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Internship report: October 26th 2015 – February 26th 2016

Findings on: Environmental impact in Dutch arable farming, experimental data on soybean yield potential, the yield gaps of sugarcane and sugar beet, and N2Africa baseline studies.

Report date: February 26th 2016

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Introduction

During my BSc Thesis in 2015 most of my work took place in my room at home as a result of a shortage of work places. While this work was very efficient, I hardly came in contact with members of the chair group, didn't experience the depth of research to the extent that is desirable during the Thesis and didn't attend any meetings other than the regular meetings with my supervisor. This missing experience was a driving factor to consider an internship at one of the chair groups at the university. I chose PPS specifically because of the focus on various aspects within the chair group which really appealed to me: Working on an international level, making use of models which simulate agricultural practices on the farm or crop level and a minor focus on Dutch agricultural practices as well. All of these aspects have been united under the banner of PPS and drew my attention. The goals set for the internship were as follows:

- Experience the international aspects of research and be actively involved in them.
- Discover the large spectrum of scientific research potential within the context of the PPS chair group.
- Contribute to multiple ongoing projects in smaller formats while maintaining a high level of scientific quality.
- Better understand the factors surrounding agriculture in the Netherlands on both the farm and the policy level other than just nutrient management.
- Gain a deeper understanding of yield gap analyses performed both within and outside the PPS chair group.

On October 26th 2016 this internship commenced. I had been given two assignments initially to be expanded upon later, within the context of my internship goals. Initially I was to evaluate the environmental impact of arable farming in the Netherlands as well as collect experimental data for the estimation of potential yields for soybean. This later also included research into yield gaps of sugarcane and sugar beet as well as work on the N2Africa baseline studies to obtain more experience into working on the datasets available within the N2Africa project. Each of the assignments offered me a possibility to come into contact with members of the PPS chair group as well as international members of the N2Africa project.

In the following chapters each of the projects will be presented in a short format in the context of the research questions associated with each respective assignment. In the final chapter the experience obtained in each project in the context of my goals will be discussed, partly summarizing my reflection report as well.

Environmental impact of arable farming in the Netherlands

Agriculture in the Netherlands is subject to various national laws as well as EU regulations. This results in developments in the use of fertilizer, GMO crops, crop protection agents (CPAs), water and energy. Each of these factors has been analyzed in this assignment. Through data collection from the national statistic agencies as well as measurement networks from both scientific sources and governmental agencies these trends in both regulation and compliance have been determined. Most notable is the introduction of the Nitrates Directive by the EU, which has heavily influenced the Dutch laws in the past two decades. As a result of the maximum application limits as well as controlled application techniques the use of nitrogen fertilizer has decreased from levels close to 270 kg/ha to 220 kg/ha. The surplus also decreased accordingly from 170 kg/ha to a stable 110 kg/ha. Leaching, volatilization and emissions of nitrogen have also decreased. A similar trend is visible for phosphorus, with annual accumulation and surplus decreasing to 0 kg/ha in recent years. GMO crops have suffered much under recent regulations, reducing the amount of trials with GMO crops as well as halting research as a result of cuts in financing. Pollution by crop protection agents has decreased in the waters and on food products, but remain a problem for soil biota. Efforts continue to further reduce drift and protect the health of local residents. The reduction of fertilizer use, introduction of new regulations in the industrial sector as well as the fertilizer production sector has also reduced the net flow of heavy metals to the soil significantly (up to 80% reduction compared to 1980). Irrigation remains heavily influenced by the climate and the water source depends greatly on the distance from rivers and ponds. Irrigation can be expected to increase with climate change to irrigate during droughts. Dutch arable farmers are net electricity producers since 2007 and make use of an increasing amount of renewable energy sources.

Though progress has been made, further changes are required to various factors to improve the sustainability, in which both the EU and national government play a big role.

Experimental data collection for soybean yield potential estimation

Developing countries face many problems currently and in the future: food scarcity, poor soil fertility, climate change and many others. Legume crops can help tackle some of these problems with their biological nitrogen fixation (BNF) to enhance soil fertility and as direct food or feed to reduce food scarcity. Within the N2Africa project (http://www.n2africa.org/) many legumes, soybean in particular, have been introduced or promoted in Africa, improving the soil quality and nutrition for many households. However, no assessment has been performed with regard to the yield gap, making it hard to put the obtained yields into context. Using the procedures of the Global Yield Gap Atlas (GYGA, http://www.yieldgap.org/) as well as the SSM-Legume model developed by Soltani et al. (2013) the potential yields for these legumes can be determined. Although, for this model some parameters needed to be determined, which were collected from literature. Dynamics for the LAI and Harvest Index were found, as well as phyllochron data. Overall, the phyllochron ranged from 49.1 to 71.4 °Cdays, with differences in phenological development between cultivars being a main driver for the variation. The Specific Leaf Area (SLA) was found to range from 0.0175 to 0.0245 m^2/g in publications from 1986 to 1988, but no more recent figures were found. In addition to the parameters found for the SSM model, some other research into potential yields was found for soybean, showing potential yields of 3.9 ton/ha for Argentina and around 6.0 ton/ha for the U.S.. Various parameters have yet to be determined, such as the critical photoperiod and optimal growing temperatures, but with the parameters found so far potential yield estimation for soybean in Africa is within reach.

Yield gaps in sugar beet (*Beta vulgaris*) and sugarcane (*Saccharum officinarum*)

Sugarcane and sugar beet are being used for the production of raw sugar as well as bio-ethanol. The dry matter yield of these crops is among the highest in the world and is well-known as a cash crop, but globally only a few countries, mainly Brazil, are responsible for the production of these products. This study aimed to collect information on the global production as well as give estimates of the global yield gap for these two crops.

The sugarcane market is being dominated by Brazil with a production of $4.64 \cdot 10^8$ ton/y between 1993 and 2013. This is the result of the subsidies available for the production of bio-ethanol. The largest sugar beet producers are France, the U.S., Germany and Russia with an annual production of 3.19, 2.85, 2.57 and $2.33 \cdot 10^7$ ton/year respectively between 1993 and 2013. Harvested area for sugar beet has decreased globally, largely due to the loss of 100,000 ha/y between 2001 and 2013 in Europe. Sugarcane harvested area increased by 635,000 ha/y between 2001 and 2013, mainly due to an increase of 508,000 ha/y in Latin-America. Production conditions (rainfed or irrigated) varies greatly per country and are greatly influenced by national regulations, indicated by the greatly varying production conditions in west Africa per country. Sugar beet yields have increased globally by about 1.38 ton/ha/y between 2001 and 2013, resulting in a yield of 57 ton/ha in 2013. Yield increases are greatest in western and eastern Europe and are smaller and/or absent around the Mediterranean Sea and Black Sea. Sugarcane yields increased between 2001 and 2007, but levelled off afterwards at around 71 ton/ha in 2013. Increases in yield were noted in south-eastern Asia and Brazil, decreases were noted in north-western and southern Africa.

Yields for sugarcane in Brazil were estimated to be around 61% of their potential water-limited yields and estimates for the potential yield ranged from 96 to 130 ton/ha. Sugar beet yield gaps are smallest in north-western Europe (10-25%) and increase towards eastern Europe (up to 60%). This gradient is explained through the fertilizer subsidies in eastern Europe which were abolished after the 1980s, greatly decreasing the available nutrients for crop growth.

Adjustments in policies, production and processing will need to be made to ensure continued yield improvements and sufficient yield for food production in the future climates.

N2Africa Baseline

To be able to assess the results of the efforts of the N2Africa project, which aims to enhance both nutrition and soil fertility through legumes, baseline surveys were held in 2013 and 2014 in Ethiopia, Tanzania and Uganda. The data from these surveys has been analyzed and compared between regions within a country and between countries.

Males hold the most important position within the households in all countries, with household heads being male in 80-90% of the cases. Fields were managed by both husband and wife in 62% of the cases in Ethiopia and Tanzania, but only in 47% of the cases in Uganda, where the wives managed the fields more frequently. Harvest sales are often decided by both husband and wife (60-70%). Differences in livestock are also observed, with cattle being more prominent in Ethiopia (96% of households have cattle), poultry being more common in Tanzania (87% of households) and goat/sheep being more common in Uganda (75%). Large differences are also observed in legume cultivation, with bush bean being cultivated by 58% of the households in Tanzania versus 20-30% in the other countries. Fertilizer use is very limited in all countries (<10% of fields) with the exception of the use of DAP/Urea in Ethiopia (23% of fields). Apart from legumes maize is the most cultivated crop in all countries (89% of households in Tanzania). Crop residues are often fed to the livestock in Ethiopia (92%), but less often in Uganda (5%) or Tanzania (31%). In Tanzania and Uganda crop residues are mainly used for mulching (61% and 70%, respectively). Of most crops about half of the harvest is used for sales in each country.

This baseline study provides the N2Africa researchers with information usable for comparisons between the newly established situation and the past conditions.

Environmental impact of arable farming in the Netherlands

Assignment description

The past decades the Dutch agricultural sector has become subject to an increasing number of both EU and national laws and regulations. Many of these regulations target the use of fertilizer to reduce leaching, others target the energy use by farmers to make their practices more sustainable and some target the use of crop protection agents as a result of criticism from the general public. This study aimed to analyze these laws and regulations, find out which factors they targeted and how/whether these policies led to the preferred effects. Information is collected on nutrient management, water use, energy consumption, crop protection agent use and GMO regulations.

First of all the laws and regulations currently (or formerly) in place in each of the proposed categories were collected and analyzed to determine the parameters to be examined to judge the effectiveness of these policies. This information was collected from the Dutch government website http://www.wetten.nl/ as well as the website of the European Committee (http://www.ec.europa.eu/). Details for regulations, such as annual application limits for nitrogen and phosphorus fertilizer, were obtained through the RIVM. Next each of the relevant parameters was collected for at least the period 2006-2013 from governmental agencies (RIVM, LMM, NVWA), the national statistics agency (CBS) as well as scientific research and measurements (LEI, WUR) and various other specific sources. All data was compiled per subject and analyzed. Tables and figures obtained through these analyses were discussed in the context of both the policies as well as the changing climate.

Figure 1: The front page slide of the presentation created as end product of the arable farming assignment.

Findings

Nutrients

In 1991 the EU came up with the Nitrates Directive, a series of goals and regulations that should reduce nitrate leaching and as such pollution of the surface- and groundwater. Each country was asked to introduce their own legislation following the Nitrates Directive. The Netherlands came with MINAS, which was based on the farm-gate principle. However, in 2003 this system was deemed insufficient by the European Court, forcing the Dutch government to go back to the drawing board. The new incarnation was called Mestbeleid, introduced in 2006, and limited the amount of nitrogen allowed to be applied on the field annually. For each crop and soil type and sometimes even region a specific maximum nitrogen application was determined, which is adjusted each year. The results from each policy are striking, as the N application per hectare decreased greatly between 1998 and 2001, the peak years of the MINAS policy (Figure 2). After the introduction of the Mestbeleid the nitrogen application rates remained stable around 220 kg/ha/y, which is still a reduction of 50 kg/ha compared to the peak year of 1998 and 20 kg/ha lower than at the start of the MINAS policies. The derogation currently available to Dutch farmers is likely a cause for the continued high N application rates.

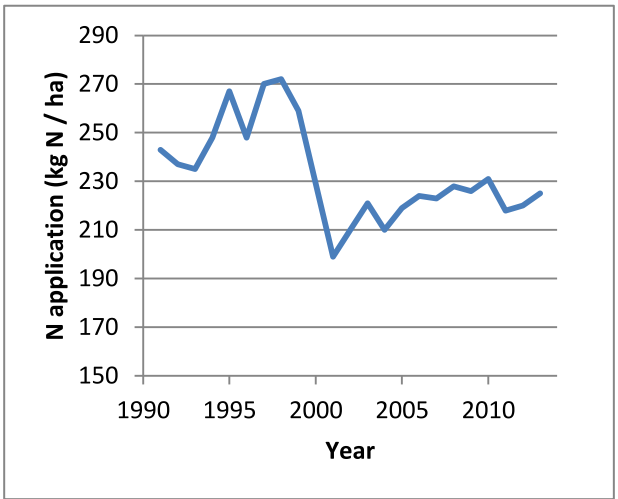

Figure 2: Nitrogen application rates in the Netherlands per hectare. Source: LEI - Wageningen UR & LMM.

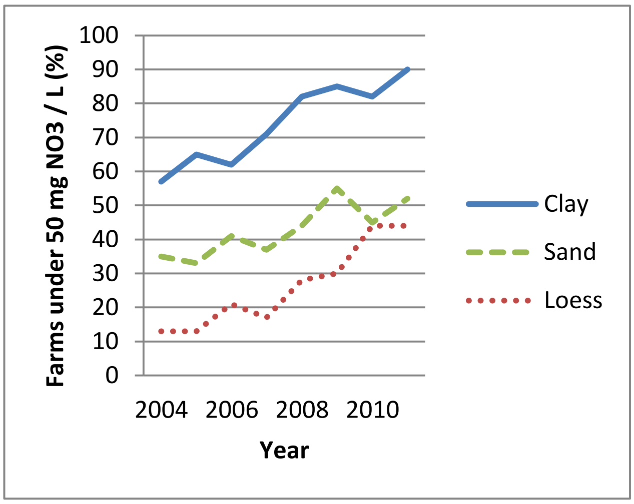

Figure 3: Dutch arable farmers with surface water nitrate concentrations below the Nitrates Directive threshold. Source: LMM / RIVM.

These reductions in input rates as well as improved management techniques introduced by the Nitrates Directive have led to a reduction in nitrate leaching (though loess and sandy soils still recorded nitrate concentrations above 50 mg/L), nitrous oxide emissions and ammonia volatilization. The compliance of farmers does increase over time, however, with nearly all the farms on clay soils recording nitrate concentrations below the threshold by 2013 (Figure 3). As most farms are located on clay soils this is a positive trend on the national scale.

Phosphorus is showing a trend similar to nitrogen, with application rates decreasing between 1998 and 2001. The accumulation and surplus of phosphorus have been decreasing steadily and are close to zero. Saturation remains a problem in Dutch soils, though the severity is lessened with the reduction in the accumulation.

Potassium surplus is expected to have reached zero as well due to the reduction in the use of potassium. Leaching of potassium only shows a mildly decreasing trend for clay soils, but no improvement in sandy soils.

The accumulation of heavy metals in the soil has also decreased, for some metals by up to 90% since 1979. This is mainly the result of the increased regulations for the fertilizer producers and the heavy industry to limit direct application and atmospheric deposition, respectively.

GMOs

The Netherlands has supported research into GMOs for a long time, but recent changes in opinion in the general public have caused the Netherlands to take some steps back and to declare the country GMO-free through the 2015 EU agreements. The upside to this agreement is that scientific research may not be impeded, unless it directly conflicts with the original reasoning behind the declaration of a GMO-free zone. The results of these decisions are clearly visible with the Dutch government ceasing financing into GMO potato crops with double resistance genes against *Phytophthora infestans* and the number of scientific field trials decreasing since 2001.

Crop Protection Agents

The residues of crop protection agents (CPAs) have been of great concern to policy makers the past years, causing them to set goals for reductions in environmental impact and for residues on food. The use of CPAs hasn't decreased between 2002 and 2012, but the environmental impact (expressed in Environmental Impact Points) of the agents on the groundwater and surface water did decrease (Figure 4). This is likely the result of changes in application techniques and limitations set for application though regulations. Only for soil biota did the environmental impact not change. Residues on food have decreased significantly as well, mainly through harmonization of regulations within the EU. The new incarnation of the Dutch regulations on CPAs aims to reduce drift by another 75%, eliminate all issues with residues in drinking water by 2023 and introduce additional measurements to ensure the health and safety of residents around fields with heavy spraying of CPAs.

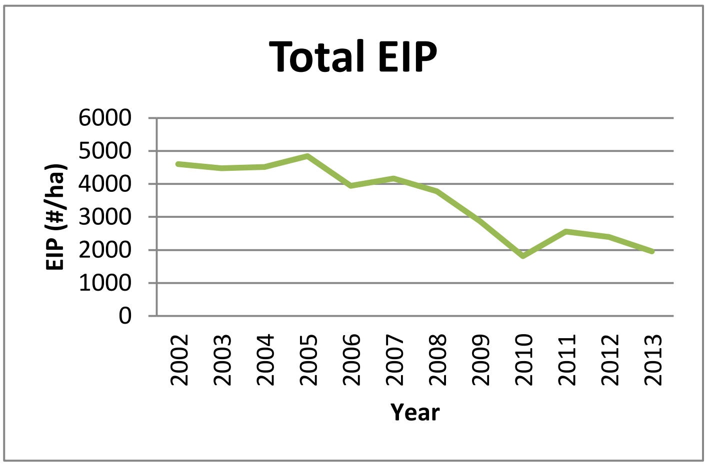

Figure 4: The Environmental Impact Points (EIP) measured per hectare per spraying for Dutch arable farming. Measurements include effects on surface water, groundwater and soil biota. Source: LEI – Wageningen UR.

Water and climate

The climate in the Netherlands is heavily influenced by the seas and requires farmers to make use of irrigation during droughts. The main irrigation source within the Netherlands is the groundwater, which is primarily for farmers south of the rivers, and surface water for farmers close to the seas. Tap water is hardly used as water source. The use of irrigation depends greatly on the rainfall and the region. In 2015 the rainfall was limited until mid-July, after which the entire country received a substantial amount of rain. The recorded droughts immediately decreased substantially.
The KNMI (Dutch Meteorologic Centre) has come up with some predictions for future climate in the Netherlands based on the IPCC models. The results indicate that the Dutch climate will become much more variable with more droughts, more heavy rainfall, a longer growing season and a greater level of transpiration for crops, with the parameters used only influencing the magnitude of the change.

Energy

The aim in the use of energy is to make it more sustainable. For farmers this meant that investments had to be done in windmills, solar panels and other technologies for renewable energy. Some techniques, like the use of bio fuel, were enforced by the Dutch government upon the fuel producers, but farmers sometimes took this a step further by using bio fuel even more frequently. The goal set for 2020, to make 14% of the national energy used sustainable, has to come partly from farmers. A total of 12 PJ electrical energy has to be produced annually by farmers by 2020, 40 PJ needs to come from biomass and the use of fossil fuels needs to decrease by 2% every year between 2010 and 2020. The results so far are very positive. Since 2007 farmers are net electricity producers (Figure 5), this is without including greenhouse horticulture, and by 2012 a total of 11 PJ was already being produced annually by farmers through the use of windmills.

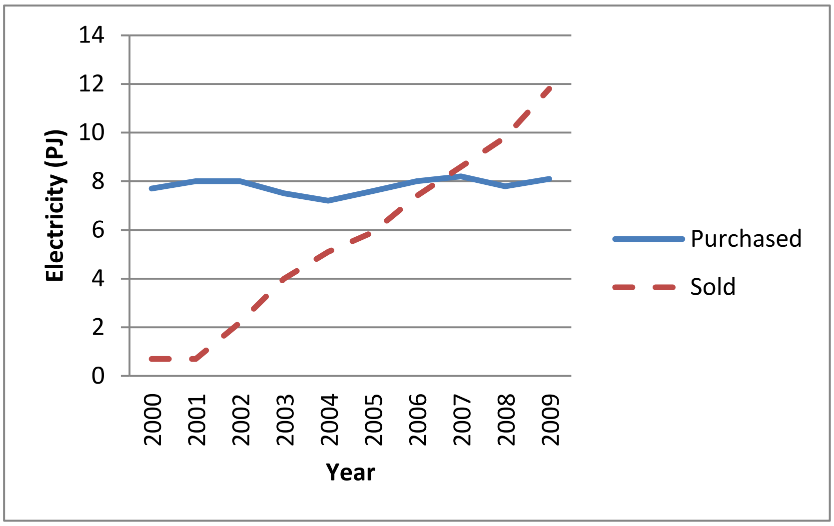

Figure 5: Electricity produced and sold by Dutch arable farmers and livestock farmers between 2000 and 2009. Source: Energie- en klimaatmonitor Agrosectoren 2011.

The total use of energy has increased by 35-40% per farm between 2002 and 2013, but as the number of farms went down as well in that same period, the total use of energy by the sector remained constant. The fraction of diesel in this total energy use has increased over time while the use of fossil fuels has decreased, indicating an increase in the use of biodiesel. The resulting CO_2 emissions were stable the past decades, though a decrease is expected for 2014 (preliminary results).

Further research and recommendations

Overall the Dutch agricultural sector is performing well and is complying with the regulations they face. However, the fact that a derogation is still required for the use of nitrogen is a less positive note. If farmers can find a way to use their nitrogen more efficiently, the application rates could go down and a derogation would no longer be required. The lacking governmental support for GMO crops in recent years is also a negative development and could have severe consequences within the context of climate change as well as continued economic losses by pests and diseases such as *P. infestans*. Policies with regards to CPAs are having their effect, though a further reduction of drift and additional attention for the reduction of environmental impact on soil biota is feasible. Policy makers should also take another look at the use of bio fuels as energy source, as they are cultivated at the cost of agricultural land for food production and still release CO^2 into the atmosphere. Further stimulating (and potentially subsidising) the use of windmills and solar panels is a more sustainable pathway than the use of bio fuels.

Experimental data collection for soybean yield potential estimation

Assignment description

The Global Yield Gap Atlas (GYGA) has been developed in recent years to calculate and visualize the yield gap across the globe for many crops, primarily cereal crops. Understanding the size of the yield gap and determining the underlying causes can help increase the yield in specific regions around the world. Closing these yield gaps is a high priority as the world population is increasing and claiming more land is in many cases unsustainable or even impossible. Instead of the closure of yield gaps of cereal crops a shift in crops can also be considered. One of these crops is soybean.

Soybean is a highly nutritious bean which benefits from Biological Nitrogen Fixation (BNF). Through BNF the soil can be enriched with nitrogen, limiting the amount of fertilizer required for farmers to reach higher yields. Especially for African countries this is of vital importance. A project already invested in this is the N2Africa project, which aims to change legume cultivation in Africa to a more optimal standard as well as increase the use of legumes as crop in Africa. Using the information from the N2Africa project, a first step can be taken towards the calculation of yield gaps for soybean in African countries.

Another step to be taken before yield gaps can be calculated is to determine the potential yields. For this a model capable of simulating the growth of soybean is required. One such model is the SSM-Legume model. This model calculates the yield based on phenological development, changes in harvest index and soil water balances. However, the SSM model requires over 50 parameters to run, which requires a solid number of input sources.

The assignment for this project was as follows: "Extract as many relevant parameters for the SSM-Legume model from N2Africa trials and literature to be able to model the potential yields of soybean for Sub-Saharan African countries. To achieve this the following steps were taken: (1) Evaluate the SSM-Legume model and create a list of required parameters, (2) Collect as much relevant data from the N2Africa agronomy trials and (3) Collect as many missing parameters from literature as possible.

Figure 6: Picture of a soybean trial in Rwanda performed within the N2Africa project. Source: http://www.n2africa.org/.

Findings

SSM-Legume

The SSM-model simulates crop development based on the cumulative biological day (BD), in which a BD is a day with “optimal temperature, photoperiod and moisture content for plant development” (Soltani et al., 2013). Crop development rate is being determined by the mean daily temperature and photoperiod. The temperature and photoperiod functions are described using beta and quadratic equations, respectively. Sensitivity of the crop to photoperiod as well as the base temperature for development affects the contribution of both functions to the crop development rate. A water deficit stress factor is being used to increase the development rate under drought conditions, which is relevant mostly for crops like wheat. Vernalization is also included in the model through a cumulative vernalization response, similar to the accumulation of BD.

Leaf area development is being simulated using a crop-specific phyllochron, main stem leaf number and water and nitrogen availability. Main stem leaf production stops at the appearance of the flag leaf ligule. The leaf production period is determined by the temperature, photoperiod, vernalization and water availability. In the model plant density determines the potential plant leaf area through a simple power function. LAI is calculated from the leaf area and plant density and then reduced by the nitrogen availability. Allocation of dry matter to the leaf area and SLA determines the leaf development between the appearance of the flag leaf ligule and seed growth. Leaf senescence is calculated from the LAI and N availability, allowing for nitrogen to be mobilized. When nitrogen is not limiting, leaf senescence is calculated directly from the LAI, following a linear decrease to 0 from the beginning of seed growth until maturity. Freezing events may destroy LAI, at a rate of 1% for each degree below -5 °C.

The production of dry matter and partitioning are being simulated using incoming photosynthetically active radiation (PAR), the LAI and the canopy extinction coefficient to calculate the intercepted PAR (iRUE). The iRUE is corrected for temperature, water deficit and atmospheric CO_2 to compute the final RUE. The partitioning is being simulated throughout the development for three sinks: leaves, grains and other organs.

The crop nitrogen requirement is calculated both before and after the start of seed growth. Before seed growth the determining factors are the daily LAI increase, specific N content in green leaves, daily stem dry matter increase and green stem N content. After the seed growth has commenced the seeds are the primary sinks with a daily N requirement calculated from the daily seed growth and seed N concentration (constant).

Crop yield is being determined using the total seed dry matter as well as a scaling factor of changing HI for the remaining crop dry matter, allowing for dry matter reallocation. This reallocation only takes place if the daily dry matter production is lower than the potential reallocation dry matter.

Soil water is being factored in using up to ten layers, using input parameters such as volumetric soil water content at saturation and drained upper limit, extractable soil water content, drainage factor and soil moisture availability index for each layer. From these parameters the soil water content, actual transpirable soil water, total transpirable soil water and fraction transpirable soil water are being calculated. Drainage from each layer is limited through the use of a drainage factor. Runoff is calculated using the soil curve number, soil water content, actual water content and daily rainfall. This model is robust for many soil types, limiting the soil data required for modelling. Soil evaporation is calculated on a daily basis using two stages: (I) Evaporation from the top layer and (II) Evaporation from the lower layers, calculated similarly to stage I, diminishes over time, but returns back to its full value if precipitation greater than 10 mm occurs. Preference for evaporation is of course placed on the upper layer. Transpiration follows from the crop dry matter production, transpiration efficiency coefficient and vapour pressure deficit. Drought is incorporated as a scaling effect on the growth, leaf development and phenological development. Effects of drought are being controlled through predetermined thresholds for each process.

To simulate all of these processes a series of parameters is required. Some parameters, such as the soil quality, are fairly robust and can be used from previous legume simulations. Other parameters, such as the phyllochron, LAI and soil water content the model is more sensitive to. Below an overview is presented of the required parameters for simulating soybean:

Daily weather data:

Radiation, minimum temperature, maximum temperature, mean temperature, rainfall.

Soil/water data:

Soil depth, top layer depth, soil albedo, soil curve number, drainage factor, soil saturation limit, soil drained upper limit, soil extractable moisture, moisture availability index top layer, soil moisture availability index, initial soil nitrogen before BNF.

Management data:

Field latitude, sowing date, planting density, irrigated/rainfed conditions.

Crop data:

Phyllochron, main stem node number coefficients (constant ad power), SLA, base temperature for DM production, lower optimum temperature DM production, upper optimum temperature DM production, ceiling temperature DM production, extinction coefficient PAR, RUE under optimal growth conditions, partitioning to leaves at low levels of crop mass, partitioning to leaves at high levels of crop mass, crop mass partitioning parameter (switch from low to high crop mass parameter), partitioning to leaves after termination leaf growth, translocatable crop mass at start seed growth, HI daily coefficient, GCF, rooting depth, effective depth of water extraction by roots, potential daily increase root depth, transpiration efficiency coefficient, fraction transpirable soil water threshold when nitrogen fixation declines, base temperature for development, lower optimum temperature for development, upper optimum temperature for development, ceiling temperature for development, critical photoperiod, photoperiod sensitivity coefficient, emergence date, flowering date, podding date, seed filling date, start maturity date, full maturity date, photoperiod temperature sensitivity (start and end), drought threshold factor, termination of flowering, seed growth temperature sensitivity (start and end), root growth temperature sensitivity (start and end), thermal time at which BFN starts, lethal drought factor, lethal flooding factor, vapour pressure deficit factor and critical vapour pressure deficit.

On top of these parameters a series of yields and dry matter accumulation during the development will need to be collected to help calibrating the model.

N2Africa

A part of this data can be collected from the N2Africa project. N2Africa is a cooperative effort between researchers across the world to promote the use of legumes in Africa, reducing food scarcity and improving soil fertility (Giller et al. ; http://www.n2africa.org/). They do this through various trials and initiatives, in which they tailor the use of legumes and the technologies involved to each country and region to maximize yield, improve local expertise, address gender disparities, establish new value chains and input supply chains, and improve inoculant use and availability.

Various trials have been set up for various crops, including soybean, groundnut, common bean, chickpea and others. These crops are listed as target legumes for one or more regions, marking them as a suitable and promoted legume in these areas. The trials set up within the N2Africa project to promote the use of these legumes, improve the legume technology as well as assess the progress made include: Agronomy trials, adaptation trials, diagnostic trials, demonstration trials, dissemination trials, focal adaptation trials, nutrient omission trials, nutritional studies, baseline surveys, impact surveys, use surveys and others. For the parameterization of the SSM model the agronomy trials are the most relevant trials.

The agronomy trials, divided between input, variety, and inoculation trials, provide information on the growth and development of a crop variety in a test plot. This information ranges from management data to crop development dates to biomass assessments. The management data includes (in many cases) the planting density, sowing date and type of fertilizer used as well as the use of an inoculant and the eventual harvest date. The crop development has been recorded through the collection of dates on which a specific percentage of the crop reached a certain phenological stage. These stages include flowering (50%), podding (50%) and maturity (100%). Biomass assessments have been performed in the R6 stage of development as well as at harvest. Description of the stages can be taken from Pedersen (2004). Various values have also been calculated from the measured data, including the aboveground biomass at stage R6, root biomass at stage R6 and seed yield at harvest per hectare. The equations used for these calculations can be found in the documentation of the data files, at the end of this document. Cultivar names in the N2Africa trials are often marked using SB-codes, which can partly be translated to the original cultivar names using Mahasi et al. (2011).

Parameters from literature and project trials

A part of the parameters for the SSM-model can be collected from the N2Africa project, but a large number will need to be obtained from previous SSM-model research, GYGA procedures and soybean research as well. The information from N2Africa trials includes, in many cases, GPS data. Not only does this mean that we have an accurate value of the latitude for the model, it also makes it possible to select a weather station as close to the actual site as possible, to get an accurate overview of the climatic growing conditions. However, the weather stations in Africa often don't have a complete collection of the data, especially not daily. The procedure described in van Wart et al. (2015) has been used in the GYGA project to obtain weather data from areas where weather data is scarce. The weather data files generated are, for many locations, available from the GYGA website (http://www.yieldgap.org/). In some cases these weather data files are not available due to licensing of the original data. For at least one country in which N2Africa research took place, weather data is available from the GYGA project: Kenya.

Together with the weather data from the GYGA project, some of the phenological parameters can be calculated using the N2Africa data. As noted before, the model requires the input of seven dates for the accurate modelling of the phenological stages. Four of these dates are available from the N2Africa data, making it mandatory to either make assumptions for the remaining dates or estimate them using literature. In addition to this a minimum temperature for development has to be found. According to Streck et al. (2005) this base temperature can be assumed to be 10 °C, which they took from Sinclair et al. (1986), while Sinclair et al. (2003) argues for a base temperature of 8 °C and a base temperature of 11.2 °C only two years later (Sinclair et al, 2005). Osborne et al. (2013) make use of a base temperature for soybean of only 7 °C, which shows that this parameter is far from certain and likely varies between cultivars.

Apart from this phenological data, only the biomass assessment at stage R6 of development and the final yield (split between grain, haulm and husk) is available from the N2Africa trials in terms of crop development and growth. This data can be used for the eventual calibration, but still leaves many variables to be determined. Through literature some of these parameters can be determined:

Leaf Area Index (LAI): This characteristic has been measured in increments of 15 days after emergence (DAE) for 20 soybean cultivars by Khan et al. (2015). This was done in Bangladesh between January 2011 and June 2011. In addition to the LAI, the total dry matter per plant (every 15 DAE and dry matter partitioning (at 90 DAE) have also been measured. Leaf area dynamics have also been measured by Aduloju et al. (2009) for various soybean cultivars in a southern Guinea savannah environment. LAI varied greatly between cultivars and was also significantly different between different phosphorus fertilizer application rates.

Phyllochron: Different studies have measured the phyllochron, and while it is generally close to 50-60 °Cdays, there is a lot of variation between cultivars. Streck et al. (2005), for instance, calculated the phyllochron from Sinclair et al. (1986), which was 55.5 °Cdays. In the same year, Sinclair et al. (2005) published an overview of soybean cultivars, classified in three different development categories, with their phyllochron. In this article the phyllochron is shown to vary amongst cultivars between 49.1 and 64.2 °Cdays. In Sinclair et al. (2003) the 1986 model was adjusted to the Brazilian climate, which resulted in a shift in phyllochron from 55.5 to 71.4 °Cdays. This change was the result of a change in the leaf appearance rate in the model, which was more in line with the field data. Similar to the base development temperature, the phyllochron is not set in stone and varies greatly between cultivars.

Daily Harvest Index increase (PDHI): Few articles exist with detailed information on the change in HI. Sinclair et al. (1986) made use of a fixed increase in HI of 0.011 per day. Their sensitivity analysis showed that changes in this parameter affected the final yield only little.

Specific Leaf Area (SLA): The SLA has been calculated in various studies. Lieth et al. (1986) studied the effect of elevated CO_2 levels on the leaf area of soybean in the field. They formulated an equation which made use of the atmospheric CO_2 concentration to determine the leaf area. From this formula, using the current CO_2 level of 402.52 ppm (www.co2.earth), the SLA of soybean can be determined, which is 0.0245 m^2/g. Leadly and Reynolds (1988) took the work of Lieth et al. (1986) a step further and performed their measurements on the plant level instead of the field level. The resulting SLA, also calculated using the current CO_2 level, was lower than the SLA calculated by Lieth et al. (1986), namely 0.0175 m^2/g. Nyambane (2009) used the CROPGRO model to simulate crop growth for various soybean cultivars, making use of both the unmodified CROPGRO parameters (around 0.0380 m^2/g) and adjusted parameters (0.0300 m^2/g). Here the adjusted parameters were set to the lowest level possible in CROPGRO, as the field trial measurements showed a much lower SLA for all cultivars. Hence, the SLA is likely closer to 0.0200 m^2/g than 0.0300 m^2/g.

Nitrogen concentration: The nitrogen concentration of the aboveground biomass has been studied and reported by Pengelly et al. (1999). Through three experiments based around radiation interception various parameters were collected, one of which being the aboveground nitrogen content. From these measurements the N content was determined to be 0.028 g/g. This value seemed to fit the measurements well until near-maturity. Similarly, Muchow et al. (1993a) determined the aboveground N content just before near-maturity, which was equal to 0.032 g/g.

Radiation Use Efficiency (RUE): The RUE has been determined for soybean, mung bean and cowpea by Muchow et al. (1993b). In a series of experiments under various environmental conditions the RUE was determined for each of the three crops. For soybean, though only one cultivar was used in the analysis, the RUE was determined to be 0.88 g/MJ.

Radiation extinction coefficient: In addition to measuring the nitrogen concentration, Pengelly et al. (1999) also analyzed the radiation extinction coefficient. Obtained through linear regression of the fraction of radiation intercepted (FRI) on LAI, the extinction coefficient for soybean was determined to be 0.50 ± 0.05. The formula in which they used the extinction coefficient was: $FRI = 1 - e^{(-k \times LAI)}$.

Rooting depth: The maximum rooting depth of soybean cultivars varies greatly, but seems to stay within the 250 cm range. Trials performed by Kaspar et al. (1984) showed that on average the maximum rooting depth was around 160-180 cm, but some individual plants managed to reach depths of more than 200 cm. These trials were also used to determine the root growth rate of soybean cultivars of various maturity groups. On average the taproot elongation rate was 4.5 cm/day for maturity group I, 3.5 for group II and 4.2 for group III. The rooting depth is sometimes also much lower, as is shown by Wang et al. (1986), where a rooting depth of only 135 cm was found as greatest depth.

Partitioning: In addition to the dry matter partitioning of Khan et al. (2015) the partitioning of dry matter in soybean has also been measured by Bender et al. (2015). In this study, the dry weight and nutrient contents of various plant organs were followed over time, with the inclusion of each growth stage in the time scale (Figure 7). Nutrient uptake was also measured during the trials, making these trials a valuable source of information.

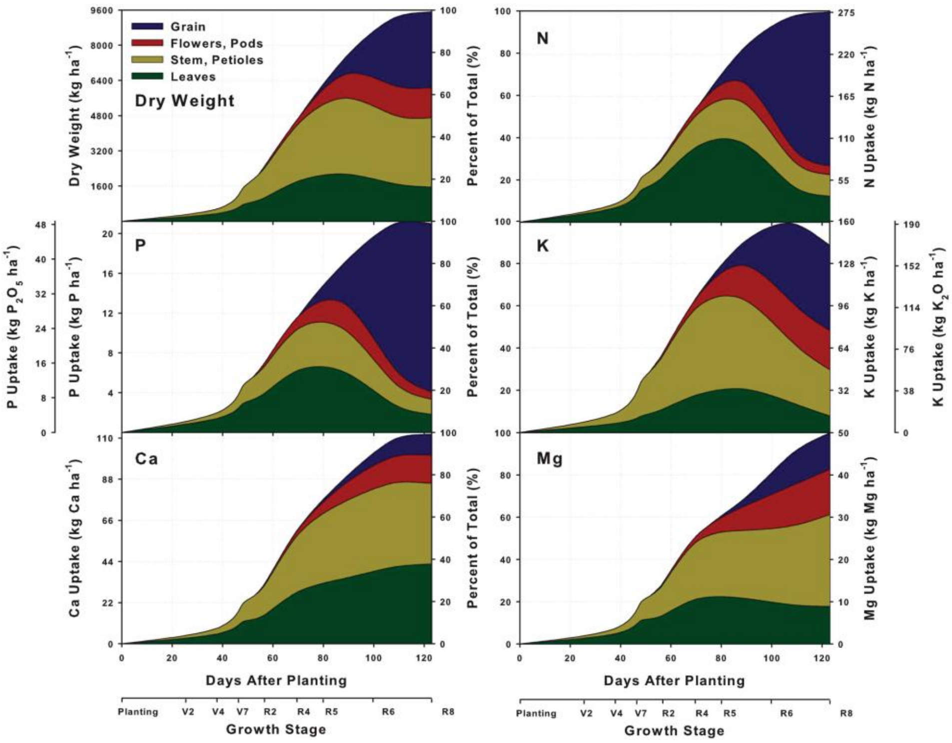

Figure 7: Dry matter and nutrient partitioning during the growth of soybean. (Source: Bender et al., 2015)

To be able to determine the yield gap for specific countries, some information also needs to be known about previous calculated potential yields to have an indication of the yield levels which may be considered close to potential. In the GYGA the potential yield (water-limited) for soybean has already been determined for Argentina, which was calculated to be 3.9 ton/ha (http://yieldgap.org/ ; Mercau et al., 2007). Specht et al. (1999) already calculated that the potential yield in the U.S. was likely to be around 6.0 to 8.0 ton/ha. These values were based on soybean yield contests in the U.S., where the winning soybean was recorded for each year. Grassini et al. (2015) performed a yield analysis in the U.S. as well and found average potential yields of 5.1 to 5.9 ton/ha.

A final potential source of information is Tefera (2011). This study documents the maturity dates and yields for various soybean lines in IITA breeding trials. These lines also include, for instance, the TGx 1740-2F cultivar used in many N2Africa trials, giving an indication of the variation which exists between cultivars.

Further research and recommendations

Even though various parameters can be found in literature, parameters related to the optimal growing and development temperatures, photoperiod and other thermal time-related factors still need to be determined. This cannot be done through the N2Africa project, as this data hasn't been collected. Some of the missing parameters can be copied over from other legume simulations, such as the one for chickpea, but this needs to be done with care. Copying over parameters which are crop- or even cultivar-specific should be avoided where possible. Parameters related to the water management and soil water content are even harder to find, as these parameters are soil-specific, cannot be copied over from literature and also haven't been collected in the N2Africa project. If trials were to be found with sufficient data to model the soil water balance this problem could be alleviated.

Yield gaps in sugar beet (*Beta vulgaris*) and sugarcane (*Saccharum officinarum)*

Assignment description

On a global scale sugar beet and sugarcane are among the highest yielding crops. The products of these two crops are being used as direct source for sugar as well as for the production of bio-ethanol. Because of these characteristics, these crops are well known as cash crops. Over the next few years the demand for sugar is expected to increase to help feed the growing world population.

Such a growing demand for a product combined with the high yielding capacities of the crop stimulates research into the current production of the crops and the yield potential. Discovering the yield gaps on a global scale can help target specific regions for improvement. Further examining the yield gaps can also expose underlying mechanisms limiting the yield production, which can lead to yield improvements if these specific mechanisms can be targeted.

The assignment description is as follows: "Investigate the developments in yield and production of sugar beet and sugarcane the past decades and summarize research into yield gaps for these crops on a global scale." To achieve this the first step was to (1) Collect yield and production data from the FAO and other sources, (2) Analyze this data for trends within countries, continents or on a global scale, (3) Investigate the production techniques (irrigated or rainfed) on a global scale and (4) Summarize yield potential research published on either sugarcane or sugar beet for specific countries.

Findings

Production

The FAO data shows that the sugarcane market is largely dominated by Brazil, with an annual production of $4.64 \cdot 10^8$ ton/y between 1993 and 2013. In 2013 this production even went as high as $7.68 \cdot 10^8$ ton. The very next country is India, which achieved production levels only half that of Brazil. China, Thailand and Pakistan complete the top five producers for sugarcane (data not shown).

Sugar beet production is a lot lower than that of sugarcane with France being the top producer of sugar beet between 1993 and 2013 with a production of $3.19 \cdot 10^7$ ton/y. In 2013 the top producer was Russia with a production of $3.93 \cdot 10^7$ ton, with France only making it to $3.36 \cdot 10^7$ ton. The top five is completed by the USA, Germany and Ukraine. In 2013 the production of Ukraine wasn't high enough to make it to the top 5, losing its spot to Turkey, which is likely the result of the ongoing political conflicts (data not shown).

Table 1: Annual harvested area change on a continental and global scale, expressed in ha/y, recorded between 2001 and 2013. Calculations done using linear regression, all trends were significant. (Source: FAOStat)

	Sugar beet	Sugarcane
Africa	9,301.77	15,791.84
Americas	-8,571.80	475,420.92
Asia	-31,970.12	154,962.75
Europe	-100,026.84	-105.24
Oceania	0	-11,280.77
World	*-131,266.99*	*634,789.53*

The harvested area of sugar beet decreased greatly worldwide, with a loss of over 130,000 ha per year between 2001 and 2013 (Table 1). The greatest losses were recorded in Europe. In all areas of Europe except eastern Europe the losses were significant ($p<0.05$) (data not shown). EU reforms put in place in 2006 are the main reason for this decrease (EU Commission, Agrosynergy, 2011). Only for

Africa an increase in harvested area was observed, for which the increase in harvested area in northern Africa is almost solely responsible.

Sugarcane shows a much more positive trend with a worldwide annual increase in harvested area of nearly 635.000 ha/y between 2001 and 2013. The greatest contributors to this increase are the Americas where the harvested area increased by 475,000 ha/y. (Table 1) Latin America in particular contributed to this with an increase of 509,000 ha/y. The net change for the Americas is reduced from the Latin America figure, as a result of losses in harvested area in the Caribbean of 51,000 ha/y. In Asia the harvested area also increased (155,000 ha/y) for which eastern Asia is the most significant contributor (46,000 ha/y) together with south-eastern Asia (39,000 ha/y). Southern Asia also recorded an increase in harvested area of 70,000 ha/y, but this increase wasn't significant (data not shown).

The increased popularity of sugarcane over sugar beet has been described by Chatin et al. (2004), where the shift is attributed to the lower production costs of sugarcane compared to sugar beet, as well as longer processing periods of the sugarcane factories. Hengsdijk and Langeveld (2009) also noticed the same shift for the production area, contrary to the harvested area, showing that the changes are likely not related to changes in cropping frequency. This is to be expected, however, as sugar beet and sugarcane are slow growing crops, making it near-impossible to increase the annual cropping frequency of these crops.

The production conditions of both crops varies greatly per country and area. The production of sugar beet takes place mainly in western and eastern Europe and is cultivated primarily under rainfed conditions. Irrigation is only used as supplementary water source. Afghanistan, Denmark, Greece and Pakistan are the most notable exceptions as the production is primarily through irrigation in these countries. In general sugar beet cultivation takes place above the equator, with Chile being the main exception.

Sugarcane production is primarily below the equator. Contrary to sugar beet the cultivation practices are more variable. Within western Africa, for instance, several countries differ completely in practices (Figure 8). In Sierra Leone, Côte d'Ivoire, Burkina Faso and Mali the production is solely based on irrigation, whereas in Guinea, Liberia, Ghana and Niger the production relies solely on rainfall. This is likely the result of governmental policies on the one hand and potential inconsistencies in the SPAM2005 database on the other hand.

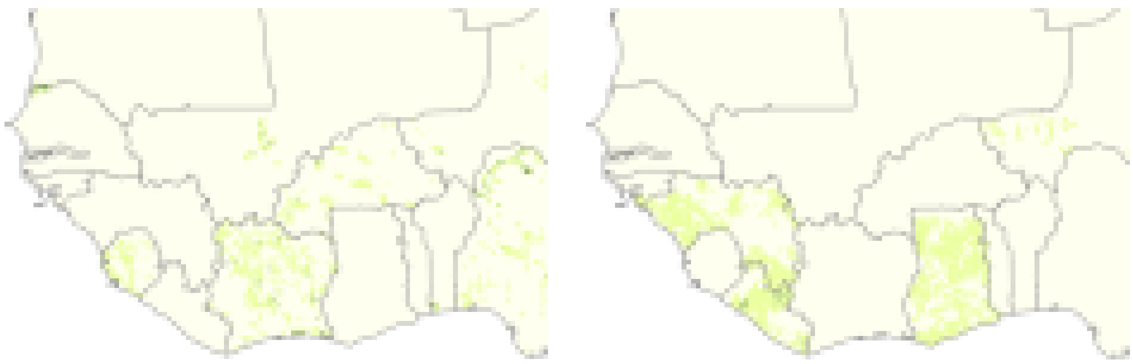

Figure 8: Growing conditions, irrigated (left) and rainfed (right), for sugarcane in Western Africa. (Source: SPAM2005 ; You et al., 2015)

Yield

The yield of sugar beet, regardless of the production condition, is highest in western Europe and gradually decreases moving into eastern Europe. The lower yields in eastern Europe compared to western Europe can be attributed to the removal of fertiliser subsidies in the 1990s, which farmers heavily relied on. Globally the yield of sugar beet increased from 40 ton/ha in 2001 to 55 ton/ha in 2013, which translates into an annual yield increase of 1.38 ton/ha/y (R^2 = 0.8919) (Figure 9).

Breaking down the trend to the level of individual countries shows that yields increased in nearly all countries (data not shown). Only east of the Black Sea does the yield not increase. Portugal is the greatest outlier, with a decrease in yield of nearly 4.0 ton/ha/y (p=0.014). This decrease, similar to the decrease in harvested area, can be attributed to the 2006 EU reforms (EU Commission, Agrosynergy, 2011). In all countries the production area has decreased in this period, but only in a few countries (including Portugal) has sugar beet cultivation completely disappeared.

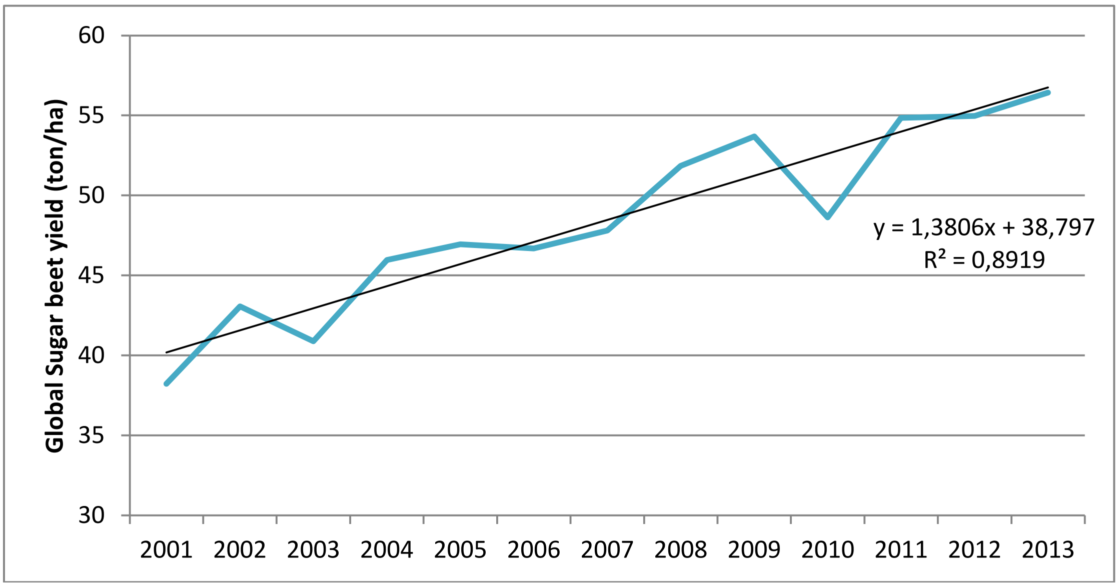

Figure 9: Average global sugar beet yield between 2001 and 2013. (Source: FAO)

For sugarcane, cultivated mainly in Brazil, south-east Asia and southeast Africa, large variation exists not only between countries but also within countries in terms of obtained yield. Climate and soil properties are a large factor in this variation. The yield increased slightly between 2001 and 2013 from 65 ton/ha to 71 ton/ha, though this increase is less significant than the increase observed for sugar beet (Figure 10). Contrary to sugar beet the developments in sugarcane yields are less uniformly positive with decreases in both north Africa and south Africa. For most countries no significant changes in achieved yield were observed. Extremes in yield difference are found in Tanzania and Mozambique. Mozambique increased its yield by 3.7 ton/ha/y between 2001 and 2013, while Tanzania, the neighbouring country, recorded yield losses of 6.0 ton/ha/y in the same period. Recovery of agriculture after the civil war in Mozambique is the main reason for the yield increase. In Tanzania the sugar production exceeded the capacity of the farms for many years, resulting in harvesting schedules to ensure a steady inflow of sugar cane for the processing plants. However, this resulted in harvest losses due to weather conditions or prolonged exposure to diseases. A farm block system has been introduced to deal with this problem, but due to poor leadership and low returns for the farmers this hasn't fulfilled its purpose (PLAAS, 2014).

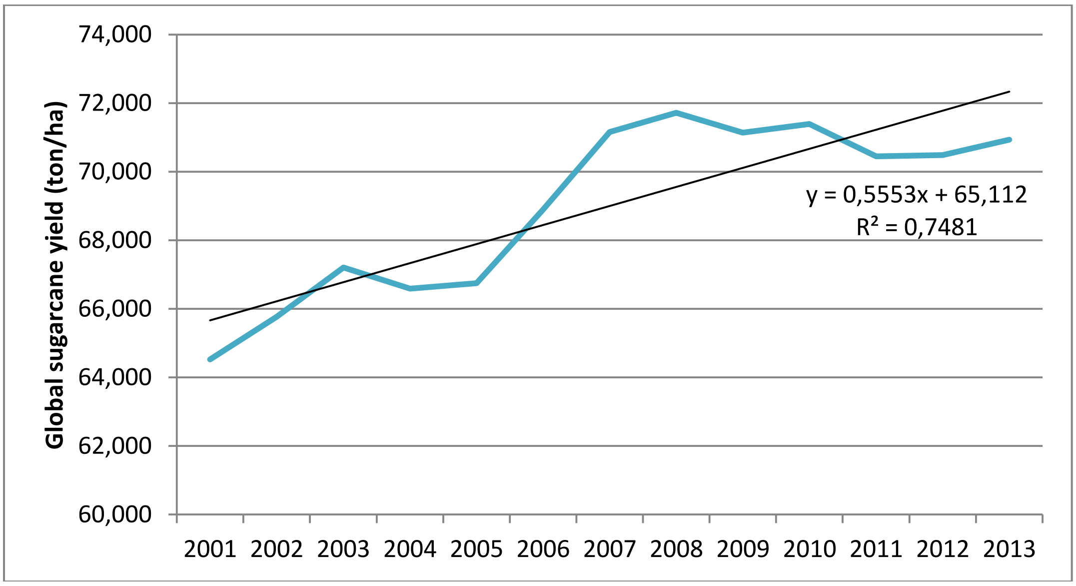

Figure 10: Average global sugarcane yield between 2001 and 2013. (Source: FAO)

Yield gaps

For both crops the yield gaps have been researched on various scales and in various countries. Licker et al. (2010) analyzed the yield gaps for both crops on a global scale. The yield gap for sugar beet shows a similar pattern as the achieved yields in Europe, where the yield gap increases from western Europe to eastern Europe (Figure 11a). The yield gap in eastern Europe is estimated to be as large as 70% of the potential yield. For sugarcane no gradients can be seen, but overall the yield gap is on average 40% of the potential yield.

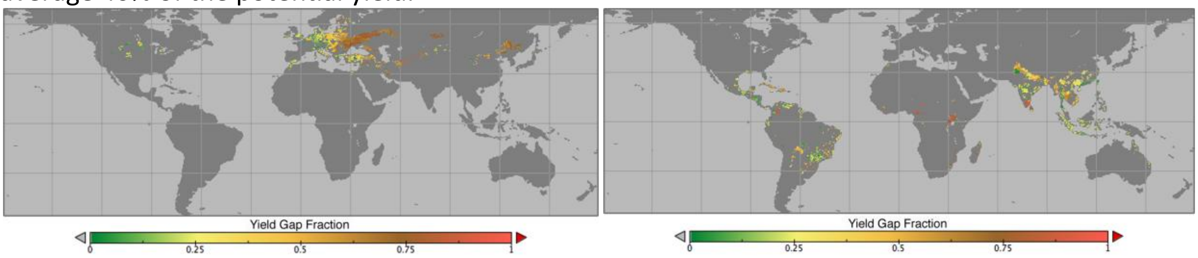

Figure 11: Yield gap fraction values on a 5 minute grid with an equirectangular projection for sugar beet (left) and sugarcane (right). (Source: Licker et al., 2010)

In the GYGA project (http://www.yieldgap.org/) the yield gap of rainfed sugarcane has also been estimated for Brazil using the CANEGRO model. Based on their calculations the yield gap in Brazil is 39% of the water-limited potential, though regional differences can be observed (Figure 12).

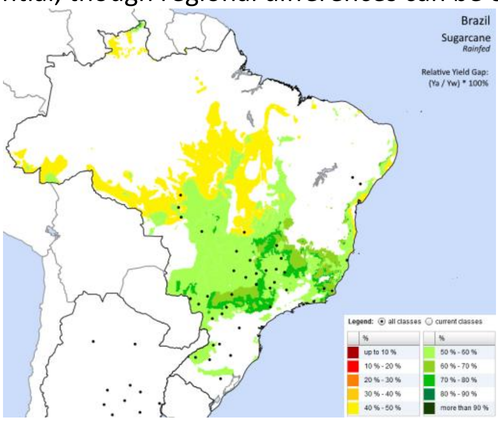

Figure 12: Relative yield gap per climate zone in Brazil for rainfed sugarcane production. (Source: GYGA)

More uncertain assessments were also done by Jaggard et al. (2012) for sugar beet. In this research the yield gaps were estimated based on the eventual sugar yield, instead of the biomass yield. The resulting relative yields were close to 80% for most countries, with the exception of Austria, England and Italy (61-63%) as well as the U.S. (96%). For the U.S. the higher observed yields were explained with the elimination of post-harvesting losses due to the processing taking place only a small time after harvest. Potentially this can help reduce yield gaps in other countries as well.

The relative yields have also been tracked over time by Supit et al. (2010). Using the Crop Growth Monitoring System in combination with observed national yields the relative yields were calculated for 1976 to 2005 (Table 2). Not only does this research show a limited form of yield gap closure for most countries, it also shows the difference between eastern (45-50%) and western (70-80%) Europe.

Table 2: Relative yields for sugar beet as calculated from Supit et al. (2010)

	Relative yield (Ya/Yp)		
Country	**1976-1995**	**1996-2005**	**1976-2005**
Austria	57%	74%	62%
Belgium	69%	84%	74%
Denmark	69%	81%	73%
Germany	55%	75%	59%
France	68%	86%	74%
Ireland	65%	73%	68%
Netherlands	73%	77%	74%
UK	58%	73%	63%
Bulgaria	44%	35%	41%
Czech R.	39%	54%	44%
Hungary	42%	55%	46%
Poland	42%	49%	44%
Romania	51%	44%	48%
Slovakia	36%	43%	39%
Greece	81%	85%	82%
Italy	52%	55%	53%
Portugal	91%	66%	79%
Spain	43%	68%	51%

Further research and recommendations

The next steps in this research would be to expand the yield gap research to more countries for both crops and to reach a level of detail closer to that of the GYGA. Additionally, the yield gaps in terms of sugar produced (as done by Jaggard et al., 2012) should be considered, as considerable losses of yield can occur between harvesting and processing. Finally a better understanding of the yield gaps need to be established. The fertilizer policies in eastern Europe are a good example of the effects of a single factor on yield gaps and potentially yield gap closure, but this is largely unknown for many countries, especially for sugarcane. Putting the yield gaps in the context of climate change can also be interesting, specifically for sugar beet due to the vernalization requirement. Potentially this will affect the yields in the long term as well.

N2Africa Baseline report

Assignment description

The N2Africa project is an international effort with the intention to better understand the cultivation of legume crops and to both promote and support the cultivation of legume crops in Africa to improve the nutrition and economic status of households as well as improve the soil fertility. This is being done through various trials and close collaboration with both local farmers and country agronomists. Trials aimed at selecting suitable varieties, optimal fertilizer inputs and *Rhizobium* inoculations are being done throughout the project, amongst other trials.

In 2013 and 2014 the N2Africa project team conducted surveys in Tanzania, Uganda and Ethiopia to create a baseline overview, which allows for assessment of the effects of their efforts at a later stage. These baseline studies, which focus on the household social, economic, agricultural and nutritional characteristics, have resulted in a series of large datasets to be evaluated and reported on. However, the data collected had not been cleaned yet and contained a large number of inconsistencies. Previous studies performed in the project formed a guideline for the reporting. The following actions were taken to be able to answer each question:

1. Clean the datasets to a level sufficient for data processing and evaluation for all three countries.
2. Create a uniform data structure for all three countries to ensure similar terms and assessments are being used.
3. Calculate figures related to all household characteristics on a regional and national level. (Most calculations were performed in Excel. Scripts used for calculations in Python are included in the Appendix.)
4. Report on the findings on a country level for all characteristics as well as on inter-national level for gender differences.

Figure 13: Logo of the N2Africa project. Source: http://www.n2africa.org/.

Findings

In all countries the position of males and females is fairly equal, with the exception of Ethiopia. In all countries in about 60% of the fields the husband and wife manage the fields and decide over the harvest sales together. In Uganda and Tanzania is the wife just as often in control as the husband in the remaining fields. Only in Ethiopia this balance is off, as the husband manages sales and manages the field much more often than the wife when decisions and management aren't shared (Table 3).

Table 3: Percentage of fields where either the husband and/or wife holds control over the use of land or harvest sales of the crop in Ethiopia, Tanzania and Uganda. Data collected in 2013/2014.

Control over	Wife	Husband	Both	Number of fields
Use of land				
Ethiopia	3%	37%	60%	1497
Tanzania	17%	18%	62%	473
Uganda	32%	21%	47%	702
Harvest of crops				
Ethiopia	4%	25%	71%	1489
Tanzania	19%	18%	59%	475
Uganda	20%	19%	61%	705

Not only the harvest of crops contributes to the household income, also other sources such as livestock, remittances or off-farm jobs. In all countries cropping is most often mentioned as income source (95-100%) together with livestock (60-80%). However, the contribution of these sources to the total income shows a different picture. Cropping only provides 70-80% of the income for most households, whereas livestock only contributes to only 10-20% of the income. In Tanzania the dependence on other income sources is very limited, whereas income sources such as salaried jobs and casual labour are more prominent in Uganda and Ethiopia (data not shown).

The crops grown vary greatly per country as well as per region. In Ethiopia, for example, maize is grown in all four regions, but the frequency varies greatly. Common bean is only found in the SSNPR, while soybean and groundnut only appear in Benishangul-Gumuz (Figure 14). Some caution is required when interpreting this data, as this data only reflects a snapshot of crops grown in the fields at the time of the survey.

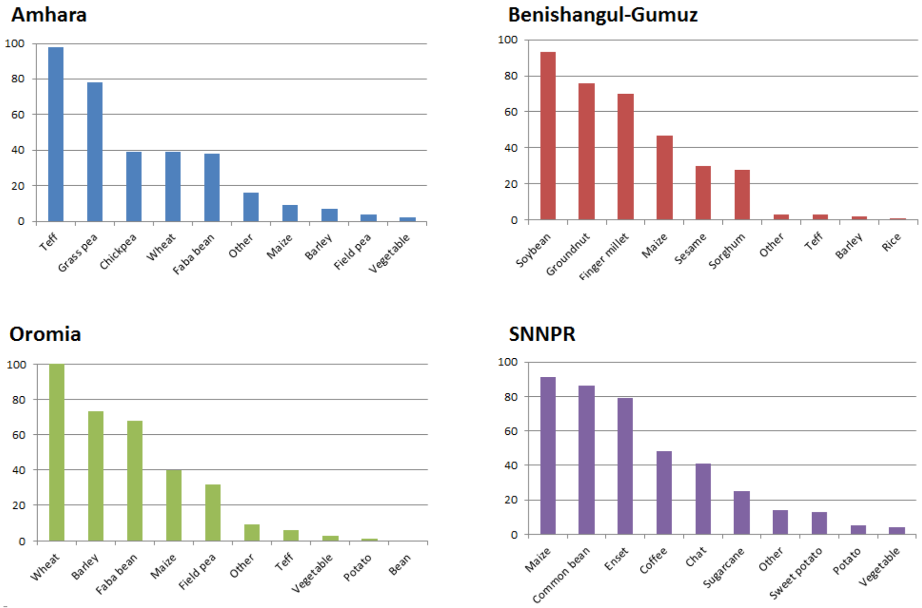

Figure 14: Crops grown in Ethiopia at the time of the baseline survey (2014). Numbers reflect the percentage of households.

From the same data the most common forms of intercropping could be extracted. For this analysis a Python script was used (script included in the Appendix). Once again, this data only reflects a snapshot of crops grown in the fields at the time of the survey. The combination of common bean with maize is most common in all countries (Table 4). In Ethiopia the combination chat-enset is mentioned only as tenth, while these two crops are a more common occurrence in the seasonal rotations (data not shown).

Table 4: Number of fields on which combinations of crops occur during the baseline survey in 2013/2014 in Ethiopia, Tanzania and Uganda. Only the ten most commonly occuring combinations are being displayed.

Ethiopia		*Freq.*
Common bean	Maize	96
Coffee	Enset	27
Coffee	Maize	25
Chat	Coffee	24
Coffee	Common Bean	21
Enset	Maize	20
Chat	Common Bean	19
Chat	Maize	19
Common bean	Enset	18
Chat	Enset	10

Tanzania		*Freq.*
Common bean	Maize	531
Maize	Sunflower	229
Maize	Pigeon pea	169
Groundnut	Maize	164
Cowpea	Maize	138
Maize	Vegetable	88
Pigeon pea	Sunflower	84
Cowpea	Sunflower	71
Common bean	Sunflower	69
Bambaranut	Groundnut	68

Uganda		*Freq.*
Common bean	Maize	67
Banana	Common bean	29
Maize	Peas	13
Cassava	Common bean	12
Common bean	Sweet potato	12
Maize	Sweet potato	9
Banana	Maize	7
Cassava	Maize	7
Common bean	Millet	7
Maize	Soybean	7

As mentioned before, not only cropping is a large contributor to the household income, but livestock farming is as well. The types of livestock vary per country and sometimes also per region. In Table 5 the differences on the country level are shown. Ethiopian households own at least one form of cattle in nearly all cases, whereas only half of the Tanzanian and two-thirds of Ugandan households own cattle. Similarly, only in Ethiopia donkeys, horses, oxen and mules are being owned by a large number of households, but meanwhile no pigs are being owned. Poultry, similarly to cattle, is popular in all three countries, though they are less common in Ethiopian households than in Tanzanian or Ugandan households.

Table 5: Percentage of households which are in the possession of livestock, divided in livestock types, as recorded during the baseline survey in Ethiopia, Tanzania and Uganda in 2013/2014.

Livestock type	Ethiopia (n=389)	Tanzania (n=722)	Uganda (n=345)
Cattle	96%	53%	66%
Donkey	40%	1%	0%
Goat/Sheep	47%	66%	75%
Horse/Ox/Mule	17%	0%	0%
Pig	0%	16%	25%
Poultry	52%	87%	75%
Rabbit	0%	0%	1%

Further research and recommendations

With regard to the findings of the current baseline study a series of focus points have arisen. Firstly, the large dependence of households on cropping practices likely means that they are less likely to take the risk of changing their practices without proper training, guidance and potentially also a demonstration of the result of changed practices. Secondly, the large number of fields on which maize is being intercropped with common bean shows potential. By finding out why these two crops are commonly grown together a practice can be developed in line with the aims of the N2Africa which targets this specific reasoning. This can also help to increase the adoption of practices as less of a risk has to be taken by farmers when attempting a new practice. Lastly, livestock availability can also influence the fraction of ploughed land as well as the available manure fertilizer. Promoting a practice which makes use of the local livestock will likely have a greater chance of being adopted by farmers.

In addition to the findings mentioned above several other observations have been made, but many of these don't show significant differences or weren't recorded properly. Especially the recording of data has been a large obstacle in this study. In some cases up to ten translations of a single crop name could be found in the data. Typing errors were also problematic, resulting in the exclusion of many households from further analysis in certain categories. Marketing data for legumes was hardly recorded or wasn't clearly described, resulting in exclusion for the majority of households in that category. This means that the next study needs to have, in addition to well-defined questionnaires, a structured data management system to avoid indecipherable descriptions, skipped questions, loss of data and unclear definitions. The questionnaires are preferably filled in electronically at the farm location, which gives more control over the database integrity due to the close proximity of the farm and the limited number of possible answers that can be given in such a database.

Naturally, a baseline survey is only one of the first steps of a research project to be able to assess the progress made in a later stage. However, this does mean that a solid baseline survey must have been conducted. Future studies must keep the limitations of the current survey in mind and refrain from making use of incomplete or inconsistent data, such as the marketing data for legumes.

Progress learning goals

During this internship I had set goals for myself which related to the international cooperations within researches, broadening my view on research, yield gap analyses and Dutch agriculture. While a learning goal is never truly accomplished, progress has certainly been made. For instance, in order to obtain enough information for some of the assignments I had to make inquiries within the PPS chair group. Even if questions weren't answered, I was always able to receive some guidance or suggestions which I could put to good use.

The international aspect of research has certainly been highlighted within this internship. I may not have travelled to any foreign country myself, I did come into contact with researchers abroad. For the baseline study we had to make use of some contacts in Africa to help explain the trends we observed in the data. And in the data collection for the estimation of soybean yield potential I've been able to make good use of the publications, tips and suggestions from Hélène Marrou (Montpellier, France).

Not only on an international level, but also here in Wageningen, I had to adjust to the hierarchy and realize that all the researchers within PPS are available to help you. And while it took me a while to reach that point, I'm glad I eventually did. The meetings and interactions have brought me into contact with new people and new studies, and have given me new insights. Joining the N2Africa team for a few weeks has been a great experience and helped me to not only gain a better understanding of the data (which was my original intention) but also better understand the management behind such sizable projects.

The courses at the university have taught me bits and pieces of yield gaps and Dutch arable farming, but never before did I get the chance to delve deeper and to find likely causes for certain trends and observations. Learning how the GYGA protocols worked in practice and how many different techniques exist to estimate yield gaps for crops has astounded me. And the same thing happened when delving into the environmental impact of Dutch arable farming. Never before did I realize how many rules and regulations farmers have to deal with and what progress they've already made. The best example is probably the electric self-sufficiency of Dutch arable farmers since 2007, which is a good step forwards, but is largely ignored by the masses.

Overall, the internship has been a success. New contacts, new knowledge and new insights. Likely the greatest insight of the internship for me was: "You can never understand everything, and realizing that is the first step on a road of failures and misunderstandings to success, wisdom and truth."

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Appendix

The full reports for each of the assignments are included in the .zip file.

Python scripts

In order to determine the crops involved in intercropping from the N2Africa baseline data, a Python script had to be written. This script consists of two parts: (1) Collecting a list of all crops in the file and printing them on the screen, allowing for screening of duplicate entries which have emerged as a result of added spaces or typos and (2) Trying out every potential combination of two crops from the list and listing the combination and frequency in a new .csv file.

Script (1): Listing crop names

```
def CSVFileReader(FileName, CropList):
    import csv
    with open(FileName, 'rb') as csvfile:
            spamreader = csv.reader(csvfile, delimiter=';', quotechar='|')
            for row in spamreader:
                for i in row:
                    Step=0
                    while Step<len(row):
                        Crop=row[Step]
                        if Crop in CropList or Crop == "":
                            CropList=CropList
                        else:
                            CropList=CropList+[Crop]
                        Step=Step+1
    CropList.sort(key=lambda s: s.lower())
    print CropList

def ScriptRun():
    CropList=list()
    FileName=raw_input('What is the name of the file you would like to analyze?')+'.csv'
    CSVFileReader(FileName, CropList)
    ___dummy___=raw_input('Press Enter to terminate.')

ScriptRun()
```

Script (2): Trying crop combinations and listing them with frequency

```
def CSVFileReader(FileName, FileName2, CropList):
    import csv
    with open(FileName, 'rb') as csvfile:
            spamreader = csv.reader(csvfile, delimiter=';', quotechar='|')
            for row in spamreader:
                for i in row:
                    Step=0
                    while Step<len(row):
                        Crop=row[Step]
                        if Crop in CropList or Crop == "":
                            CropList=CropList
                        else:
                            CropList=CropList+[Crop]
                        Step=Step+1
    CropList.sort()
    Intercropping(FileName, FileName2, CropList)

def Intercropping(FileName, FileName2, CropList):
    from operator import itemgetter
    InterCropList=list()
    CropStep=0
    Crop1=list()
    Crop2=list()
    while CropStep < (len(CropList)-1):
        Crop1=Crop1+[CropList[CropStep]]
        Crop2=Crop2+[CropList[(CropStep+1)]]
        CropStep=CropStep+1
    InterCountOne=0
    while InterCountOne < len(Crop1):
```

```
    InterCountTwo=0
    for step in range((InterCountOne+InterCountTwo),len(Crop1)):
      CropCount=0
      import csv
      with open(FileName, 'rb') as csvfile:
            spamreader = csv.reader(csvfile, delimiter=';', quotechar='|')
            for row in spamreader:
              if Crop1[InterCountOne] in row and Crop2[(InterCountOne+InterCountTwo)] in row:
                CropCount=CropCount+1
            if CropCount>0:
              IntercropList=IntercropList+[[Crop1[InterCountOne],Crop2[(InterCountOne+InterCountTwo)],CropCount]]
      InterCountTwo=InterCountTwo+1
    InterCountOne=InterCountOne+1
  IntercropList.sort(key=lambda x: x[2], reverse=True)
  import csv
  with open(FileName2, 'wb') as csvfile:
      for k in range(0,len(IntercropList)):
        spamwriter2 = csv.writer(csvfile, delimiter=';', quotechar='|', quoting=csv.QUOTE_MINIMAL)
        spamwriter2.writerow([IntercropList[k][0],IntercropList[k][1],IntercropList[k][2]])

def ScriptRun():
  CropList=list()
  FileName=raw_input('What is the name of the file you would like to analyze?')+'.csv'
  FileName2=raw_input('What would you like to call the output file?')+'.csv'
  CSVFileReader(FileName, FileName2, CropList)
  ___dummy___=raw_input('Press Enter to terminate.')

ScriptRun()
```