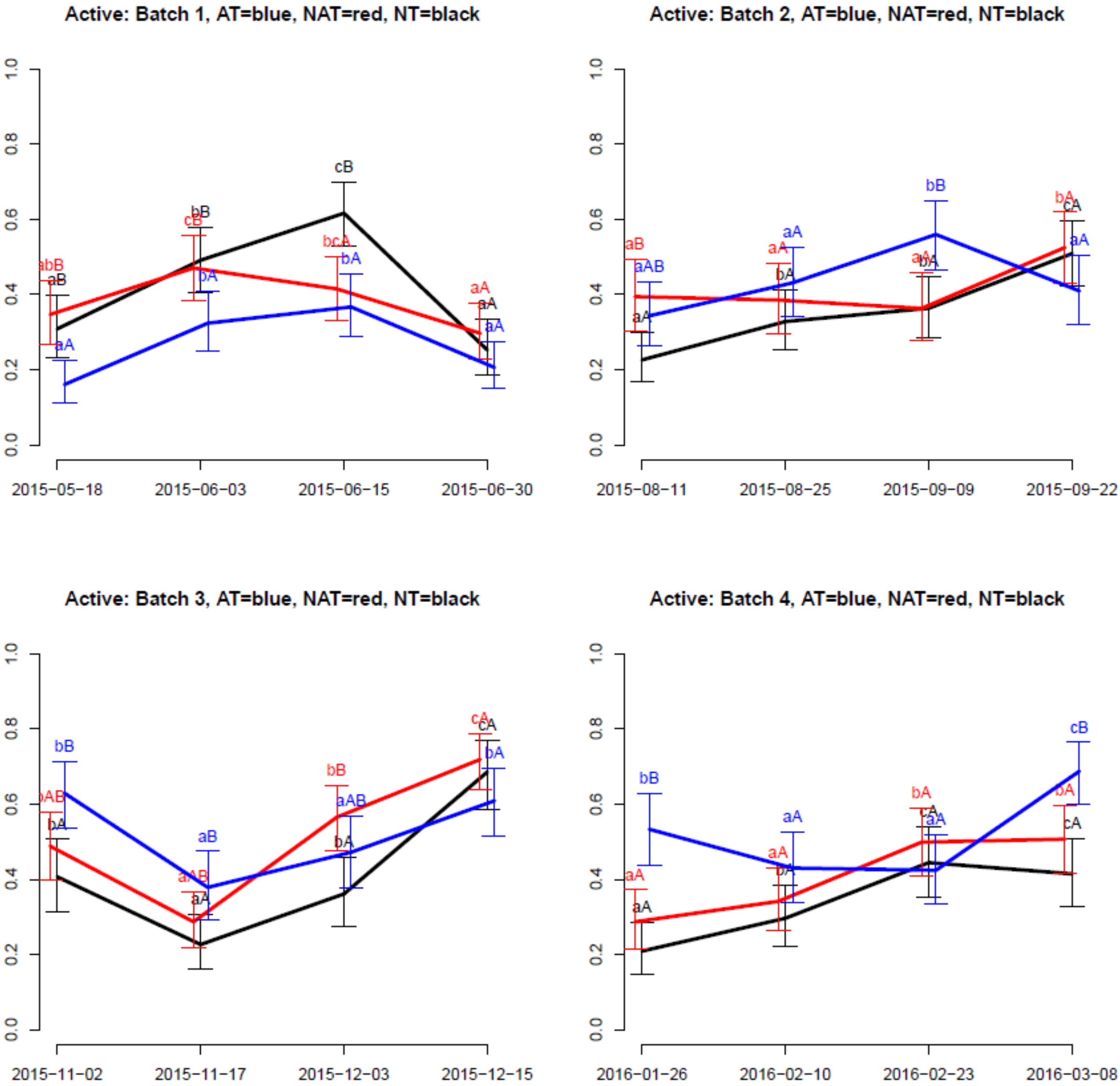


Figure 7.4 Proportion of active out of total observations per sow on each observation day (indicated by date on the x-axis) in four batches of lactating sows subjected to three paddock treatments. AT: access to an area with poplars, NAT: without access to an area with poplars (trees fenced off), NT: no trees = control. Different letters show differences at $p \leq 0.05$ within treatment (lowercase) or between treatments (uppercase).

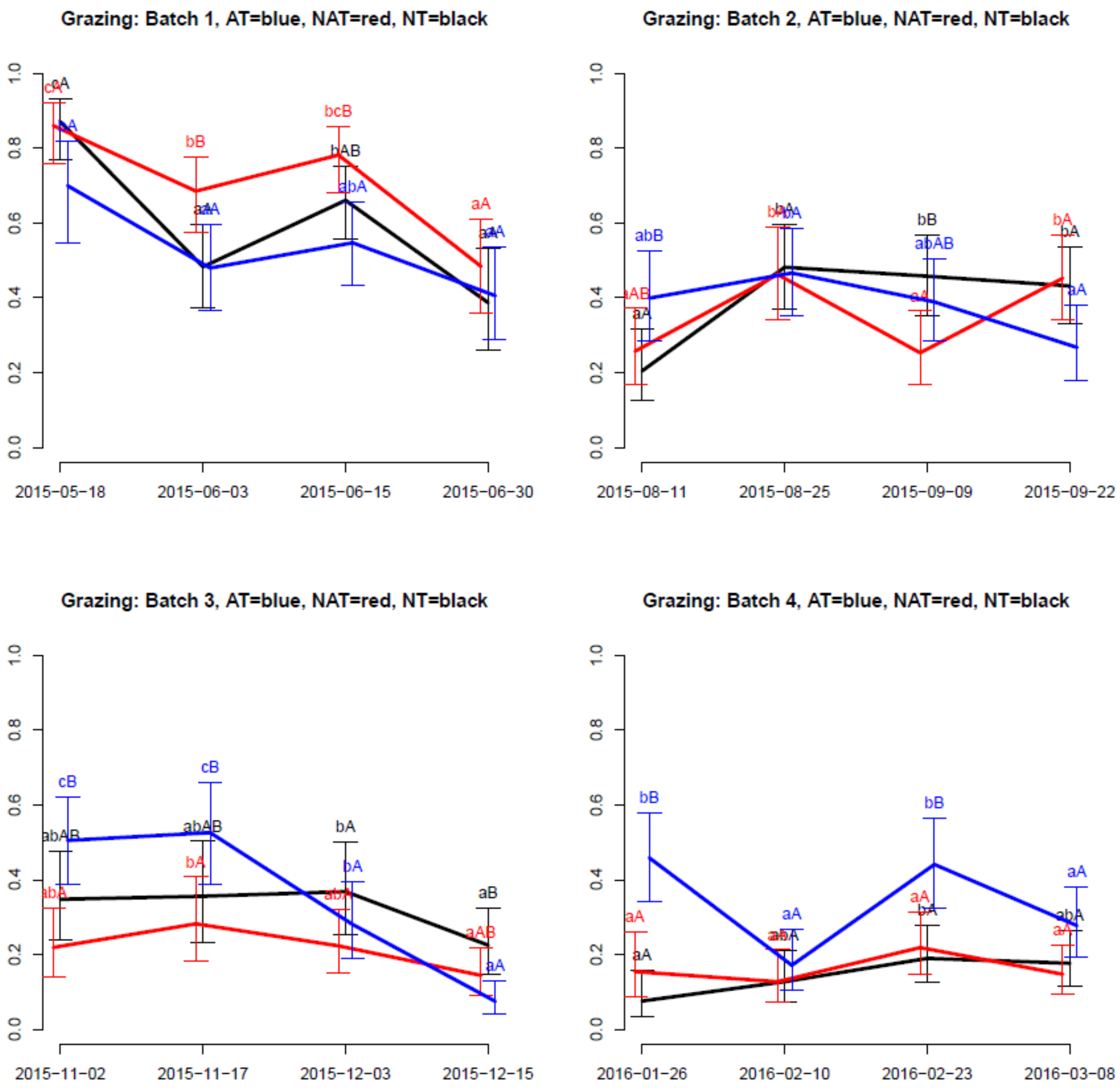


Figure 7.5 Proportion of grazing out of total active observations per sow on each observation day (indicated by date on the x-axis) in four batches of lactating sows subjected to three paddock treatments. AT: access to an area with poplars, NAT: without access to an area with poplars (trees fenced off), NT: no trees = control. Different letters show differences at $p \leq 0.05$ within treatment (lowercase) or between treatments (uppercase).

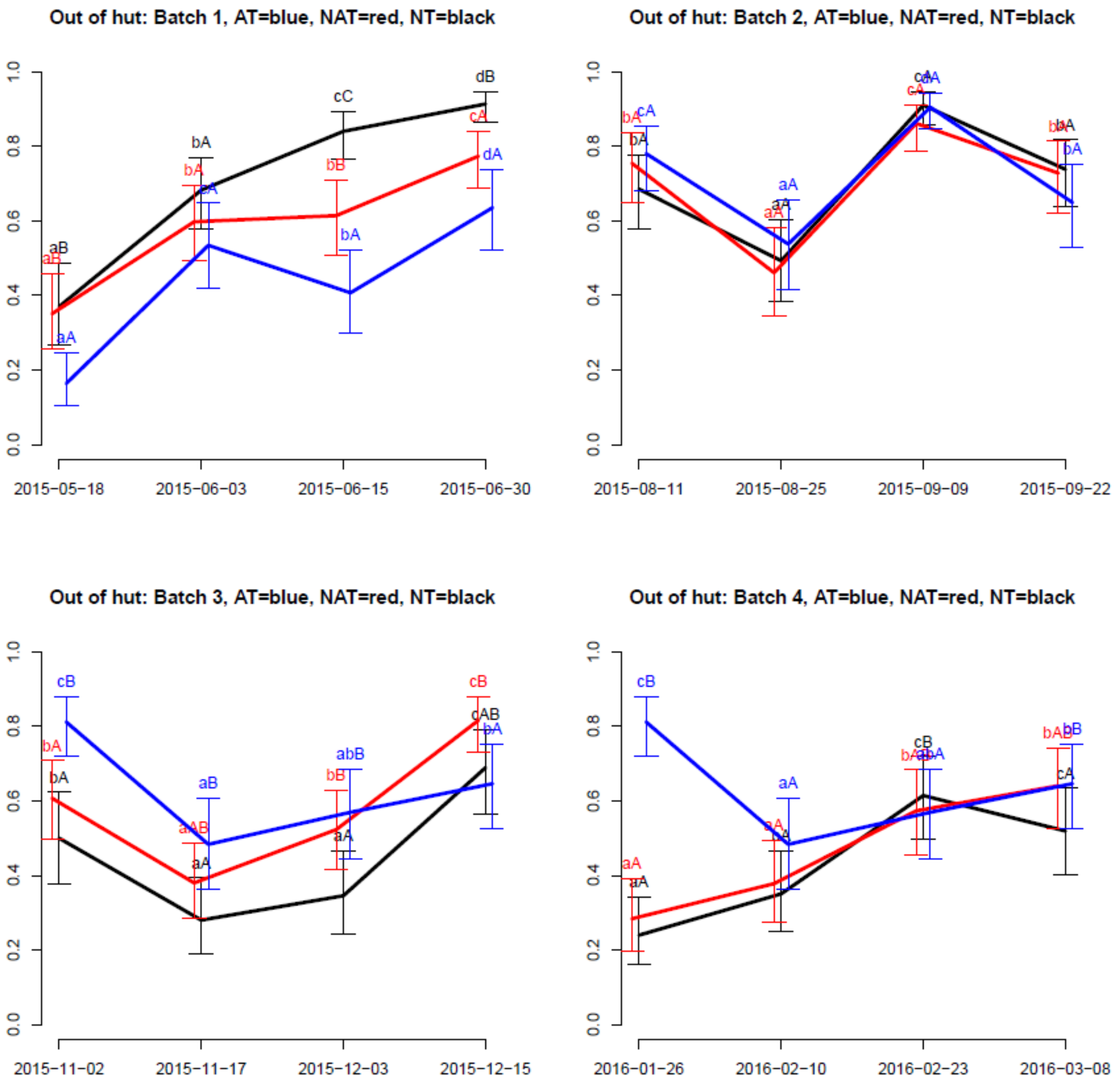


Figure 7.6 Proportion of observations 'out of hut' out of total observations per sow on each observation day (indicated by date on the x-axis) in four batches of lactating sows subjected to three paddock treatments. AT: access to an area with poplars, NAT: without access to an area with poplars (trees fenced off), NT: no trees = control. Different letters show differences at *p* ≤ 0.05 within treatment (lowercase) or between treatments (uppercase).

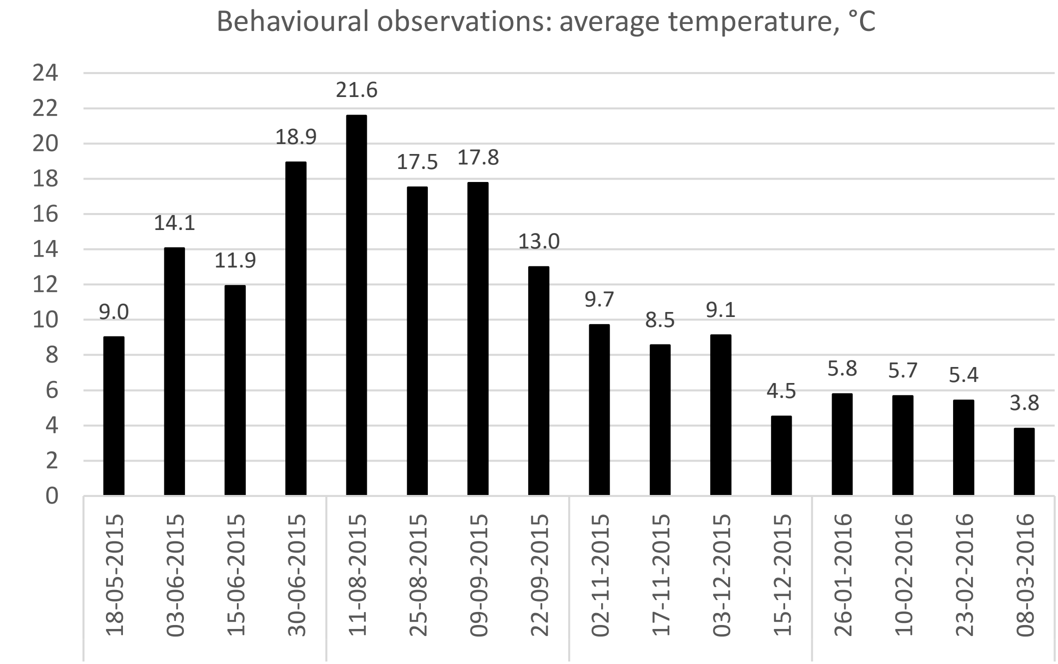


Figure 7.7. Daily mean temperature during days of behavioural observations of sows.

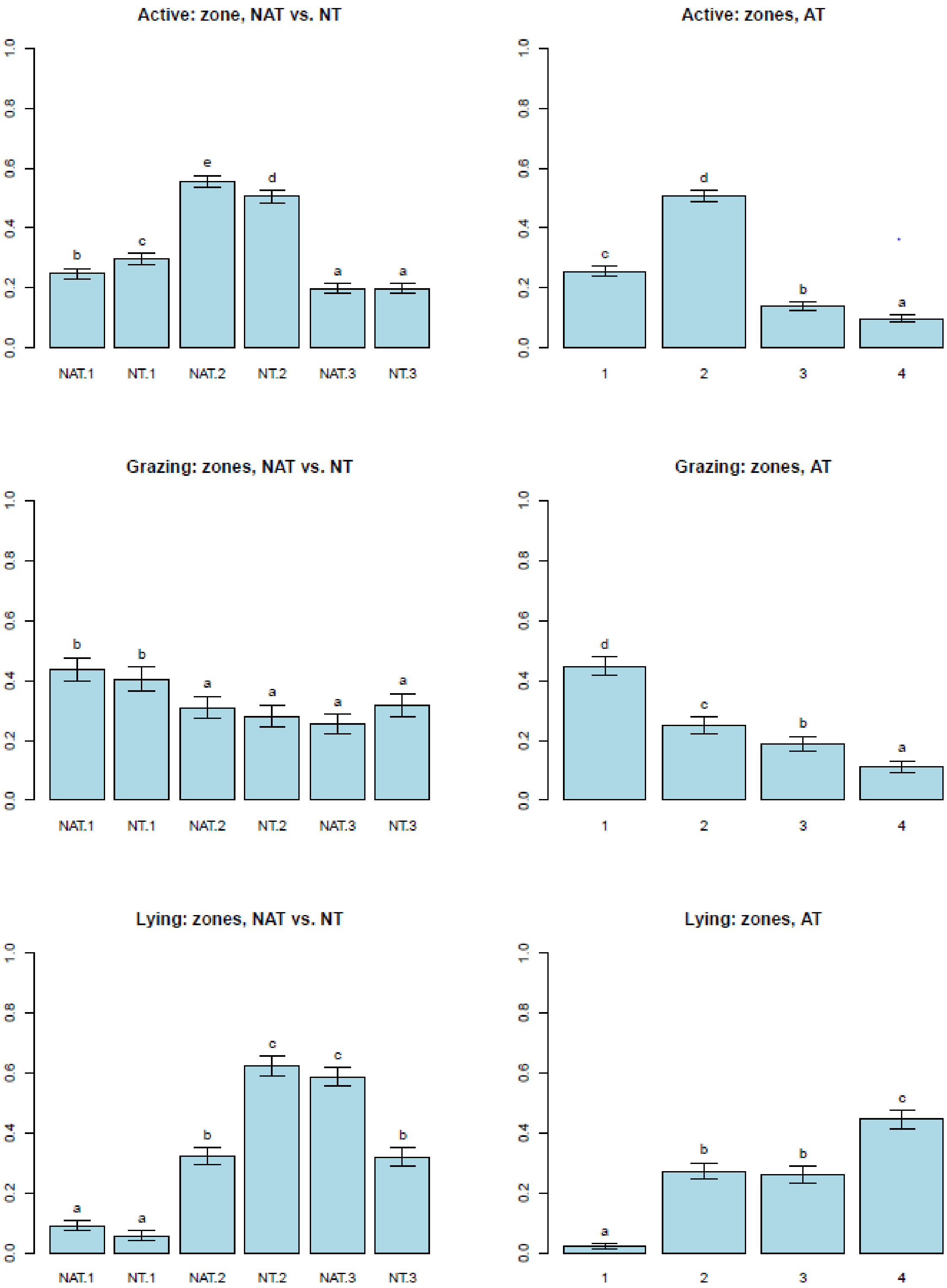


Figure 7.8. Top: Proportion of activity out of total number of observations per sow, Middle: Proportion of grazing out of total number of active observations per sow, Bottom: proportion of lying out of total number of observations per sow in zone 1, 2 (including feeding), 3 (including hut) and zone 4 (poplars) respectively in lactating sows in individual paddocks without access to trees (NAT: trees fenced off), no trees (NT = control)) and with access to trees (AT). Error bars show the standard error of the mean. Different letters show differences at $p \leq 0.05$ between zones and treatment for the NAT and NT treatments and between zones for the AT treatment.

Behaviour – all occurrences

The sows used the trees for scratching numerically more in batch 3 and 4 (November-March) than in batch 1 and 2 (May-September) (Figure 7.9). Only on four occasions a sow was observed to bite or chew on a branch or a tree trunk, which was in contrast to the tree damages found (section 7.2.1). During winter (batch 3 and 4) the occurrence of stone chewing was numerically higher compared to summer (batch 1 and 2), which may be explained by the limited possibilities for exploration during winter compared to summer, with less grass and no leaves on the trees. Numerically, the number of times suckling was performed outside the hut in AT sows was higher than in NAT and NT sows during summer compared to winter. The majority of nursing was performed in the tree area (results not shown), which indicates that the sows benefitted from the tree providing shade or considering it being a protected area.

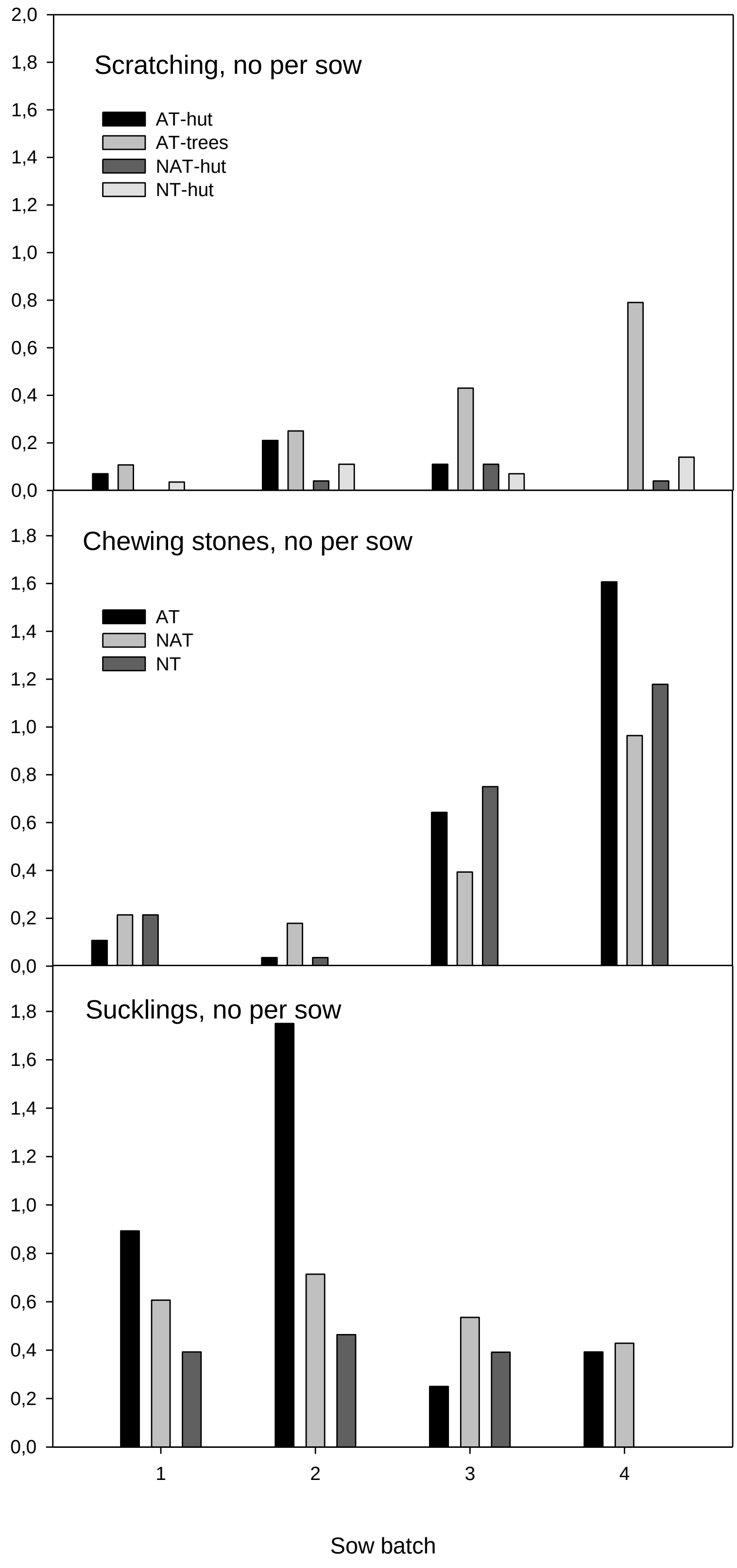


Figure 7.9. Scratching, stone chewing, and suckling, (no of occurrences per sow across all 4 observation days) for each of the four sow batches subjected to three types of individual paddocks: access to an area with poplar trees (AT), no access to an area with poplars (NAT: tree area fenced off) and with pasture only (NT = control).

7.2.1 Side effects – crop damage

Introduction of an area with poplar trees into paddocks allowed the sows to interact directly with the trees. Thus, it is important to evaluate whether the poplars were able to withstand manipulations from the sows, otherwise it is not feasible to produce pork and tree biomass on the same area.

Watercolour painting by Birte Mølgaard

Poplar trees

The level of damage to the poplars turned out not to be devastating. In the two fields with poplars, no trees were lost during the experimental period as a consequence of sow damage. In Field 1, on June 1 2016 (eight months after weaning of sow batch 2), the relatively few poplar trees, which had been severely damaged were in the process of recovery.

In each of the four sow batches, the percentage of branches left on the trees at the day of weaning compared to the first day of registration was relatively high (Table 7.6). Only in a few paddocks, the number of branches left were considerably reduced, indicating the tree damage to be related to individual sows rather than being a general effect.

On some occasions, we observed a sow tearing of branches resulting in removal of bark, a behaviour, which was primarily observed during nest building. For each sow batch, along the days of registration, for the most part trees were scored with no bark damage. The most severe damage happened from January-March 2016 (sow batch 4), but only a few poplar trees were severely damaged with 60-80% of the bark removed up to 1.1 m of the tree height.

The trees were four years at the beginning of the experiment and at that time the circumference was on average 18 cm in Field 1 and 19 cm in Field 2 (table 7.7). The growth of the poplars did not seem to be affected by pigs having access or not, in fact the trees in paddocks with access had an increased growth compared to the trees without access. In Field 1, the circumference per tree on average increased 12 cm from the beginning of the experimental period and 18 months ahead, thus, going through two growth periods. In Field 2 the figure was a little less, about 11 cm from the day prior to insertion of sow batch 3 and 13 months ahead, representing one growth period.

Table 7.6. Total number of branches left in poplar trees (1.1 m above ground) in seven individual paddocks at the day of removal of sows (after seven weeks of lactation) in percentage of the total number of branches in week two in the lactation period for four consecutive sow batches. The total number of branches in week two of the lactation period was set to 100%. However, for sow batch 1, week 3 was the first day of registration.

Sow batch	First registration day	Last registration day	Branches left (%)
1	11-6-2015	9-7-2015	68.1
2	20-8-2015	1-10-2015	78.0
3	29-10-2015	23-12-2015	81.0
4	4-2-2016	17-3-2016	67.8

Table 7.7. Circumference of poplars (cm), mean per tree in a tree height of 1.1 m

	No of trees	Date of measurements		Growth, cm
Field 1 (batch 1+2)		29-5-2015	29-11-2016	
All trees	71	17.9	30.1	12.2
+ access	36	18.7	32.0	13.3
÷ access	35	17.1	28.1	11.0
Field 2 (batch 3+4)		29-10-2015	29-11-2016	
All trees	53	19.2	29.8	10.6
+ access	31	21.5	32.6	11.1
÷ access	22	16.0	25.7	9.7

Grass-clover cover

From May to October 2015, across treatments and paddock zones, the grass-clover vegetation was to a large extent intact (Figure 7.10). However, from February to March 2016, vegetation was severely reduced across treatments and zones. It must be noted that all feedings and other interventions in paddocks were performed by use of a tractor, which is suggested to have contributed to the reduced vegetation cover.

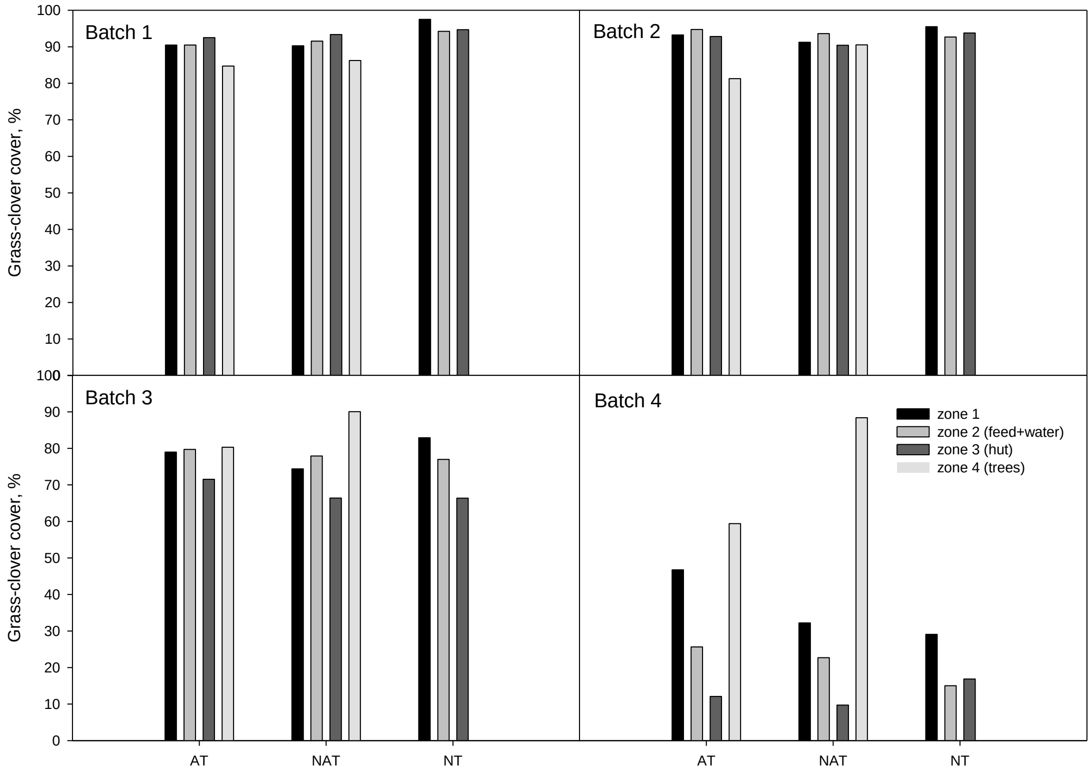


Figure 7.10. Percentage of grass-clover cover in zones (average across evaluation days) in individual paddocks occupied by lactating sows with access to an area with poplar trees (AT), without access to an area with trees (NAT: trees fenced off) or pasture only/no trees (NT = control).

8 Discussion

8.1 Foraging - a feasible management strategy in organic pig production?

Some of the challenges in the current practice with sows on pasture and growing pigs housed indoors with access to outdoor concrete areas are the ammonia emissions from the outdoor concrete areas and the high N load on pasture due to the high input of supplementary feed. Furthermore, growing pigs housed indoors does not comply with the organic principles in terms of the possibility to perform species-specific behaviour such as foraging. Alternatively, growing pigs could be integrated into the crop rotation, which would demand a system relying on foraging as much as possible and thus, decrease the input of N in supplementary feed into the system. Based on this, two alternative scenarios with foraging, grass-clover and alternative crops (lucerne and Jerusalem artichokes), respectively, were set up and compared with a scenario resembling the current practice in terms of the environmental consequences of relying on foraging. The indicators representing environmental effects were GHG emissions and potential N leaching.

The *alternative crops* scenario showed the best environmental performance with regards to GHG emissions. This was primarily due to the lower import of supplementary feed compared to the other scenarios. On the contrary, estimated potential N leaching was highest in the *alternative crops* scenario. Thus, a system integrating foraging of grass-clover, lucerne and Jerusalem artichokes did not improve the N recirculation at farm level. In the alternative scenarios the input of imported feed was lower than in the scenario representing current practice, which was the rationale behind to introduce foraging. However, the estimated input from biological N fixation of lucerne in the alternative crops scenario was an important contributing factor for the higher N leached.

Based on these results it is relevant to investigate the possibilities to improve the balance between N fixating and non-fixating crops in the crop rotation by introducing other crops with a favourable nutrient composition for pigs, e.g. dandelion, which has a CP and lysine content comparable with lucerne (Jakobsen *et al.*, 2015).

It may also be relevant to combine foraging with other management strategies such as a reduction in supplementary protein feed as a lower N surplus and thereby reduced risk of potential N leaching is related to restricted feeding as found in the study by Eriksen *et al.* (2006a). A system with growing pigs foraging on lucerne and restricted in protein (107 g CP kg^{-1} DM feed ~48% reduction) was found to improve the N efficiency of the system by using 169 g less supplementary feed CP kg^{-1} weight gain compared to a system where pigs were fed according to recommendations (Jakobsen *et al.*, 2015). However, the restricted pigs had a lower daily gain (741 g) compared to non-restricted pigs (900 g) and thus, they have to stay longer in the system before they reach slaughter weight and thus occupy valuable land resources. The study was based on strip grazing, thus optimizing the availability of forage and reducing pigs' trampling, which destroys the crop. In practice, the concept of strip grazing has to be developed in terms of technical solutions to decrease the workload related to moving the fences. An additional benefit of strip grazing may be a more even distribution of urine and faeces within paddocks as Stern and Andresen (2003) found that growing pigs given 50 m^2 of new pasture each morning, eliminated primarily in that area.

Another strategy to decrease potential N leaching is to reduce the stocking density as reported in Jørgensen *et al.* (2018). However, combining foraging in the range area with a reduced stocking density may not to be a viable management option as land is a limited resource. Currently, compared to conventional pig production, yields and feed conversion are poorer in organic farming resulting in a higher pressure on land use (van Wagenberg *et al.*, 2017). Hence, preventing N losses is an important prerequisite for increasing yields, thereby improving the production of home-grown crops. In that context, mobile systems may prove useful in distributing the urine and faeces more evenly across the field and by that increase yields as compared to the current practice with nutrient hot-spots exceeding plant nutrient uptake. Furthermore, it is important to identify high yielding crops of a high nutrient value for pigs.

Another possibility may be to combine foraging with seasonal production and include the rooting abilities of pigs to tillage the soil and to forage for root crops and left over crops. In that case, the production of pigs takes place during the growing season with plenty of forage crops and not during winter where the risk of N leaching is high. Also, the capability of pigs for rooting is used as an asset in the system, which would eliminate snout ringing. This demands adaptation of the whole farming systems to this type of production and pigs that are well integrated in the crop rotation. Possibly it needs to be combined with other types of on-farm production and elicit a premium price to make the system economically viable for farmers. Of relevance is also to reduce the input of feed into the system by providing protein according to the pigs' requirements. Also, it is relevant to reduce feed waste by adequate feed troughs and feed techniques.

In summary

Improved foraging of lucerne, Jerusalem artichokes and grass-clover in the range area turned out to be a feasible strategy in order to reduce GHG emissions but was unsuccessful with regards to reducing estimated potential N leaching compared to current practice. Foraging is an interesting alternative that needs to be developed in terms of technical solutions to allow strip grazing. The system may benefit from implementing the rooting abilities of pigs. Foraging combined with other production strategies such as seasonal production is suggested to lead to a significant reduction in nitrate leaching.

8.2 Silvo-pasture - a feasible production strategy to reduce nitrate leaching in organic pig production?

8.2.1 Spatial distribution of nitrogen

The risk of nitrate leaching is assumed to be affected by the spatial distribution of urine and faeces in the paddock and in relation to the presence of trees in particular. Several methods were used to describe the elimination behaviour – direct monitoring of the urination and defecation behaviour of sows in predetermined paddock zones, visual estimation of faeces in predetermined grids after each sow batch and distribution of mineral N in one paddock within each treatment.

Based on the findings of elimination behaviour in growing pigs with access to zones with energy crops (Horsted *et al.*, 2012), it was hypothesised that the sows would perform the majority of eliminations in the poplar area, which was not the case according to the behavioural observations. However, the visual estimations of faeces showed that sows did defecate in the poplar area but also in the area opposite the hut along the paddock fence. In addition, soil mineral N distribution indicated eliminations in the poplar area and in the area around the hut and towards the fence to the tree area. Soil mineral N levels being high in most of zone 3 (including the hut) was suggested to be due to the movement of the hut between batch 1 and batch 2. Also, feed and water troughs were moved to the opposite side of the paddock after batch 1. Still, it was quite clear from the visual estimations that sows avoided defecating around the resources. This indicated that sows were not affected by the location of faeces from the previous sow batch. The differences between the findings by Horsted *et al.* (2012) and the current study may also be related to the fact that sows nursing piglets and housed in individual paddocks may well behave differently than growing pigs housed in groups.

The results of the direct observations of sow behaviour were not completely in accordance with the visual estimation of faeces and soil mineral N distribution. The observations of sow elimination behaviour showed a random distribution between the defined zones, except for urinations in paddocks with access to trees where sows preferred to urinate in zone 1 located in the opposite end of the paddock compared to the tree zone. This is in contrast to other studies with free-range pigs where a non-random behaviour has been observed (Stern and Andresen, 2003; Watson *et al.*, 2003; Salomon *et al.*, 2007; Horsted *et al.*, 2012; Ferretti *et al.*, 2015), although it must be stated that no sows were observed to eliminate within 1 m around the feed trough. Partly, this may be explained by the fact that the observations began at 09:00 in the morning and during summer months, morning urinations are suggested to have taken place prior to observation start and thus, we may well have missed some observations in the zone with the hut (zone 3). The visual estimation of faeces load in paddocks across the four sow batches clearly displayed a non-random defecation behaviour with no faeces around resources (hut, feed and water). In fact, the location of faeces differed more within the defined paddock zones than between them. Hence, prior to behavioural observations, it would have been beneficial to have organised a more detailed division of the paddock zones according to the location of resources. Also, in paddocks without sow access to trees, it would have been relevant to include a zone along the fence of the poplar zone to get information about the number of observed eliminations near the tree zone.

The results of the spatial distribution of soil mineral N displayed the large variety in mineral N load within individual paddocks as also found in other studies of free-range pigs (Eriksen and Kristensen, 2001; Eriksen *et al.*, 2002; Watson *et al.*, 2003; Eriksen *et al.*, 2006b; Jørgensen *et al.*, 2018). The highest mineral N load was found around the hut, which in AT paddocks was the zone with the lowest number of observed urinations. According to the visual estimation, the area around the hut was kept free from faeces. The high N load in part of the zone with poplars was in accordance with the findings of the visual estimation. In zone 2 where the feed was located, there was a relatively high mineral N load in both paddock treatments but the high load was distributed across a larger area (into part of zone 1) in the paddocks without access to trees. This is in accordance with Eriksen and Kristensen (2001), who found high levels of mineral N around the hut and the feeding place. In the current study, the high N load in the feeding area may be related to feed waste. The farmer or farm manager fed by use of a tractor and had to be precise in order for the feed pipe to be located just above the trough. Also, water was applied in the feed trough, which in several cases was seen leading to feed waste. The differences in findings may also be related to the visual estimations being performed after weaning of each of the four sow batches and then averaged, while the soil samples were collected at the end of October after sow batch 1 and 2.

The results show that sow elimination behaviour was affected by the location of resources and that pigs do not defecate near the sleeping area (hut), nor urinate and defecate near the feeding place, which is in accordance with other studies (Stolba and Woodgush, 1989; Watson *et al.*, 2003; Eriksen *et al.*, 2006a; Salomon *et al.*, 2007). Also, it has been reported that pigs avoid eliminating near the wallow (Sambraus, 1981; Salomon *et al.*, 2007; Andersen *et al.*, 2017). Andersen *et al.* (2017) investigated the effect of the spatial arrangement of an area with poplar trees located at one end of the paddock (two rows with four trees in each row, representing 34% of the paddock area), hut, feed and wallow on elimination behaviour of lactating sows in individual paddocks. The preliminary data analysis showed that sows did not eliminate within 1 m around the resources. To some extent it was possible to manipulate sows' elimination behaviour by the spatial arrangement of resources. The most optimal arrangement to motivate sows to eliminate in the poplar area, was to locate the hut nearby the poplar area and the feeding place in the area furthest away from the tree area. The least optimal arrangement was to locate both the hut and the feeding place nearby the poplar area.

In the study by Andersen *et al.* (2017) and the current study, the poplar area was located at one end of the paddock. Thus, it was not possible to locate the hut and the feeding place on each side of the tree area, which was the case in the study by Horsted *et al.* (2012) of growing pigs and suggested to be the reason for the high number of eliminations observed in the zone with willows.

Pigs eliminating between the hut and the feeding place was also found in the study of growing pigs by Benfalk *et al.* (2005) and in Salomon *et al.* (2007) (same study), as the area 1-15 m away from the hut was covered with manure. Also, Stolba and Woodgush (1989) found that family groups in a semi-natural environment defecated 5-15 m away from the hut. In the latter study, during day-time the pigs defecated in wide paths running through gorse bushes. Hence, when trying to locate resources most optimal, it is suggested that at least two situations must be taken into consideration, the one where the pig leaves the hut after resting for a period of time and the one where the pig is active and exploring including foraging.

As part of my PhD education I went to Spain to visit the Dehesa (semi-natural silvo-pasture system with oak trees and Iberian pigs) and together with researchers and veterinary students I performed behavioural observations of pregnant Iberian sows. Focal sows were followed from feeding at 09:00 until the sows returned to the resting place in the evening at around 18:00. The results of these observations are not ready yet, but according to my own anecdotal description of the sows' elimination behaviour, during mornings they eliminated approximately 10-20 m away from the sleeping area, which was connected to a concrete yard where they were fed. After being fed they moved to the Dehesa where they stayed all day and then returned to the sleeping area after 7-8 hours of grazing. During grazing they performed eliminations where they were situated at that particular time. Thus, they did not seem to walk away with the purpose of eliminating and often when defecating they did so while still grazing. In the current study, the behavioural observations of eliminations were not in accordance with the location of activity during day time as pigs in all paddock treatments were found to be most active in zone 2 (feed). It must be taken into consideration that the system with 60 pregnant sows in a semi-natural silvo-pasture system with 30 ha was very different from the more confined paddock system in the present study. However, studies of pigs in semi-natural systems give us indications of the pig's preferences when given plenty of space. Hence, it provides us with information as to what must be taken into consideration when designing paddock systems with the purpose of directing elimination behaviour where it is most appropriate in terms of environmental protection. At the farm where the current study was performed, the farmer has recently decided to locate the farrowing hut in the zone with poplar trees. The rationale behind this is to keep the hut in the shade to reduce the temperature inside the hut during periods of warm weather and consequently improve the welfare of the sows. Also, this is expected to prevent sows from farrowing outside the farrowing hut, thus reducing the risk of predation by foxes. Furthermore, the idea behind locating the hut in the tree area is that the sows will eliminate there on their way to the feed, which is situated just outside the tree area.

Depending on season and thus temperature, another situation may be considered. During periods of hot weather, pigs may choose to rest outside the hut or in the area with trees. Hence, the location of the lying area may affect the sow's choice of elimination location after getting up from resting, which depends on whether the pig is e.g. hungry, thirsty or aims for the wallow. Furthermore, if the sow prefers to use the tree area for lying, it may not be considered an appropriate place for eliminations. This may depend on the size of the area with trees as it may be possible for the sow to use part of the tree area for resting and another part for eliminating.

8.2.2 Nitrate leaching

Total mineral N load at the end of October (depth 0-50 cm) in paddocks with access to trees (AT) was similar in the grass area and the poplar area, whereas the N leaching was higher in the grass area compared to the poplar area, which indicated uptake of nutrients by the poplar trees.

The high levels of N leached in the control area in paddocks with no trees (NT) compared to the N leached in the poplar area in paddocks with access to trees (AT) indicated an N uptake by the poplar trees. However, this is also suggested to be related to a shorter distance between the hut and the suction cup located in the control area in paddocks with no trees (NT) compared to paddocks with tree access (AT), thereby changing the location of sows' eliminations.

The reasons for the unexpected high leaching in the grass area in paddocks with access to trees (AT) compared to paddocks without trees (NAT) is not immediately explainable. In almost all paddocks the areas around the suction cups were kept free from vegetation by the pigs throughout the experimental period as the time from implementation of suction cups until insertion of sows was too short for the grass to re-establish, also in between sow batches. The suction cup in the grass area was located in zone 2 where the feed was located. On some occasions feed troughs had been mowed by sows from the side of the paddock close to the fence (original location) towards the middle of the paddock and as considerable feed waste was observed during some feedings, this might have affected the amount of N leached. This may also have been one explanation for the high variation in N leaching between paddocks observed in the grass area in all paddock treatments.

There was no difference between the mineral N load in the grass areas of AT paddocks and NAT paddocks and similar results were found with respect to estimated N leaching. However, there was a large variance in estimated N leaching between paddocks. Also, mineral N distribution within individual paddocks clearly showed the large variation in load. Hence, if the two suction cups in each paddock had been placed below an area with a high N load, inevitably this would have affected the amount leached. In the current study, there were seven replicates within each treatment, however, it may have been relevant to introduce several suction cups in each paddock to represent the large variation of N load in the paddock. However, this was a matter of resources and counteracted by collecting several soil samples in the individual paddock that represented the large variation.

Calculated as a weighted average of the poplar area and the grass area, estimated N leaching was numerically lowest in paddocks without tree access (NAT) with 101 kg N ha^{-1}, which was related to the low leaching in the poplar area without sow access. Estimated N leaching in paddocks with access to trees (AT) with 175 kg N ha^{-1} was very similar to the leaching in paddocks with no trees (NT) with 206 kg N ha^{-1}. As the paddocks with no trees were situated in another field compared to paddocks with trees, the results may not be directly comparable. Rather, they can be used as a control in terms of estimated N leached within the current organic farming practice.

In paddocks with access to trees, the presence of six poplar trees, corresponding to approximately 20% tree cover, on average, reduced N leaching by 75% compared to the grass area even though soil samples (mineral N) indicated corresponding N loads in the poplar and grass areas. This result indicated that poplar trees were more effective in reducing the nutrient leaching compared to grass. However, 20% tree cover is not sufficient to reduce N leaching on a paddock area basis in systems with a very high N surplus of around 400 kg N ha^{-1}.

The immediate answer to the fact that the poplar trees on a paddock basis were not able to reduce N leaching sufficiently might be 'just' to plant more poplar trees. However, as land resources are scarce and the consequence would be less area available for production of home-grown feed, this may not be an optimal solution, unless the poplar trees are able to provide an income in terms of biomass production that is able to counteract the reduction in cereal production. Furthermore, larger areas with tree cover may hinder the surveillance of piglets and encourage sows to farrow outside the huts in warm seasons with a potential detrimental effect on piglet survival.

As discussed in the section related to elimination behaviour, locating the tree zone between the hut and the feeding area may have led to a further reduction in N leaching. Obviously, it is of major importance to be aware of the location of paddock resources and the spatial distribution between them in order to obtain the most appropriate distribution of N within the paddock. As suggested in the section on foraging, the N load in the system would be reduced by lowering the stocking density and changing the production to take place during the growing season. A reduced stocking density could be represented by having pigs on the area every year with 1.4 AU, corresponding to 140 kg N ha^{-1} $year^{-1}$ instead of doubling the stocking density every second year as is currently common practice. With regards to seasonal production (during the growing season), this might not be an option for farmers who have already invested heavily in buildings and equipment for indoor housing of growing pigs. It might be possible to establish collaborations with pig producers and producers of energy crops in order to increase the outdoor free-range pig production. As the production of growing pigs is less knowledge specific compared to the piglet production, it may show productive to combine energy crops with the production of pork.

Another contribution in terms of reducing N leaching might be related to the management of the trees. During autumn, prior to defoliation, poplar trees accumulate large amounts of storage protein in the bark. This is kept as a reserve and is ready for use when the trees begin the growth cycle again during spring (Vancleve and Apel, 1993; Millard and Grelet, 2010). Hence, to remove N from the system, it would be relevant to harvest the leaves during the growing season as the trees would then again accumulate N in the leaves. However, this may coincide with the time of year where the leaves are needed to provide shade and add to the workload of tree management. Sows' use of branches and leaves from trees for nutrient purposes is another element that could potentially lead to an increased N recirculation in the system if the consequence was a decreased input of supplementary feed, although the nutrient contribution is suggested to be minor due to the relatively large content of lignin.

In summary

Inclusion of 6 poplar trees corresponding to around 20% tree cover in individual paddocks with access to trees on average reduced the N leaching by 75% compared to the area with grass, which was not sufficient to reduce N leaching on a paddock area basis. It is suggested to be possible to reduce N leaching further if the spatial arrangement of the resources in the paddock are optimized as much as possible in order to manipulate sows to eliminate in the tree area. Also it is suggested to be reduced as the trees grow older and are able to take up more N. Increasing the tree area would probably reduce the N leaching even further but it needs to be counterbalanced by an income from the tree biomass as it reduces the area available for cereal production in between years with pigs. Different management and production strategies such as reduced stocking density, seasonal production and cooperation with producers of energy crops might prove useful depending on the possibilities and goals of the individual farmer.

8.3 Benefits for the animals

For Danish organic farmers who have implemented trees in sow paddocks, one of the main reasons was related to the welfare of the pigs, which was confirmed in a recent study on perception of agroforestry in Europe (García de Jalón *et al.*, 2017). The argument is that the pig is a forest animal and that the trees to some extent mimic a natural environment in addition to providing shade for thermoregulation. As the farmer, where the experimental work was conducted, stated:

"Pigs are forest animals – with the poplar trees I wanted to provide as much as possible a natural environment for them and I believe they really enjoy having the area with trees".

The fact that sows in paddocks with access to trees preferred to lie in the poplar area when outside the hut suggested that the trees provided some benefits, e.g. in terms of shade. Schild *et al.* (2018b) found that lactating sows lay more in the poplar area (8 x 4 rows, 212 m^2) at increased hut temperature when the temperatures in the area with poplar trees were lower than temperatures inside the hut and in the pasture area of the paddock. Also, Bonde (2016) reported that lactating sows with piglets of 1-4 weeks lay more in an area with willows at ambient temperatures above 15°C. When temperatures reached above 20°C the willow area was the preferred area to rest in for sows with piglets from 4-7 weeks, which supports the suggestion that the shade of the trees was used for thermoregulation. In addition to shade, it may be that the poplar area constituted a protected area for the sow and piglets compared to the open grassland as also argued by Bonde (2016).

Watercolour painting by Birte Mølgaard

In the current study, the sows in paddocks with the tree area fenced off preferred to lie in zone 3 (the zone next to the tree area). The farrowing hut was located in zone 3 and the zone was 90 m^2. Hence, it was not possible to elucidate if the sow rested in the part of zone 3 that was near the zone with poplars. As poplar trees must be fenced off for a period of 3-4 years, until they are able to withstand manipulations by sows, it would be important to investigate if an area with trees, even though it was not accessible, would be able to provide shade or 'perceived' as a more protected environment compared to the paddocks with open grassland. Hence, it would have been relevant to include a zone of 1-2 m from the tree area along the fence and record lying behaviour including recording of whether the sow was in shade or not. Similarly, it would have been relevant to include a zone around the farrowing hut. Lying was recorded on the basis of six categories in relation to sow postures along with whether 50% of the sow was in shade or not, which would give an indication whether the hut or the trees were able to provide shade. However, these data have not yet been analysed. In contrast to the two other paddock treatments, sows in paddocks with no trees (NT) preferred to lie in zone 2 and there is no immediate explanation to this as wallowing (located in zone 2) was recorded separately. However, due to the sandy soil in some paddocks, the wallows were very difficult to maintain. Hence, some sows may have been lying in the area around the water trough as water application was performed with a tractor and a pipe that wasted water around the trough.

In all treatments the preferred zone for grazing was zone 1, which was not in accordance with the results from Bonde (2016) who found that in particular sows with piglets from 4-7 weeks used the willow area for grazing and rooting (some sows were not ringed) as compared to the pasture area. Also, Schild *et al.* (2018b) reported that use of a poplar area was high *pre partum* and in late lactation, indicating that the sows preferred the poplar area for other reasons. In the current study, there were no resources, other than grass, located in zone 1 and it may well have been perceived by the sows as an area for foraging, thus resembling the preference of wild boar and feral pigs for grazing in open areas that are partly grassland adjacent to forest or dense bushes (Graves, 1984).

Rooting was observed at a very low level probably due to snout ringing of sows. Considering that rooting is of high priority in pigs (Studnitz *et al.*, 2007) and a behavioural need (Horrell *et al.*, 2001), this type of intervention may be considered a violation of the animal's integrity. This is very much in contrast to the organic principles and actions otherwise taken in terms of providing a system, which in many other ways offers the animals the opportunity to perform a wide repertoire of behaviours. As snout-ringed pigs have been found to substitute rooting with other behaviours such as chewing, nudging and sniffing (Studnitz *et al.*, 2003), it may be that the pigs in the current study substituted the lack of possibility for rooting with grazing during summer and possibly stone chewing during winter. Hence, the fact that pigs had the possibility to perform other explorative behaviours than rooting is suggested to have impaired their welfare less than a lack of stimuli in the environment (Studnitz *et al.*, 2003). As stated previously, the argument for snout ringing sows is environmental concern. Snout ringing prevents the pig from rooting and rooting destroys the grass cover in paddocks, which thereby increases the risk of N leaching. Eriksen *et al.* (2006b) investigated snout ringing in pregnant and lactating sows and the effect on grass cover and nutrient deposition and found that although snout ringing did preserve grass cover, the main contributing factors for potential N losses were feeding, stocking density and distribution of nutrients (eliminations). Thus, it seems possible to refrain from snout-ringing sows, in particular if they can be manipulated to eliminate in dedicated areas such as within the area with poplar trees by the spatial arrangement of resources in the paddock. Although, some farmers report that rooting from sows can be profoundly and in some occasions leaves the field in a three-dimensional shape, significantly increasing the workload for seedbed preparation after sow occupation. It must be taking into consideration that in addition to rooting for exploratory purposes, pigs are 'comfort rooting' (Andresen and Redbo, 1999). Thus, providing a proper wallow and a cool place for lying may decrease destruction of the paddock as found in the study of pregnant sows by van der Mheen and Spoolder (2005).

As sows did not have equal access to wallows due to the sandy soil in some paddocks, it was not possible to relate the use of the wallow with the use of the poplar area in terms of providing shade for thermoregulation, as it may be tempting to suggest that an area with trees represents a substitute for the wallow. Bonde (2016) found that in lactating sows the use of the wallow did not depend on whether they had access to an area with willow or not, suggesting that an area with trees in paddocks for lactating sows cannot replace wallowing. Rubbing or scratching is the most frequent behaviour performed after wallowing (Bracke, 2011), which could be confirmed according to my own anecdotal observations of Iberian sows in the Spanish Dehesa during my stay at the University of Córdoba (Figure 8.1). This suggests, that rubbing on trees after wallowing is related to skin care and thus, has an additional purpose other than thermoregulation and therefore wallowing cannot be replaced by a tree area. In the current study, during winter, sows with access to trees were rubbing their bodies numerically more compared to sows in the other paddock treatments and the rubbing was performed on the poplar trees. Rubbing on trees may be considered a type of displacement activity as suggested by Studnitz *et al.* (2003) related to the lack of stimuli in the paddock during winter in addition to snout-ringing preventing rooting.

Figure 8.1. Mud on tree trunk from pigs' rubbing after wallowing in the Spanish Dehesa system. Photos: Malene Jakobsen.

The behavioural recordings of activity, grazing and 'out of hut' can be considered as indirect indicators of animal benefits. More direct indicators are suggested to be sunburn or heat stress. Hence, it may be anticipated that access to an area with trees would prevent sunburn in sows, which is expected to be associated with pain. A pilot study was conducted during the experimental period of the current study and the level of sunburn in sows did not differ between the three paddock treatments (Jakobsen *et al.*, 2017). Within all treatments, the majority of sows (85%) had severely sunburned ears with wounds and flaking skin. Hence, about 20% tree cover was not able to prevent severe sunburn on ears. This was in accordance with the level of sunburn recorded in another study of lactating sows in individual paddocks with 30% tree cover (poplars), where 59% of the sows had severely sunburned ears (Jakobsen *et al.*, 2017). Sunburn is affected by the possibility to wallow and as sows in the current study did not have equal access to wallows due to the sandy soil in particular in some paddocks, this may have affected the results of the pilot observations. However, it may also be argued that it is not possible to avoid sunburn when using white genotypes. In the study with 30% tree cover, during summer, sow respiration rate (breaths per 60 seconds) was lower in the area with poplars than in the farrowing hut. Thus, the trees were able to reduce or prevent heat stress and may provide an area for sows to thermoregulate in the medium temperature range.

8.4 Crop damages

The Danish organic pig producers that have planted trees also refer to the trees' aesthetic value – as the organic farmer where the study was performed stated:

"I didn't like to see those flat fields with just grass – it looks beautiful with the threes. A working environment with trees and pigs is simply much more satisfying".

To maintain trees in paddocks requires trees surving from the pigs' manipulation and that the workload related to fencing and the trees is manageable. As stated previously, all of the poplar trees survived and only a few trees were severely damaged and were in the process of recovering at the evaluation approximately eight months after removal of sow batch 2. It is unknown whether the trees would have recovered if they had not been allowed to rest for a relatively long period of time. Common practice is to occupy paddocks for an entire year every second year and these paddocks were only occupied with pigs from May until the beginning of October.

Some farmers may want to reduce the sows' use of branches for nesting material due to a possible negative effect on piglet mortality. There is to my knowledge no scientific evidence but it may be suggested that the presence of branches inside the hut decreases the possibility for the piglets to avoid being crushed by the sow. Also, it may be argued that it is an additional workload to pull out branches from the farrowing huts. Currently, the farmer, where the present study was conducted, has solved this by cutting off branches below 1 m tree height. Also, this reduces the amount of tree damage as tearing of branches by sows was related to a relatively large amount of bark being removed from the tree stem on some occasions. The results from the current study suggest that individual sows tear of branches and use them for nesting material, rather than the behaviour being a general trend among sows. This was in accordance with the study by Schild *et al.* (2018b) where only a few sows were reported to use branches for nest building. Also, Bonde (2016) reported that one sow out of seven was observed gathering willow branches for nesting material.

Biting branches or tree trunks was only observed five times, hence, the behavioural observations were not in accordance with the observed damage to the trees, although no trees were severely damaged. The relatively low level of damage to the trees may be related to the sows being ringed in the current study as Bonde (2016) reported a higher level of damage to willows in one herd with un-ringed sows compared to ringed sows. Also, the fact that a larger area in paddocks with un-ringed sows consisted of willows was suggested as a reason for the higher level of damage.

Other trees in combination with energy crops might prove useful in a system with pigs. As poplar trees during winter are not expected to provide shelter, incorporation of evergreen trees such as pine might serve that purpose. Other trees may provide nutritional supplements in terms of nuts and fruits. In addition, the landscape aesthetics is improved.

9 Conclusions

Based on pigs' species-specific and natural behaviour, improved foraging and poplar trees were introduced into organic pig production as alternative management and production strategies in order to improve the nutrient-efficiency of the system.

By modelling, improved foraging in the range area was introduced in order to improve the overall environmental effects at farm level. Two alternative systems integrating foraging by sows and growing pigs were hypothesised to reduce GHG emissions compared to the current practice with sows on pasture and growing pigs in stables. In addition, growing pigs in an improved forage crop system were hypothesised to reduce N leaching at farm level compared to a system with growing pigs foraging on grass-clover. Furthermore, the improved forage system was expected to improve overall farm environmental performance compared to current practice.

Improved foraging, represented by pigs foraging on lucerne, Jerusalem artichokes and grass-clover in the range area, is a feasible strategy in terms of reducing GHG emissions. However, in terms of reducing N leaching, it must be combined with other management and production strategies such as a reduced stocking density, mobile systems (strip grazing) and seasonal production of pork during the growing season of crops. Also, possibilities for an improved balance between nitrogen fixating and non-fixating crops in the rotation must be considered, in addition to introduction of high yielding crops with a favourable protein composition for pigs, which entails supplying pigs with protein according to their requirements in the total feed ration.

In a farm experiment, an area with six poplar trees (20% tree coverage) was introduced into individual paddocks with lactating sows in order to investigate environmental and animal benefits. It was hypothesised that an area with poplar trees would reduce nitrate leaching compared to the grass area.

The level of soil mineral nitrogen in a depth of 0-50 cm in the area with poplar trees compared to the level in the pasture area at the end of October 2015, indicated similar N loads in the two areas after the growth period where paddocks were occupied with sows and piglets. However, in late winter and early spring, the poplar trees were apparently more efficient than grass in taking up nitrate in the deeper layers of the soil (depth 50-100 cm). This was indicated by a low level of soil mineral N in the area with poplar trees compared to the area with grass in spring, six months after sow occupation.

In the paddocks where sows had access to poplar trees nitrate leaching was reduced by 75% compared to the area with grass. However, on a paddock area basis this is not enough to substantially reduce nitrate leaching in a system with an estimated potential N surplus of approximately 400 kg N ha^{-1}. Hence, it may be concluded that the area with trees must be increased beyond the 20% coverage as was the case in the present study. However, increasing the tree area will reduce the area available for growing cereals and thereby reduce the production of home-grown feed. Thus, the loss in feed production must be counterbalanced by an income related to the energy crops, in terms of products in addition to the benefits provided such as public goods.

Integrating an area with poplar trees into individual paddocks with lactating sows is a feasible strategy in terms of improving the environmental performance of the system. The sows did eliminate in the tree area but it is suggested that a larger reduction in nitrate leaching would be possible with a more optimal distribution of resources (hut, feed, water and wallow) to motivate sows to primarily eliminate in the area with poplar trees. Additional management strategies such as a reduced stocking density and seasonal production might prove useful.

The trees were able to recover from the damages exerted by two batches of sows even though some were servery damaged. Sows preferred to lie in the area with poplars, thus, they considered it an attractive place to be. However, from the current study, it was not possible to determine the affecting factors.

10 Outlook

10.1 Practical implications

In tropical areas of the world, agroforestry is widely recognized for the benefits provided, whereas in temperate regions less is known about how agroforestry is perceived (García de Jalón *et al.*, 2017). This is of paramount importance in terms of identifying the bottlenecks for a wider adoption of agroforestry in Europe. Obviously, this includes famers and other key stakeholders but also policy and support mechanisms need to be in order. For the individual farmer, silvo-pastoral systems represents a heterogeneous environment making the decision and management processes more complex. Also, adaptation of trees in the farming system is a long term investment that may well represent an obstacle for farmers. Within free-range pig production in Northern Europe, a prerequisite for adaptation of agroforestry may be to know to what extent the trees are able to provide the animal and environmental benefits suggested, establishment costs, the practical management including workload and the possible outcomes of trees including economic returns.

With regards to poplar trees in paddocks for lactating sows, the current study identified benefits both in terms of the environment and the animals. In outdoor free-range pig production, sows' possibilities to perform thermoregulatory behaviour during warm periods is essential for the welfare of sows. In that sense, introduction of trees to provide shade is an important step forward. Still, wallowing is crucial for sows during periods of high temperatures as the heat dissipation is significant compared to shade. Also, wallowing is related to skin care in addition to preventing sunburn. Furthermore, by placing the hut in the tree area as the farmer in the current study has decided to do, the heat load of sows is reduced and the sows may be motivated to farrow in the hut and not in the area with trees, the latter is considered a challenge on some farms.

The thermoregulatory effect of an area with trees has been adopted in the recently accepted code of conduct (May 1st 2018) between organic pig producers and other involved key stakeholders, as the requirement of access to shade for lactating sows during the summer months may be constituted by the presence of trees in paddocks (Anonymous, 2018).

Probably a larger area than 20% coverage with trees is needed to potentially reduce the leaching further. The immediate downside of an increased area with trees is a reduction in the area available for growing cereals in years without pigs. Less home-grown feed means that the farmer must purchase more feed, which must be counterbalanced by an equivalent income from the production of biomass. Also, the benefits from the trees must outweigh the cost for establishment and management of the trees (García de Jalón *et al.*, 2017).

The results suggest that a more optimal distribution of the resources in the paddock in relation to the trees might motivate the sows to eliminate mainly in the tree area, leading to a further reduction in N leaching. In this study, the trees were located at the end of the paddock, and a more optimal distribution may be achieved by placing the feed and the hut on each side of the tree area or by placing the feed at the opposite end of the paddock compared to the tree area.

For farmers to make an income from trees, knowledge about possible establishment costs, sources of income and management accordingly (e.g. for production of biogas in the case of energy crops) is required. In terms of management of trees, removal of biomass may coincide with the time of year where the benefits from the trees in terms of shade are needed. Woodchips can be used for bedding or rooting material for pigs but are obviously not enough to provide the extra income needed.

Another aspect is the common goods provided by trees at local and regional scale that farmers are currently not paid for such as e.g. carbon storage, biodiversity, wildlife habitats, pest control, pollination services, soil conservation, nutrient retention and improved landscape aesthetics. Hence, the farmers would need to be able to establish trees without losing area subsidies from direct payments according to Pillar I within the Common Agricultural Policy (European Commission, 2013). Pillar II related to rural development also contains measures acknowledging agroforestry practices but that remains to be realized.

In Danish free-range pig production, it is mandatory to keep an effective grass cover in paddocks (Poulsen, 2014) and that may prove difficult to maintain in areas below trees. Currently, legislation is not promoting implementation of trees in paddocks with pigs. Hence, it is important that legislation refrains from the focus on grass cover when it comes to farmers practicing agroforestry as this will impair development of new initiatives within the free-range pig production.

Trees in free-range pig production may pave the way for a more diversified source of income, making the farm less vulnerable to external factors affecting one of the productions. Also, a system integrating trees and pigs may elicit a marketing premium as the consumers may well want to value a system that mimics the natural habitat of the pigs in addition to providing public goods. Currently, one Danish organic pig producer, integrating trees and pigs, receives an additional premium on the basis of the concept of pigs and poplar trees.

10.2 Future research

Eliminations

It still remains to be solved how the different groups of pigs can be motivated to distribute their eliminations in dedicated areas, preferably in the tree area. The spatial distribution of resources in the paddock seems to be important.

Methods to estimate nutrient load

Collecting and analysing soil samples and soil water samples is work intensive and expensive but as the visual estimation of faeces does not include urine it has to be combined with another method. In the current study, electromagnetic soil conductivity measures (milliSiemens m^{-1}) were performed in the sow paddocks after sow batch 1 and 2 to detect areas of urine as the method has been reported to correlate with mineral N, even though the detection threshold is high (Rodhe *et al.*, 2010). Clearly, there were differences in soil conductivity across the individual paddocks with high levels in the area with the hut and the feeding area. In combination with the visual estimation of faeces it may provide useful information on the spatial distribution of N within paddocks.

Until the trees are strong enough (3-4 years) to withstand manipulation by sows, it is necessary to fence off the trees. On this background it is relevant to investigate if the trees attract the pigs to perform eliminations adjacent to the tree area.

Animal benefits

More information is needed about the animal benefits of a tree area, particularly in combination with access to a wallow and the use of trees for skin care and the level of sunburn.

Originally, the idea was to refrain from snout-ringing half of the sows within each treatment in order to investigate the effect in terms of environmental indicators as well as the potential damaging effects on poplar trees and grass cover. However, the farmer was not willing to try it out as he was worried about the effect on his land. As snout-ringing is very much in contrast to the organic principles it is an area of great concern and needs to be investigated, in particular how it can be combined with agroforestry to reduce the risk of nutrient losses.

Knowledge regarding the welfare of suckling piglets in pasture systems is to my knowledge almost non-existing. It may be assumed that the welfare is relatively high as the piglets are able to roam within neighbouring paddocks and in the surrounding areas. Sunburn was identified in individual piglets but the level is not known. Also, studies of piglets' potential interactions with trees, use of the trees as a shaded area as well as play in a system with trees would provide more information about the animal benefits in a system with trees.

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This thesis addresses the challenge of reducing the environmental and climatic impact of organic pigs, while supporting the organic principles of providing the animals opportunity to perform natural behavior.

Two alternative strategies to improve the nutrient-efficiency were investigated: 1) Increased free-range foraging combined with alternative foraging crops and 2) Introduction of poplar trees in the free-range area.

The results were promising in terms of reducing greenhouse gas emissions (strategy 1) and nitrate leaching (strategy 2), although additional interventions are needed such as more tree cover, reduced stocking density, seasonal production and mobile systems. It is important to gain more knowledge on how to motivate sows to excrete in dedicated areas.

ISBN nr. 978-87-93643-76-5