Plant Production Systems

Opportunities for Thesis and Internship

At Plant Production Systems we work on urgent societal issues such as global food security, agricultural and environmental policies, competition for natural resources, food-feed-fuel interactions and global environmental change. We provide grounded, quantitative analysis to understand and respond to these challenges, and to allow the design of sustainable production systems.

Societal problems require analysis at multiple levels, and a key research issue is scaling from the field to farm, region and the global level. Our research and teaching approach combines empirical knowledge and production ecological theory with understanding of farming systems derived from surveys and databases. We start from a process-based understanding of current farming systems to design new systems that contribute to addressing societal problems of global significance. We use various modelling approaches for analysis and exploration based on simulation of crop and animal production, bio-economic optimization and statistical techniques. An interdisciplinary approach is central, as the issues deal with complex human systems. Our focus lies firmly in the natural sciences but close collaboration with groups from social sciences (e.g. economics, rural sociology, communication science) furthers integrated assessment.

If you choose to do your thesis, internship or research practice with us, you will become a member of a group where we strive to maintain a collegial working atmosphere. We inform and engage each other through weekly lunchtime discussion meetings that are attended by all staff and students (both MSc and PhD). We discuss research plans, presentations for conferences, draft papers or key concepts, with substantial time for discussion. MSc students support each other by meeting each week in a thesis ring to discuss research proposals, progress and problems. The thesis ring is led by the students and facilitated by a member of staff.

Our MSc thesis and internship projects use a variety of approaches and methods. Some are predominantly field based, either in the Netherlands, further afield in Europe or in the tropics where we have strong collaborations. Methods used include experiments, surveys, focus group discussions, serious games and quantitative farming system analysis. Other studies are desk-based studies that employ data-science, optimization and simulation modelling. Sometimes a combination of experimental and modelling work is used. We try and link all student projects to ongoing research projects led by staff or PhD candidates to ensure a firm embedding in the work of the group and to provide close supervision and adequate resources.

Here, we highlight the main themes around which our work is organized, together with names of the staff involved. If you are interested in a thesis study at PPS feel free to enquire directly with staff mentioned and also copy your enquiry to Dr Danaë Rozendaal - danae.rozendaal@wur.nl – who coordinates the thesis, internship and research practice projects of the group.

Have a look at this short clip introducing the main themes.

Research themes and sub-themes

1. Farms and farmers in Africa

2. Sustainable agriculture in Europe

3. Climate change and adaptation

4. Yield Gap analysis

5. Agriculture and Forests

6. Circular agriculture and food systems

7. Sustainable production of perennial crops

8. Agronomy at different scales

9. Production ecology, modelling and data analysis

10. Agronomy, livelihoods, and development

1. Farms and farmers in Africa

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Farming systems in sub-Saharan Africa will undergo drastic changes in years to come, as the human population is increasing fast and increasing numbers of people suffer from poverty and food insecurity. Smallholder farmers are particularly vulnerable to changes in markets, land fragmentation and to the adverse effects of climate change. On the positive side, with currently large yield gaps for crops and livestock, African agriculture also exhibits unequalled potential for improvement. African agriculture will change tremendously in the coming decades and scientific understanding is needed to guide this transformation into a sustainable direction that will improve livelihoods and lead to a healthy environment. Potential solutions to the above challenges exist in the form of sustainable and/or agro-ecological intensification and climate-smart agriculture. These strategies strive for improved productivity and resource use efficiency of farming, in conjunction with improvements in the environmental, social and economic dimensions of sustainability. Whereas numerous promising agricultural options have been described and experimentally tested, the low uptake by smallholders of these options often remains problematic. In the research by PPS, we work with farmers and other local actors to better understand the constraints and opportunities of the farming system they are operating in, with the aim to better tailor the proposed options to that context. By exploring with farmers what could work for whom, where and why, we co-design innovative systems and pathways to a more sustainable future. Participatory research is at the core of this work, which combines diverse activities including (on-farm) experiments, crop and whole-farm modelling, household surveys, workshops and discussions with farmers and other actors.

Working with farmers to analyse their systems and sustainable futures

In order to develop inclusive and tailored options for sustainable and/or agro-ecological intensification, situated understandings of the multiple dimensions of smallholder farming systems and their drivers is needed. Participatory research among and with farmers and other stakeholders in the wider agricultural system is indispensable not only for the (co-) development of socially and environmentally sustainable futures, but also in assessing the uptake and adaptation of interventions in smallholder agriculture.

Thesis work under this sub-theme is focused on: (1) understanding the functioning of smallholder farming systems in development contexts, and; (2) the identification of options for (and/or constraints to) change, or; (3) the assessment of the outcomes and impacts of development interventions in smallholder agriculture. It typically builds on field research, uses and develops both quantitative and qualitative research methodologies (e.g. participant observation, resource flow mapping, interviews, focus group discussions, agricultural surveys, etc.). It situates farming practices in the context of farming households' livelihood activities, the wider socio-economic environment, *and* the development (intervention) contexts in which agricultural research usually takes place, to explore (or evaluate) agro-technological change in smallholder farming systems together with those involved.

Agroecological Intensification of mixed crop-livestock systems

Mixed crop-livestock systems are the predominant farming system in many regions in sub-Saharan Africa. These systems are characterized by interactions between the crop and livestock component, such as the use of animal manure for crop fertilization and animal draught power for land cultivation and the use of crop residues as livestock feed. Agro-ecological or sustainable intensification of these systems can be achieved by options targeted at the crop component, the livestock component or through better integration of both. Examples include intercropping cereals with legumes, the use of adapted and nutritious crop varieties, the incorporation of fodder legume crops, better nutrient cycling by improved manure storage.

Thesis topics under this sub-theme typically consist of experimental work in which various improvement options are tested on-farm or on-station. Students collaborate with local researchers in the setup, monitoring and harvesting of trials. Field data collection is followed by data entry and statistical analysis of the data. Agronomic data collection can be combined with farmer evaluations.

Another type of thesis under this sub-theme can rely on modelling work. In this case, crop, livestock or farm-level models can be used to explore the potential effects of various improvement options (see theme 9 for more information on modelling). Modelling work can be combined with field work for data collection that is used in model calibration and testing; or with field work during which model results are discussed with farmers. In the latter case of participatory modelling, tools like visualizations or games can be used.

Finally, sustainable or agroecological intensification can be investigated through scenario analysis. A thesis subject on scenario analysis typically makes use of existing data (e.g. household characteristics, experimental trial data) to explore effects of contrasting future pathways. The effects can be assessed in multiple sustainability domains, allowing the analysis of trade-offs. This work can be combined with field work to discuss and refine the scenarios with different types of local stakeholders.

Co-learning with smallholder farmers (link with theme 10)

Co-learning by farmers and facilitators (e.g. researchers, development actors, extension agents) together helps to adapt farming options to the diversity of local conditions. Co-learning allows to enrich external knowledge and information about new options with farmers' knowledge on local relevance and feasibility. In various projects, we implement iterative research and learning cycles together with farmers to develop shared and contextualized knowledge.

A thesis under this sub-theme can contribute to this research in various ways. Students can participate in the co-learning work with farmers and describe changes in farmers' and researchers' behaviour, perceptions and knowledge through participant observation, detailed farm monitoring, Q-methodology, in-depth interviews or other types of qualitative data collection. Alternatively, students can focus on visualization techniques that help to communicate research results or farmers' views. Also, students can collaborate in household surveys and subsequent analyses to capture changes in farmers' agency, competences and knowledge.

2. Sustainable agriculture in Europe

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The human population in Europe is stable or may even decrease, and is ageing. Net demand for food may decrease rather than increase, also since diets are likely to change towards healthier diets with some substitution of livestock products by plant-based products. Although Europe is a net exporter of agricultural products and has a role on the world market, its prime concern is not producing more, but maintaining high-quality production with much less impact on the environment. The European Green Deal captures the ambition of the European Union to make its economy sustainable and have zero net greenhouse gas emissions by the year 2050. The main objectives of European agriculture must be understood in that context. European agriculture (and broader, European food systems) have to become much cleaner, with less use of finite resources and avoiding negative impacts on biodiversity. At the same time there is political concern about rural development and the role of agriculture to support rural areas and the landscape. And the climate is changing which may work out positively for agricultural production in Northern Europe, while it will challenge Southern Europe. Throughout Europe extreme weather events will become more frequent and adaptation and resilience of agricultural systems will therefore be critical.

Sustainability and resilience of European farming systems

Agriculture in Europe is increasingly subject to a variety of stresses and shocks. These disturbances provide challenges and opportunities for farming systems and affect their ability to deliver private and public goods. Farming systems in the EU vary widely in terms of characteristics, production, actors involved and challenges faced. Dependent on the context, they function differently and show different degrees of sustainability and resilience, two complementary concepts. Sustainability can be defined as an adequate performance of all system functions across the environmental, economic and social domains. We define resilience of a farming system as its ability to ensure the provision of the system functions in the face of increasingly complex and accumulating economic, social, environmental and institutional shocks and stresses, through capacities of robustness, adaptability and transformability. A proper understanding of the local context and underlying mechanisms of resilience is essential for designing adequate and relevant strategies and policies. In a thesis subject you can investigate the sustainability and resilience of farming systems using participatory approaches, data analysis using statistical methods, and dynamic modelling.

Circular agriculture

A transition to a circular agriculture or circular food systems is regarded as one of the promising avenues to reduce environmental impact of agriculture, contribute to a green economy and move towards more healthy diets. Principles of a circular agriculture include using arable land primarily for human consumption, to avoid losses, re-use by-products while using animals for what they are good at, i.e. upgrading low-opportunity cost biomass. In thesis subjects you can investigate these principles and analysis the optimum hierarchical levels at which circularity should be developed: how local must cycles of nutrients and biomass be closed to achieve the lowest environmental impact and highest efficiencies? What are the best uses of crop residues and by-products and how can nutrients from the city be re-used? (see Theme 6). An MSc thesis can be model based at different scales, investigating grassroot examples of circularity or use a more participatory approach.

Comparisons between organic and mainstream agricultural systems

Organic agriculture and other types of agriculture that avoid using external inputs come with lower local environmental impact, but also lower yields. This is true at single crop level, but even more so at systems level, as these types of agriculture depend on nutrients from animal manure and legume crops which require (additional) land. Hence to produce the same amount of food substantial extra land is needed. How much extra land is a relevant question, not only for the development of organic agriculture, but also for circular systems that rely on recycling of nutrients and aim to lower the use of mineral fertilisers. In thesis subjects you can investigate this yield gap at systems level and estimate other environmental performance criteria of organic and other alternatives to mainstream agriculture. Your thesis will be a combination of analysis of experimental and secondary data, together with model-based work.

Analysing yield variability for sustainable potato production

Improving the sustainability of European agriculture, also requires attention for specific crops. For example, in the Netherlands, potato is a major cash crop, and management can be improved to make production more sustainable. We use yield gap analysis to explain yield gaps and resource use efficiencies at crop and farm level (link with theme 4, 8 and 9). By disentangling yield gaps, they can be better explained, and management strategies and policies can be suggested. In thesis subjects you can analyse yield gaps and resource use efficiencies of potato, and possibly other crops, performing experiments, analysing data and using crop models. This includes assessing impacts of weather variability and exploring impacts of climate change (link with theme 3). Collaboration with farmers and industry will ensure impact in practice.

3. Climate change and adaptation

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Climate change is expected to negatively affect crop and livestock production through increasing temperature, changing rainfall patterns, increased climate variability and increased frequency of extreme events. Yet, the agricultural sector is not only a victim but also a culprit of climate change as it emits a large share of global greenhouse gas emissions. Hence, there is a strong need for adapting to climate change and mitigating agriculture's contribution to greenhouse gas emissions. At the same time, agriculture will have to meet demands for food that are expected to sharply increase in the coming decades. The climate-smart agriculture concept offers scope to analyse this three-pronged challenge of food security, resilience and mitigation in an integrated way.

At PPS we conduct integrated, multi-criteria and cross-scale assessments of climate change impacts, adaptation and mitigation in both low-input and high-input farming systems. The research is often implemented with active stakeholder involvement to understand farmers' perceptions and identify solutions that are relevant for the farmers who are intended to use them. In this work, we combine crop, livestock and whole-farm models to assess climate change impacts and evaluate adaptation options based on stakeholder workshops and farmer interviews. The models can be both dynamic or static to simulate or optimize (with e.g. linear programming) systems (link with theme 9). Building resilience to climate change and weather variability and extremes is an important component of improving the sustainability of farming systems, which explains the link with theme 1 and theme 2.

Vulnerability of smallholder farmers and adaptation options in African farming systems

Smallholder farming systems are vulnerable to climate change and need to adapt in order to improve productivity and sustain people's livelihoods. Although the impact of climate change is projected to be large, many uncertainties persist, not only with respect to crop production, but also with respect to the livestock and grazing components of the system. In particular the effects on the resilience of heterogeneous farm populations are not well understood. Numerous climate adaptation options exist for crop–livestock systems, but despite the potential solutions, smallholders face major constraints and barriers at various scales that limit the adoption potential.

A thesis under this sub-theme will focus on assessing vulnerability, resilience or climate adaptation, or a combination of those for the smallholder context in West, East or southern Africa. Using simulated future climate data as a starting point, students can use crop models to quantify the expected impacts of climate change on crop and biomass productivity and map changes in land suitability. Such information can be integrated with household level information to map vulnerability hotspots.

Alternatively, students can focus on unpacking the resilience concept by assessing attributes that describe the resilience concepts of robustness, adaptability and transformability of different types of smallholder systems. Data on farm system characteristics and performance of adaptation options (for example from experiments (see theme 1) or from literature) can be combined with simulation modelling to explore how resilience could be improved.

Adapting to climate change in European farming systems

Impacts of climate change on agriculture are often projected using crop models, focusing on crop productivity. These models suggest that impacts of climate change can be both positive and negative, depending on the agro-ecological conditions, crop type and management. In the Netherlands, gradual climate change largely has positive impacts on crop yields. However, also the frequency of extreme events is increasing, and impacts of these are largely negative. For example, in 2016, extreme rainfall events led to crop failures, and in 2018, droughts reduced potato yields in the Netherlands with an estimated 18%. Reduced crop growth also leads to reduced nitrogen uptake and larger nitrogen losses to the environment. Impacts on income depend on market responses.

At PPS, we perform integrated assessments in which we combine crop models with semi-quantitative participatory approaches and bio-economic models. Impacts of climate change are considered in the context of changes in technology, markets and policies, and we address impacts on economic, environmental and social indicators.

A thesis under this sub-theme can contribute to improve understanding of the impacts of climate change on crop yields and other agricultural functions. Experiments may be performed on-station or on-farm, farm surveys organized and analysed, crop models improved, and stakeholders interviewed to improve impact assessments. Also statistical, dynamic and optimization modelling can be used to analyse and explore impacts. Most projects take place in the Netherlands, but options may be available in other European regions.

Climate smart agriculture

The climate-smart agriculture (CSA) concept brings together the three pillars of food security, resilience and mitigation in an integrated way. Numerous agricultural options are claimed to be climate-smart (e.g. conservation agriculture), but many claims of triple-wins do not withstand detailed scrutiny, as benefits for one CSA pillar often go hand in hand with drawbacks for another pillar or compromises in terms of social or economic sustainability. In addition, constraints to the adoption of CSA options limit the adaptation and mitigation capacity of the current system. Policies to underpin pathways towards CSA must take account of the possible trade-offs and synergies between the CSA pillars, which depend on the context and the scale of the analysis.

A thesis under this sub-theme can contribute to understanding this complexity and finding holistic solutions, through an analysis that takes a farming system and/or food systems perspective. A systems approach is characterized by accounting for the interactions between system components (e.g. crops and livestock), cross-scale dynamics (e.g. field to farm to regional scale) and through multi-dimensional assessments (e.g. integrating agronomic, economic and environmental aspects). To assess the trade-offs between the three CSA pillars, a thesis can rely on a literature review, building a (simple) model, using existing models, analysis of existing (farm and household) level data and/or scenario analysis. Also more qualitative analyses can be conducted, e.g. relying on stakeholder workshops to identify, evaluate and prioritize CSA options. A thesis can focus both on high- and low-input systems.

4. Yield Gap analysis

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Feeding a growing population within the planetary boundaries is one of the grand tasks of humankind in the 21st century and at the heart of multiple Sustainable Development Goals (SDGs). Implications of this vary across the world. In sub-Saharan Africa a tripling food demand is anticipated by 2050, which means production of nutritious food must increase at unprecedented rates. In other regions, such as North-western Europe, developing resource-use efficient food production is a key priority to deal with the challenges of finite resources and environmental pressures.

Local data with global relevance on agricultural production, resource use and environmental implications are critical to address simultaneously questions of food availability, finite resources, and environmental impacts. As we have demonstrated through the Global Yield Gap Atlas, such data can reveal a gap between actual and potential production (the yield gap), quantifying where improvement of agricultural management can increase yields, and which resources (land, water, nutrients, etc.) are in under- or oversupply. The Atlas brings together all biophysical knowledge on todays and future crop yields and land, water and nutrient use of the world's major food crops, including effects of climate change. Scientifically, it allows to assess the possibilities to feed growing populations with finite resources, within the planetary boundaries. Societally, it provides decision-makers with robust data to develop pathways in sustainable agricultural development and resource use and conservation.

Yield gap studies in European farming systems

Yield gaps can be decomposed into efficiency, resource, and technology yield gaps. In intensive agriculture, the resource and technology gaps are often small, and the yield gap is mainly explained by the efficiency gap. This implies that inputs are not efficiently used, and resource use efficiency can be increased. Despite the relatively small overall yield gaps, yields still vary across farms, across fields and within fields, and understanding and managing this yield variability allows to reduce the overall yield gap. In your thesis you can contribute to understanding variability in yields and resource use efficiencies, using on-farm experiments, data analysis and crop modelling (link with theme 4, 8 and 9). In PPS, there is specific focus on the Netherlands, and its main arable crops, like potato, wheat and sugar beet.

Yield gap analysis in perennial crops

Most perennial crops are cultivated in former forested areas and further deforestation is highly undesirable for reasons of biodiversity and carbon loss. In response to higher consumer demands it is therefore preferred to increase yield on existing hectares instead of area expansion. Especially for smallholders, actual yields are far below potential yields. Since 2018 yield gap analysis in oil palm has therefore been conducted in Indonesia in which potential and water limited yields have been assessed using PALMSIM crop growth simulation model. Currently data are collected to allow assessment of the biophysical and socio-economic factors responsible for the yield gap. Further research is needed to assess the relative contribution of these factors. We also aim to test the use of PALMSIM for yield gap analysis in other oil palm areas such as Colombia and Malaysia. Furthermore, it is important to explore climate change effects on potential and water limited yield. A second perennial crop of interest is cocoa, which is mainly grown in West Africa. Climate change threatens to decrease suitability of parts of West Africa for cocoa in the future. Different topics around cocoa yield gap analysis using the CASE2 model and farmer collected data as well as effects of climate change on future yields and yield gaps can be offered. Research into the different factors responsible for yield gaps is another option. For both perennial crops there is interest in making a farm typology and in further investigating why certain farmers have larger yield gaps as this may provide insights in farmer specific options to sustainably increase yields to partially close the yield gap.

Yield gap analysis under climate change

This sub-theme extends the methods of yield gap analysis employed in the Global Yield Gap Atlas with climate change. Suitability of crop growth will change as a result of climate change, and as a consequence crop areas may shift. Potential yields in particular climate-soil zones will change. Thesis work can contribute to extend the methodology for the Atlas and apply it to some defined crops and countries (e.g., sub-Saharan Africa, Europe, cereals, cassava, potato).

Narrowing yield and nutrient gaps in sub-Saharan Africa

Closing yield gaps will require an improvement in management and either an increase in the efficiency with which inputs such as nutrients are used and/or an increase in the amount of inputs. Sub-Saharan Africa is plagued with relatively low yields, combined with very low external nutrient inputs. Only increasing the efficiency will therefore most likely not result in the desired changes. In an MSc thesis, you can explore the minimum nutrient requirements for a range of crops or countries, using different scenarios of yield gap closure, combined with different management options. In addition, you can assess data from field experiments to assess impacts on the environment (such as greenhouse gas emissions) or economics of different scenarios. From a methodological point of view you thereby contribute to the benchmarking of nutrient use and nutrient use efficiency (and thus also to benchmarking of emissions). This allows the comparison of farm performance with theoretically best values, indicating the scope for improvement.

5. Agriculture and Forests

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Agriculture is the main driver of deforestation globally due to the growing demand for agricultural commodities (and timber and wood energy). In Latin America, most deforestation is due to large scale agriculture, whilst in Africa and South East Asia small scale agriculture, including for commodity crops, dominate. Our research on this theme focuses on smallholder farmers and farming systems, their interaction with forests (linking to theme 7) and the biodiversity and other ecosystem services they support.

Exploring the forest-people-water nexus through serious games

In the SESAM project, we analyse and improve decision-making processes related to water and (agro)forest landscape management across the tropics. To achieve this, we develop and implement serious games, so-called 'Scenario Evaluation Games', which are tools to analyse, support and enhance social learning, decision-making, and action. The Scenario Evaluation Games are developed and played with people and organisations who are involved in complex decision-making processes around the forest-water-people nexus.

Agroforestry

There is an increasing recognition of agronomic, socio-economic, and environmental benefits of agroforestry systems. For example, agroforestry is seen as a potential win-win solution to meet the increasing demand for shade-loving perennial crops such as cocoa and coffee whilst reducing pressure on forests. The assumption is that integrating shade trees can support (increased) productivity of cocoa systems or landscapes (so not just the cocoa itself), help diversify farmer incomes and reduce their risk, including in the face of climate change, and therefore avoid further expansion of cocoa growing into forests. Also, agroforests can likely play a role protecting local biodiversity and other ecosystem services (e.g., water, pollination). Agroforestry systems are also increasingly promoted as a tool to restore degraded agricultural lands or forests, supporting global climate change mitigation objectives through carbon sequestration whilst providing crops and other local benefits. Through our research, we seek to understand how the potential for agroforestry to meet these objectives varies according to management regimes, biophysical, socio-economic, and institutional contexts, to inform the development of sustainable (reduced- or zero-deforestation) pathways for agricultural development in the tropics (linking to theme 7).

A specific topic under this sub-theme includes the assessment of the forest transition on (agroforest) landscapes. Along the forest transition, forests are degraded through human use over time, subsequently deforestation for agricultural use may occur, but many areas now become forested again. Many of these "new" forest systems are agroforestry systems. We assess the ecosystem services that degraded forests, croplands and agroforestry systems provide across such land-use gradients. Other research topics aim contributing to assessing and balancing food security, forest conservation and climate change mitigation objectives at national scale.

6. Circular agriculture and food systems

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Most of our present production systems and food systems can be characterised as linear: they rely on external inputs and optimize production (efficiency) of single commodities. In doing so, important interactions within production systems and food systems are ignored and resource depletion and environmental impact are relatively high. For instance, in the optimization of cereal crops, the amount and quality of straw is often neglected, while in the optimization of livestock production food-feed competition and manure are generally not considered. In circular food production and food systems (including consumption) such interactions are critical. Circularity in plant and animal production assumes that plant biomass is the basis of our food system and should be used primarily to produce human food; that by-products from food production, processing and consumption are reused or recycled into the food system; and that we make the most efficient use of animals by using them to unlock biomass inedible for humans into valuable food, manure and ecosystem services. There are still many important research questions within each of these three principles that can and must be investigated to advance circularity in food production. Furthermore, the transition to more circular systems will be gradual and hurdles and trade-offs will need to be tackled. Better integration of crop and livestock sectors use of city waste will be a key first step towards circularity.

In this thesis subject you can work on one of the above principles, possibly in collaboration with other chair groups. Examples of specific subjects include: what are useful applications of crop residues of each of our important food crops and would that affect optimal crop rotations; in which ways can we optimally re-use and re-cycle carbon, nitrogen, and phosphorus in by-products (crop residues, waste, manure, etc.), to maximize food production and minimize resource use and environmental impact? Other questions may relate to the intermediate steps in the transition towards more circular systems. For example, how to best organise integration of crop and livestock farms? How can nutrients from city waste be used effectively on farm in crop rotations? How can the transition be used to reduce GHG emissions and improve biodiversity on-farm and/or in the landscape?

7. Sustainable production of perennial crops

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Tropical perennial cropping (including agroforestry) systems are a source of income for millions of households around the world. The products (such as palm oil, cocoa, coffee, tea, rubber, bananas, and other fruits) play a key role in the diets of local and global populations, providing nutrition as well as delicious flavours. Perennial cropping systems have their own unique opportunities in terms of in-field biodiversity, carbon capture, efficient use of nutrients and water, preventing erosion, enhancing soil quality, and providing farmers with a stable source of income. On the other hand, these systems face important challenges, such as the lack of flexibility, poor planting materials, ageing of plantations, poor management, long and opaque supply chains, deforestation issues, and poor commodity pricing leading to poverty among growers. Climate change also affects the future of perennial production systems. With our research we aim to contribute to more sustainable, profitable and resilient tropical perennial cropping systems.

For **oil palm**, our research focuses on several main themes, especially 1) Yield gaps in oil palm & crop modelling; 2) Good agronomic practices & intercropping (especially for smallholders) and 3) Sustainability and certification. We mainly work in Indonesia, Malaysia, Ghana, and Colombia.

In **cocoa production** there are specific threats to sustainability such as strong dependency on agrochemicals to deal with cocoa's many pest and disease problems. Our cocoa research focuses on five main themes: 1) Cocoa mineral nutrition; 2) Good Agricultural Practices in cocoa; 3) Cocoa and living income; 4) Ecosystem services such as biodiversity conservation and carbon sequestration that cocoa agroforestry systems provide; and 5) Cocoa crop growth modelling (climate change effects and yield gaps). Building on these four themes, we also seek to understand the interaction between production systems, climate change adaptation and deforestation to inform different pathways for the future of cocoa (linking to theme 5). We work in many of the cocoa producing countries, especially in Côte d'Ivoire, Ghana, Nigeria, Cameroon, Ecuador, and Indonesia.

Our research work on **East African Highland banana** cropping systems mostly takes place in Uganda. We work on the sustainable intensification of banana farming systems through integrated soil fertility management and diversification. The prospects of relieving drought stress through irrigation are also investigated. We are developing a banana growth model, to allow the exploration of potential solutions in a wide variety of agro-ecological contexts and the integration with other farming activities, such as livestock keeping. Furthermore, we engage with value chain actors to explore solutions in the marketing and processing steps of East African Highland banana.

In combination with social sciences we also facilitate research on technology adoption and adaptation processes and learning, farmers diversity and livelihood, service delivery and business models, landscape approaches, public and private policies related to each of the perennial crops.

For more information about our research on perennial crops see also https://perennialcrops.wur.nl/.

8. Agronomy at different scales

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Nutrients play a pivotal role in resource use efficiency of agricultural systems. At the field level, nutrient recovery from soils and applied fertilisers (organic, mineral or a combination of both) affects environmental impacts such as nitrate leaching or greenhouse gas emissions, but also farmers' income and yields. These dynamics go across scales, with efficient nutrient use at field scale affecting sustainability of farming systems at regional scale. At the Plant Production Systems group, students can conduct a BSc or MSc thesis looking at a diverse set of agronomic practices to improve sustainability of farming systems, across different soils and climate zones. Such research includes analysis of field experimental data, conducting a farm survey or using integrated modelling approaches. Within this theme, students can also work on an array of related subjects, such as quantitative understanding of principles around dose-response relationships in relation to management practises and environmental conditions, exploration of future nutrient input requirements or societal cost/benefit analyses of nutrient management.

In the Netherlands, the 'nitrogen-crisis' has triggered attention for better nutrient management, and tools are being developed to assist farmers in more sustainable nutrient management. This includes use of alternative nutrient sources (such as digestates, nutrients retrieved from industrial or city waste in composted or processed form). Modern agronomy is benefitting from an improved understanding of plant demand and soil supply during the season. With precision technology, major advances can be made in relation to the 4R principles. This has implications on how to manage variability. Research questions focus on spatial and temporal variability and the influence of weather variability on plant demand and soil supply, crop growth and yields, nutrient uptake and nutrient losses, and synergies and trade-offs of adaptations in crop and nutrient management.

In Africa, research questions focus on how to scale better management practices to large numbers of farmers across regions. Insights into agronomic practices often need translation to local conditions and farmer socio-economic circumstances and preferences with the use of decision support tools. At PPS, we work on a number of advisory tools, both in Europe and Africa, for farmers but also for advisors and policy makers. This includes modern digital tools on mobile phones, but also training of extension officers.

9. Production ecology, modelling and data analysis

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Production ecology and crop modelling

Production ecology deals with the generation of plant biomass in (agro-) ecosystems as a function of light, water and nutrients. It has important applications in agriculture, where it helps improve production while minimising cost and environmental impact. A thorough understanding of the production ecological principles is needed to describe, explain and optimize production systems. For many crops, dynamic models are developed to simulate crop growth under irrigated and rainfed conditions. There are still major advances made in modelling concepts to better include effects of CO_2 fertilization, climate change and weather extremes including droughts. Especially interactions between nutrient supply, drought and plant demand requires further attention to better respond to periods of drought that are expected more frequently for many places. For example, how should nutrient supply be adapted for a season after a season with drought? How will crops respond to a change in nutrient supply, e.g. when applications are split, applied in different forms, at the surface or in the soil near the roots? This requires a detailed understanding of crop nutrient demand and nutrient uptake capacity. For only a few crops, nutrients limitations are included in the dynamic models. However, the concepts still require rigorous testing. In general, crop models are used a lot in science, and they are increasingly used for practical applications in decision-support systems, but improved calibration and validation are needed to allow accurate assessments and decision-support.

Farm system models

At higher levels of integration, farm system models put crop and livestock production into context in terms of management decisions and economic outcomes. These types of models are essential for exploring the interactions between biophysical conditions, production ecological processes and human decisions, actions and requirements. They thereby form powerful integrative tools that allow simulation of what is commonly referred to as Genotype x Environment x Management interaction (GEM). This type of interaction is of great interest to agronomists and plant breeders, since it determines the appropriateness of farming system interventions for different production environments and farm types. Farm system models also allow for integrated assessments, assessing impacts of multiple drivers on multiple impacts, and thereby identifying synergies and trade-offs in pathways towards sustainable development.

Agent-based models

Agent-based models (ABMs) are a suitable tool for testing what population- and landscape-level patterns can emerge from the behaviour of interacting individuals. In an ABM, autonomous entities agents (e.g. farmers) and passive objects (e.g. fields) interact with each other and with their environment. ABMs facilitate the simulation of interactions like resource (e.g. biomass, labour) exchanges and cooperation, thereby enabling a population-level analysis that is more than the sum of individual-level functions. Within PPS we use ABMs to explore the effects of diverse scenarios, with various interventions (e.g. sustainable intensification), resource distributions, rules about interaction, and shocks (e.g. climate and market shocks). The model serves to assess potential outcomes of agricultural interventions for individuals and populations, which inform strategic intervention decisions. In various projects we develop ABMs in conjunction with serious games to facilitate discussions with intended beneficiaries about novel ways to interact and remove drivers of unequal outcomes. Ultimately, this leads to the co-design of intervention strategies with the targeted population. A thesis within this sub-theme can contribute to model and game development, but also to testing and refining in collaboration with intended beneficiaries.

Statistical analysis and modelling

Simulation models can describe the expected behaviour of farming systems, but a remaining challenge is posed by the great variability typically observed in production ecological data collected on-farm. This variability reflects both systematic factors related to Genotype x Environment x Management interactions as well as environmental and experimental noise. Separating signal from noise is key to understanding and predicting the on-farm performance of new varieties and technologies in different production environments and farming systems. This requires statistical techniques to analyse the complex and noisy data generated by field trials and surveys performed on-farm. Within this sub-theme you are invited to use and develop innovative methods for the analysis of on-farm, environmental and geospatial data to answer basic questions about the causes and consequences of variation in production ecology, using unique datasets collected from farming systems across the world. Working on this topic could be a great opportunity for anyone interested in production ecology and on-farm agronomy as well as in data science, modelling and statistics.

10. Agronomy, livelihoods, and development

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Food systems need to change in response to population growth, urbanisation, climate change, environmental problems, poverty, and international agreements such as the SDGs. In food systems both producers and consumers need attention. Producers are at the same time custodians of the land, managers of natural resources, recipients of policies and actors in supply chains. Many policies, technologies and services have been proposed to smallholders to increase their yields, their incomes and other livelihood outcomes, such as food and nutrition security. Yet, progress is often (s)low. The adoption or non-adoption of new agricultural technologies or agronomic practices is often explained by farmers' resource endowments, costs or risks associated with the technology. (1) At PPS we look beyond these characteristics of adopting and non-adopting farmers, trying to ***understand farmers' (new) technology use in the context of their farm, livelihood orientations and the wider agricultural system*** in which they operate. A research topic is for instance to investigate farmers' wider aspirations and personal capabilities and how these explain responses to proposed interventions. (2) Studies of farmers' uptake of new technologies and agronomic practices, also often overlook that technology is not neutral. Technology may have benefits for wealthier farmers, for specific age or gender groups, but may at the same have negative effects on others. Therefore, another focus of research is ***social equity and equality related to technology introductions and use.***

(3) Next to farming technologies, there are also wider, institutional factors that play a role, such as the terms of engagement of smallholders in supply chains. Do farmers sell their produce either individually or collectively, does the buyer provide knowledge or inputs, are we talking about contract farming, is there a certification scheme binding farmer to consumers? The ***linkage between farmers' engagement in supply chains and farm management practices*** is a topic of research. Service delivery (by supply chains or governments) and how services fit to farmers needs and aspirations is another topic of research within this theme. Whereas supply chain research often focusses on a specific commodity, at PPS we take the farmer as entry point because farmers are known to participate in different (domestic) supply chains guiding their resource allocation decisions.

(4) When we focus on the ***relation between the consumer and farmers, topics of research are for instance the translation of consumers concerns in certification***. Certification can either focus on quality of food (nutrition, safety) or on safeguarding the natural resources while producing it (no deforestation, no pollution, low GHG emissions), both affecting farmers agronomic practices. In this topic we focus on international commodity chains (cocoa, palm oil, cotton) but certainly also on domestic value chains (maize, chicken, milk, soybean) which become increasingly important given regional economic agreements and the increase in domestic demand by fast growing cities.

(5) Since there is a growing interest in developing countries in the domestic production of the ingredients for a healthy ***diet, plant production research increasingly focuses on nutrition and healthy diets*** *as production outcomes and livelihood objectives.*

(6) Finally, while smallholder farming contributes to food security and incomes of farming households, making a living from farming is increasingly difficult. Smallholder farmers

often depend on a range of activities to make living, and this affects the way they farm and allocate resources to farming. A major focus in agricultural development is therefore how smallholders can achieve a ‘living income’, as the minimum for a decent life including the possibility to pay for healthcare, education, housing, clothing etc. In this theme we do ***research on interventions that allow farmers to reach a living income***.