



**INTERCROP
VALUES**



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D4.4 Validation of STICS & multi-site assessment of intercrop yield and ecosystem services/disservices



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Abstract

This deliverable presents the validation of the STICS intercrop model and its application to the multi-site assessment of cereal-legume intercropping systems in Europe and Sub-Saharan Africa. The objective was to evaluate the ability of the model to reproduce intercrop performance and to quantify the agronomic and environmental impacts of intercropping across contrasting pedoclimatic conditions.

The STICS model was calibrated and validated using experimental datasets from West Africa (sorghum-cowpea systems) and Europe (wheat-faba bean, maize-soybean, and durum wheat-pea systems). In West Africa, the model successfully reproduced cereal productivity in intercrops and captured key indicators of intercrop functioning, including partial Land Equivalent Ratios (pLER) and overall land-use efficiency. While the simulation of legume productivity remained more challenging, the model reproduced the main competition and complementarity processes governing intercrop performance. In Europe, calibration results showed satisfactory predictive performance for cereals, although the simulation of legumes was affected by strong interannual variability and limited calibration datasets at some sites.

The validated model was subsequently used to conduct long-term simulation experiments. In Sub-Saharan Africa, simulations over 30 historical years demonstrated that sorghum-cowpea intercropping can substantially reduce mineral nitrogen fertilizer requirements while maintaining productivity. Intercropping reduced nitrogen requirements by an average of 21 kg N ha⁻¹ for energy production and 73 kg N ha⁻¹ for protein production. The system also improved nitrogen-use efficiency and water-use efficiency through biological nitrogen fixation and enhanced resource complementarity. Environmental assessments indicated limited increases in nitrate leaching under equivalent fertilization rates, while lower fertilizer requirements are expected to reduce overall nitrogen losses per unit of production.

In Europe, multi-site simulations across Germany, Austria, and France were used to assess ecosystem services and disservices associated with intercropping. Results suggested a tendency towards lower N₂O emissions in intercrops compared with sole crops, although further validation with field measurements is required. Simulations also indicated that intercropping generally maintained similar soil water contents to sole crops, with a tendency towards slightly lower water content in deeper soil layers.

Overall, the results demonstrate that STICS provides a robust framework for analysing intercrop performance and ecosystem services across diverse environments. The simulations highlight the potential of cereal-legume intercropping to improve resource-use efficiency, reduce dependence on synthetic nitrogen fertilizers, and contribute to more sustainable and climate-resilient cropping systems.



1. Introduction

Cereal-legume intercropping offers considerable potential for the sustainable intensification of food production and is increasingly recognized as a promising strategy to enhance the resilience of cropping systems to climate variability and climate change. However, relatively few long-term field experiments have been conducted to evaluate its agronomic and environmental performance over extended periods. Soil-crop models provide a powerful tool to complement field experiments by assessing the long-term impacts of intercropping across a wide range of environmental conditions. To do so reliably, models must first be calibrated and validated for their ability to reproduce the complex interspecific interactions that occur during crop growth. This remains a major challenge, not only in European cropping systems but even more so in tropical environments, where intercropping models have been far less tested.

From an experimental perspective, it also remains unclear under which pedoclimatic and management conditions intercropping provides the greatest advantages over sole cropping. Addressing this question solely through field experimentation is difficult because of the large diversity of climates, soils, and management practices. Once adequately calibrated, soil-crop models enable the exploration of a broad range of scenarios, helping to identify the environmental conditions under which intercropping delivers the greatest productivity gains and resource-use efficiencies.

Beyond providing average productivity, models can serve to quantify environmental outcomes that are difficult to measure experimentally over long periods, such as nitrogen-use efficiency, nitrate leaching, nitrogen volatilization, greenhouse gas emissions, and changes in soil water dynamics.

In this deliverable, we first evaluate the ability of the STICS soil-crop model to reproduce the performance of cereal-legume intercrops using experimental datasets from Europe and West Africa (model validation). We then use the validated models to assess the agronomic and environmental performance of intercropping across multiple contrasting sites, climates, and management conditions, thereby providing insights into the potential of intercropping to sustainably intensify agricultural production while reducing environmental impacts.

The deliverable is based on published and in-preparation papers from the IntercropVALUES project (for Sub-Saharan Africa: de Freitas et al., 2026, de Freitas et al., submitted, de Freitas et al., in prep; for Europe: Winten et al., PhD thesis).



2. Validation of the STICS model

2.1 The STICS intercrop model

The STICS (Simulateur multiDisciplinaire pour les Cultures Standard) model is a generic, process-based crop model developed by INRAE and widely used to simulate crop growth and the interactions between crops, soil, and climate (Beaudoin et al., 2023). Operating on a daily time step, STICS simulates the major biophysical processes governing crop production, including crop phenological development, canopy growth, biomass accumulation, water and nitrogen uptake, soil water balance, soil nitrogen dynamics, and grain production.

The model has been extensively applied across a wide range of crops and environments and has been extended to represent annual intercropping systems (Brisson et al., 2004; Vezy et al., 2023). In intercropping configurations, STICS explicitly simulates the growth of two species sharing the same field, accounting for competition and complementarity in the acquisition of light, water, and nitrogen. The model therefore provides a mechanistic representation of the ecological processes underlying intercrop performance, making it a valuable tool for evaluating management strategies, quantifying ecosystem services, and assessing the impacts of climate variability and climate change.

2.2 Validation of STICS in Sub-Saharan Africa

2.2.1 Selected sites and calibration methods

The STICS model was calibrated using data from four experimental sites representative of the major semi-arid cereal-growing regions of West Africa (Burkina Faso, Mali and two sites in Senegal, see Figure 1) (de Freitas et al., 2026). These sites encompass contrasting climatic conditions, soil characteristics, and management practices, providing a robust basis for parameterizing the model across a broad range of production environments.

Calibration relied exclusively on data collected from sole sorghum, millet, and cowpea crops. This approach ensured that crop-specific parameters were estimated independently of intercropping conditions, allowing the model's ability to predict intercrop performance to be evaluated without introducing intercrop-specific parameter adjustments. The calibration dataset included detailed measurements of

crop phenology, leaf area development, biomass accumulation, grain yield, and soil water dynamics.

Species-specific parameters controlling crop development, growth, and resource acquisition were adjusted within biologically realistic ranges to improve agreement between simulated and observed values, while soil hydraulic properties were parameterized using site-specific soil information. By calibrating the model only on sole crop experiments, the study provided a rigorous test of whether the process-based representation of crop interactions implemented in STICS was sufficient to reproduce the dynamics of cereal-legume intercropping systems.

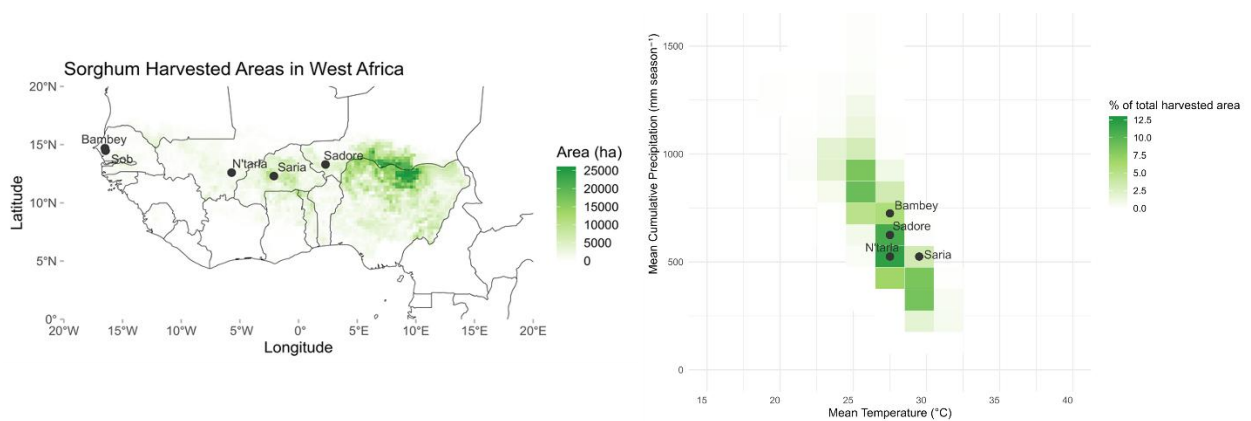


Figure 1. Contrasting validation sites in Sub-Saharan Africa.

2.2.2 Validation results

The evaluation of STICS on independent intercropping datasets demonstrated its ability to reproduce the performance of cereal-cowpea intercrops across a wide range of environmental and management conditions in West Africa (de Freitas et al., 2026). Importantly, these results were obtained without any recalibration of crop parameters for intercropping, providing a stringent test of the model's capacity to represent interspecific interactions through its underlying process-based mechanisms.

For cereals grown in intercropping, the model showed satisfactory predictive performance (Figure 2). Aboveground biomass was simulated with an rRMSE of 30% and a model efficiency (Ef) of 0.48, while grain yield was simulated with an rRMSE of 37% and an Ef of 0.49. Simulations exhibited very low bias, indicating that the model did not systematically overestimate or underestimate cereal productivity. Most discrepancies were associated with the underestimation of the highest observed biomass and grain yield values.

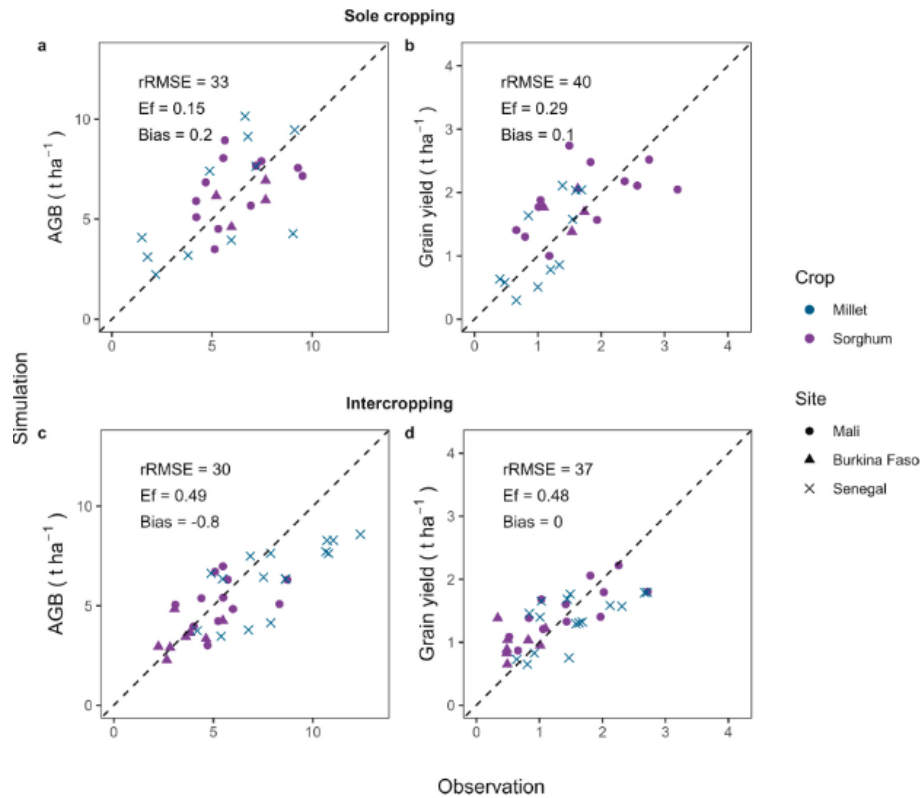


Figure 2. Validation of STICS sole crops and intercropping simulations for cereals.

The simulation of cowpea performance in intercrops was more challenging, reflecting the high variability and generally low productivity of cowpea under competitive intercropping conditions (Figure 3). Cowpea aboveground biomass was simulated with an rRMSE of 76% and an Ef of 0.31, while grain yield showed an Ef below zero, indicating that the model struggled to reproduce the observed variability in the lowest-yielding situations. Nevertheless, bias remained low, suggesting that errors were primarily related to variability rather than systematic inaccuracies.

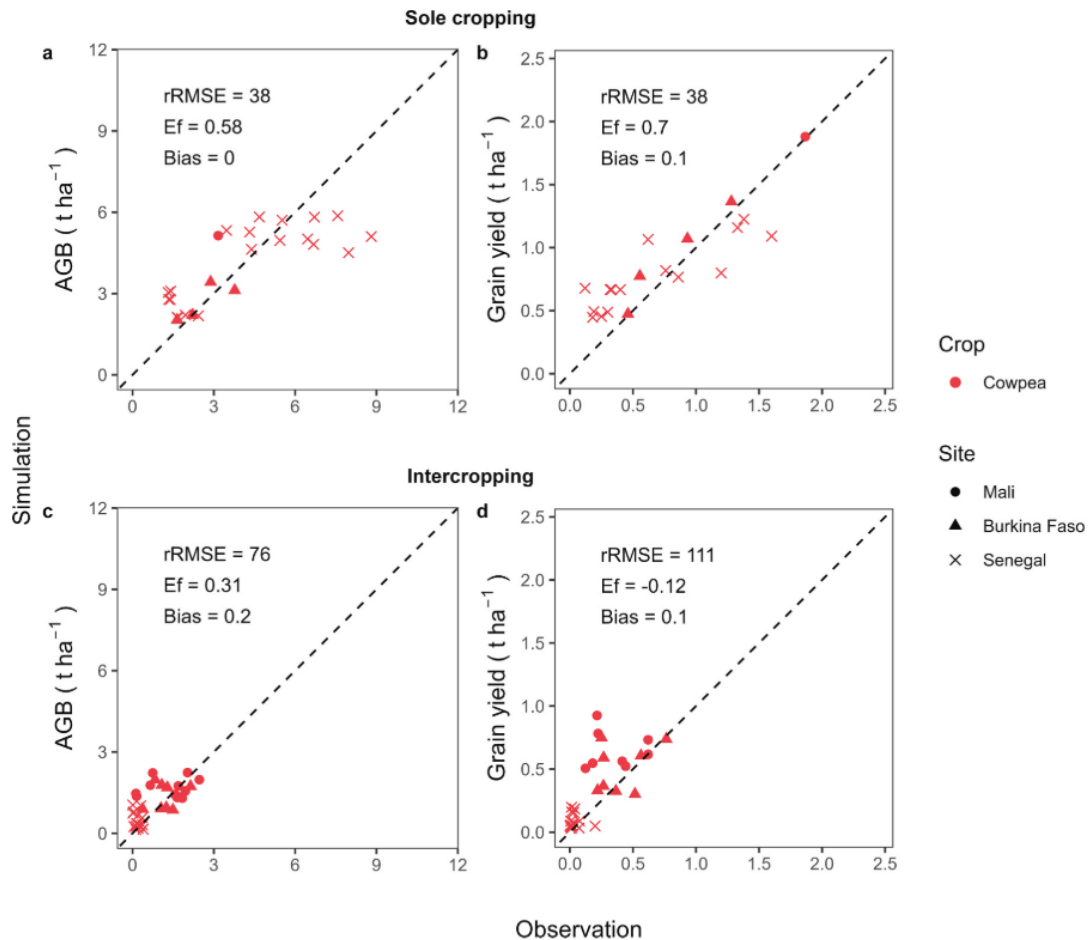


Figure 3. Validation of STICS sole crops and intercropping simulations for cowpea.

Beyond yield prediction, a key objective was to assess whether STICS could reproduce the interactions between intercrop components. The model successfully simulated land use efficiency, also called Land Equivalent Ratio (LER). partial LER (pLER) of both cereal and cowpea components were simulated with acceptable efficiencies exceeding 0.6 and negligible bias. Simulated pLER values accurately captured differences among sites, management practices, and intercrop configurations, demonstrating the model's ability to represent the balance between competition and complementarity within intercrops. Although the relative prediction errors remained relatively high (rRMSE of approximately 42% for biomass-based pLER and 49% for yield-based pLER), the model reproduced the overall productivity advantage of intercropping and the relative contribution of each species.

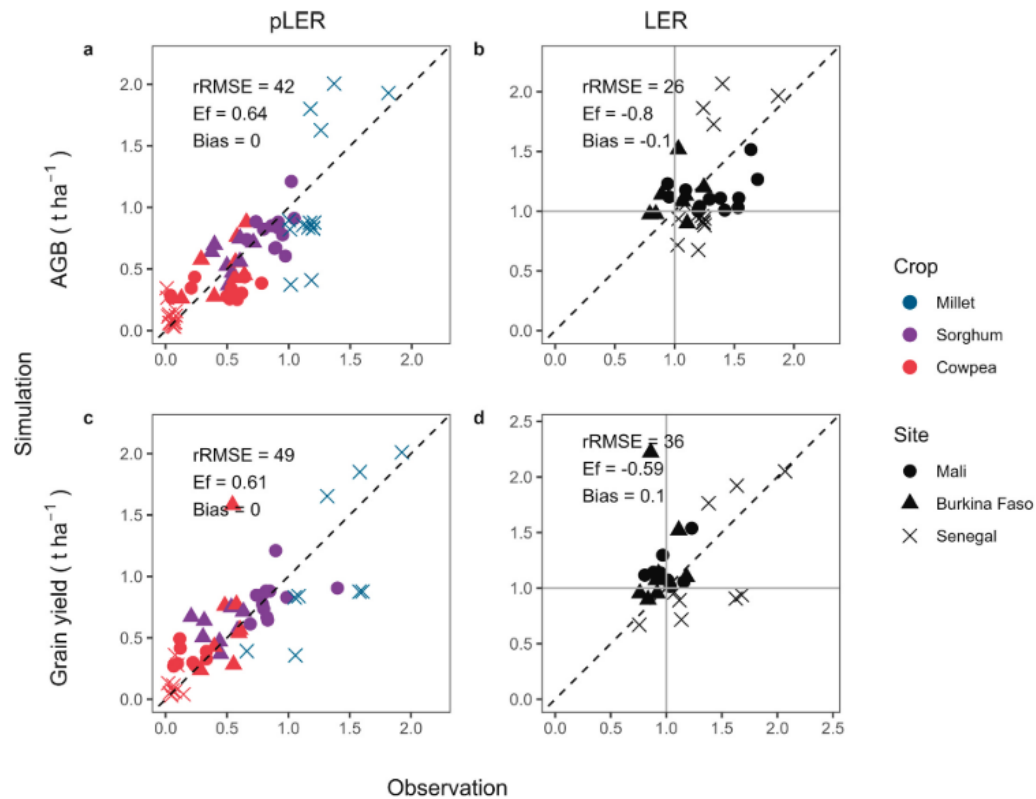


Figure 4. Comparison of observed and simulated partial Land Equivalent Ratio (pLER: a, c) and LER (b, d) for aboveground biomass at maturity (a, b) and grain yield (c, d).

The model also proved capable of reproducing the qualitative outcomes of interspecific interactions. Depending on site, fertilization, and water management conditions, STICS correctly identified whether competition or complementarity dominated in the intercrop system. Across all observations, the model reproduced the observed interaction category in approximately 53–56% of cases, while this success rate increased to more than 70% when results were aggregated by site and management treatment. These results indicate that STICS can reliably capture the main drivers of intercrop performance, particularly competition for light and the effects of water and nitrogen limitations.

Figure 5.

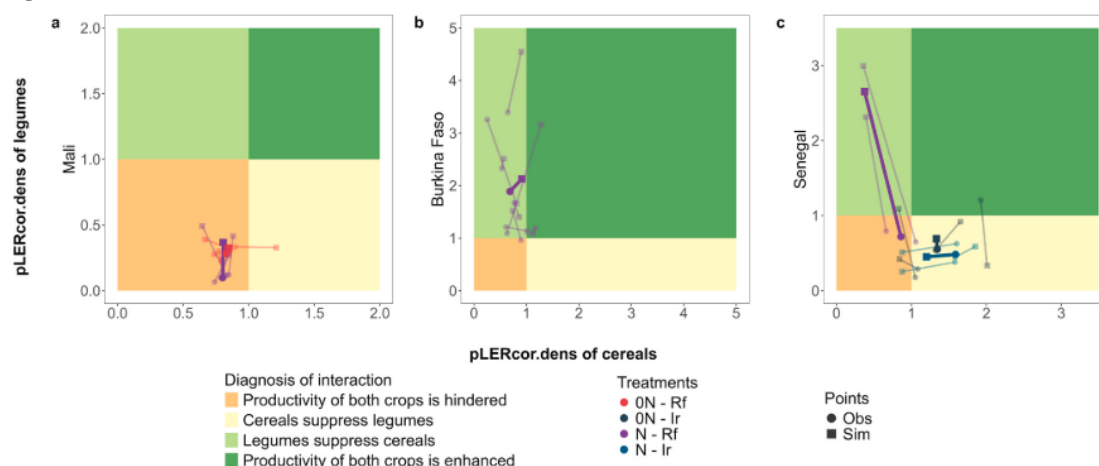


Figure 5. Observed (round point) and simulated (square point) outcome (linked by a line for same situation) in terms of final interactions calculated on grain yield when intercropping a cereal and a legume

Finally, robustness analyses showed that the model maintained consistent performance across contrasting agro-pedoclimatic conditions. Simulated responses to variations in soil properties, water availability, climate, and nitrogen supply closely matched observed trends, with near-zero bias and rRMSE values generally below 11% for major agronomic variables such as crop duration, biomass production, and grain yield. This robustness demonstrates the suitability of STICS for exploring management options and climate adaptation strategies across the diverse environments of West African dryland farming systems.

2.3 Validation of STICS in Europe

2.3.1 Selected sites and calibration methods

Three sites/datasets have been chosen for the STICS simulations. The University of Bonn (Germany) and BOKU University (Austria) datasets from WP2 of IntercropValuES. As well as the Auzeville dataset from the Remix project in southern France. Each site had a specific set of crops and cultivars. The German site featured spring wheat and faba beans, the Austrian site featured maize and soybeans, and the French site featured durum wheat and peas. Each site featured two years of experimental data for Germany and Austria and four years for France. Calibration was performed using STICS version V.10-beta, in accordance with the AgMIP calibration protocol (Wallach et al., 2025), after the appropriate default parameters for each crop were established. According to the calibration protocol, groups of parameters are selected for each field observation. Each group, i.e. each observation, was then calibrated separately and successively using the CROPTIMIZR package. The order of these groups is vital for this step of the calibration process, as it must align with the model structure. For example, the leaf area index (LAI) must be calibrated before the aboveground biomass because the biomass depends on the LAI. In general, there are

two classes of parameters: major parameters, which are calibrated regardless, and candidate parameters, which are only calibrated if they contribute to the AIC simulated result. Finally, the parameters are calibrated together, weighted by the performance of the previous step. If multiple cultivars of the same species are calibrated, this procedure may need to be modified to account for the parameter structure of STICS. A comparison of the calibration protocol and the calibration procedure by Vezy et al. (2023) shows that when set as a candidate, stress parameters are often rejected by the AIC due to the increased number of parameters. This may lead to a reduced response to different soil moisture and nitrogen fertilisation. However, the calibration protocol greatly reduces the bias of the simulations.

Calibration data sets posed challenges to the calibration procedure. The data set from Germany showed a significant difference in weather conditions between 2023 (dry) and 2024 (wet). In 2023, there was insufficient rainfall, meaning the fertiliser remained in the field for a long time. The faba beans were also affected by these dry conditions, as well as by virus diseases and aphids. The yield of faba beans in intercropping was especially low. In contrast, 2024 saw a lot of rain during the early development stage of the canopies. The faba beans exhibited unusually strong growth in above-ground biomass and height (up to 1.8 m). The Austrian dataset shows a similar weather pattern, but less extreme. However, in 2023, the crops were sown late, and there was a two-week gap between harvesting the soy and the maize. As there was only one soybean treatment, there are only two data points available for calibrating the grain yield. This limited the yield calibration to just one parameter to avoid overfitting.

Table 1 shows the calibrated yield performance metrics for all sites and crops. The bias is generally low for all of them, particularly for the German and Austrian cereals. The legumes show a higher bias. This is due to the small sample size ($n = 2$) for soybeans in Austria and the contrasting growing patterns in 2023 and 2024 for faba beans in Germany. Positive EF values indicate that the yield simulations for spring wheat, faba beans and maize are highly predictive and can explain most of the observed variation. However, the EF for soybeans is mathematically unstable. Figure 6 provides a more detailed overview of the calibration results. The model with an EF of 0.63 demonstrates solid overall performance, reliably capturing the yield trend across various treatments. The low overall bias indicates that systematic overestimates and underestimates cancel each other out. However, visual analysis of the scatter plot reveals that the regression line's slope is too flat, leading to underestimation of maximum yields in 2024 and overestimation under stress in 2023. This is reflected in the moderate relative RMSE of 27%. Nevertheless, the scatter plot of the aboveground biomass shows that the growth dynamics of the spring wheat are reasonably represented across the seasons. A similar picture can be seen for the faba bean at the same site. The extremes of the aboveground biomass are underestimated, while the lower extremes are overestimated. Due to the low sample size of $n = 4$ for the faba bean grain yield, the EF = 0.7 gives the false impression that the fit is good. Nevertheless, the RMSE and bias indicate that the model has limited capacity to represent the contrasting crop growth in 2023 and 2024. The observation for 2023 and 2024 are both outliers, which severely limits the calibration procedure. 2023 showed faba beans that were struggling with water stress and virus diseases and in 2024 the growth was abnormally high. So, the calibration effectively aimed for the average between the two years. But, the final result is still biased towards higher yields.

Table 1. Calibration results for the final grain yield for all sites and crops

Site	Crop	rRMSE	Bias	EF
CKA Germany	Spring wheat	0.27	0.0244	0.63
CKA Germany	Faba bean	0.24	0.2672	0.7
BOKU Austria	Maize	0.07	0.0313	0.62
BOKU Austria	Soy bean	0.17	-0.25	NA (n=2)

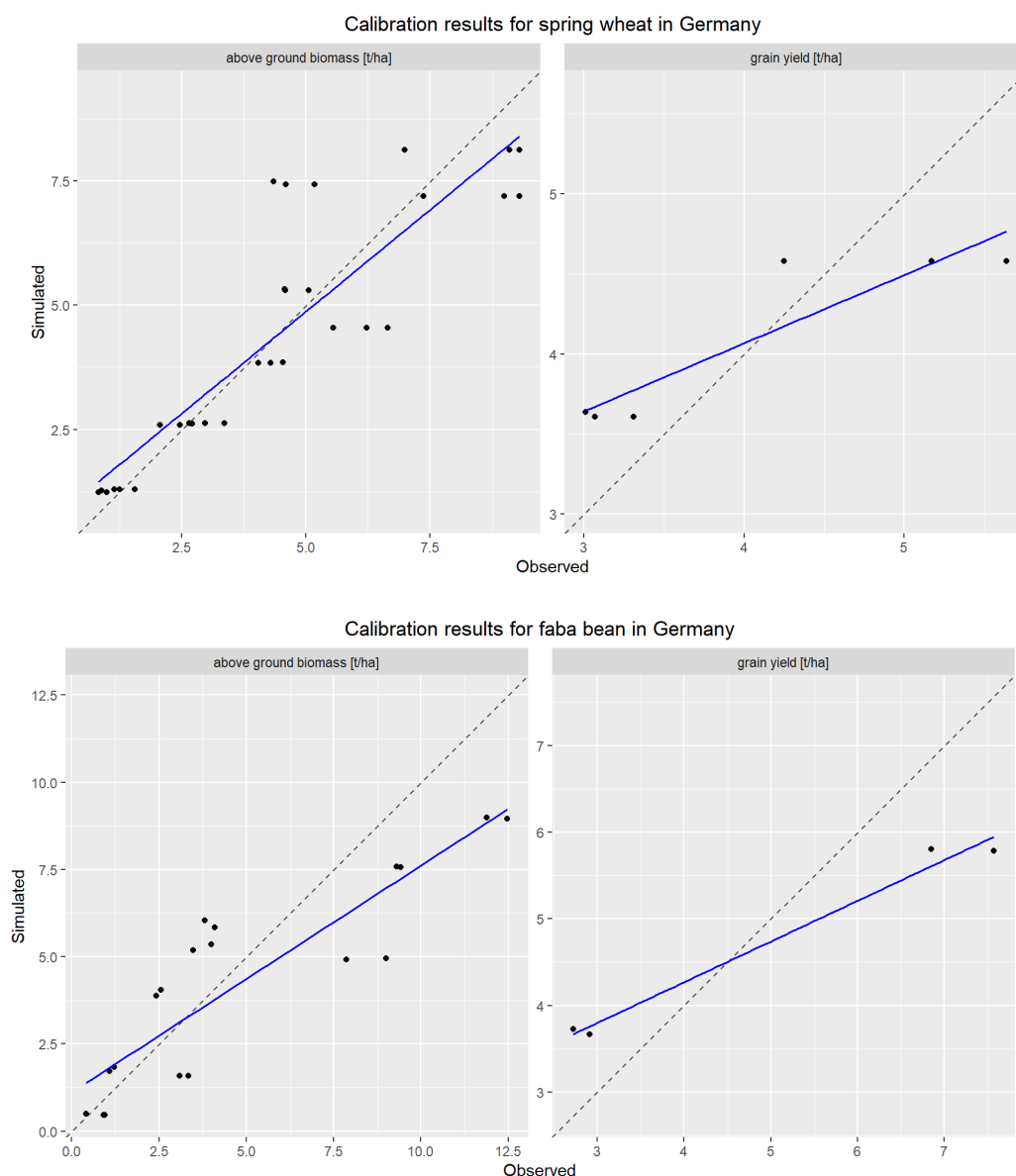
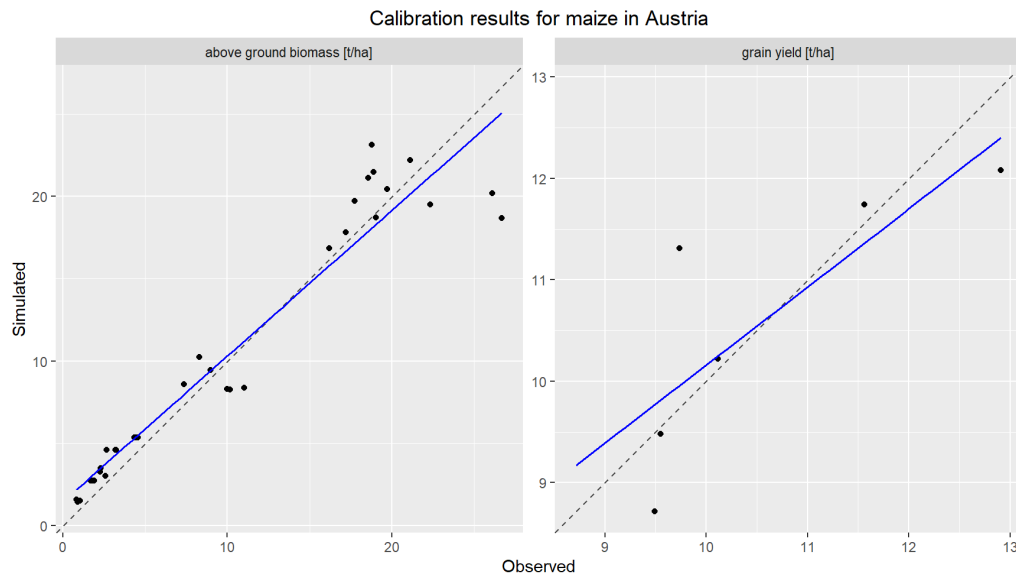


Figure 6. Calibration results of the above ground biomass and grain yield for spring wheat (top) and faba bean (bottom) from University of Bonn, Germany.

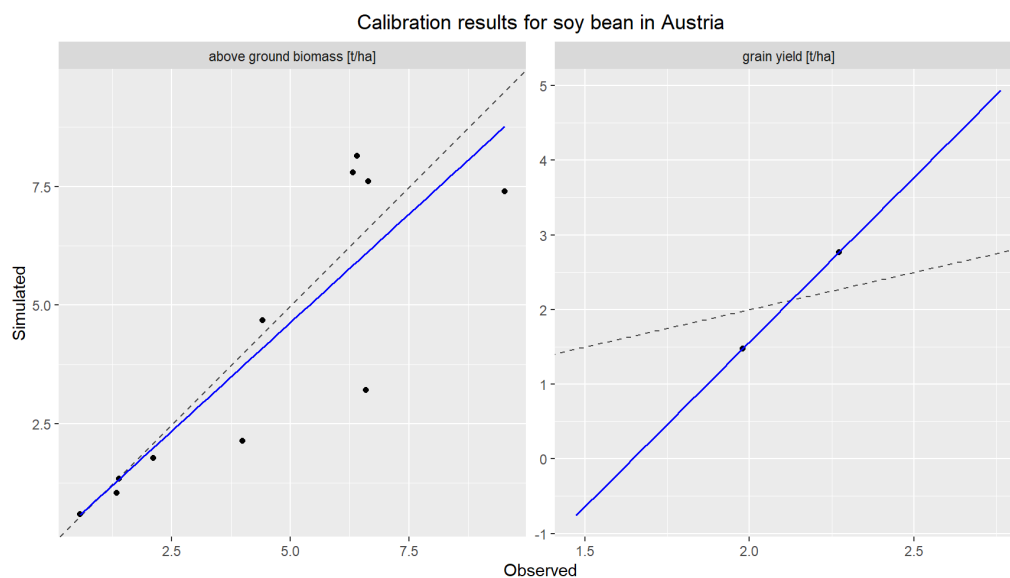
The maize calibration in Austria shows very good results, with an EF of 0.62 and low bias and RMSE values. The 1:1 plots for above-ground biomass and final grain yield show good alignment between the simulation results and observations. The

simulated above-ground biomass of soybeans shows a slight underestimation trend towards the higher end. The grain yield calibration was affected by the limited number of available observations. Consequently, the AIC only permits the calibration of one parameter. This also means that the values of the rRMSE and bias are not very reliable. The EF becomes completely unstable in this case and is therefore omitted



from Table 1.

Figure 7. Calibration results of the above ground biomass and grain yield for maize (top) and soy bean (bottom) in Austria



2.3.2 Validation results (Europe)

Validation of crops at the three sites will be based on yields, particularly the pLERs of intercropping simulations. Figure 8 shows the box plots of the simulated LERs and pLERs of the observed and simulated grain yield dry matter. Subfigure A of Figure 8 shows the plots for the German site CKA. The pLER of the spring wheat shows good agreement between the observed and measured values. However, the pLER of the faba bean is severely overestimated by the simulation. This is due to its extreme growth in 2024. The calibration showed a positive bias towards sole crop yield, and this trend continues in intercropping. The median simulated pLER clearly exceeds 0.5, while the median observed pLER is slightly below 0.5. The calibration under the abnormally high growth in 2024 may have pushed the parameters into physiologically challenging ranges, resulting in overly strong performance in the intercropping simulation. The relationship between the pLERS of faba bean and spring wheat shows that the simulated faba bean is too dominant in intercropping. In reality, this only occurred under ideal conditions in 2024. However, in 2023, the faba beans in intercropping were affected by virus diseases to a greater extent than their sole crop counterparts, as can be seen at the lower end of the observed pLER boxplot. Thus, the high pLER of the legume causes the LER to exceed the observed range, resulting in a significant overestimation of the mixture's area efficiency.

Figure 8b shows the dynamics in Austria. The intercropping simulations for maize and, in particular, soybeans show an overestimation of both pLERS. For maize, the simulated pLER is closer to the observed value. However, the interquartile distances of both intersect. As with the faba bean in Germany, the soy pLER is too strong in the mixture. This may be because the yield was only calibrated at two points. Thus, the simulated LER is overestimated again, mostly due to the legume. Figure 8C shows the pLER and LER dynamics for France. Validation of the simulated pea in southern France shows the same pattern of estimation of legume pLER performance in intercropping. However, the wheat shows an underestimation of the simulated pLER.

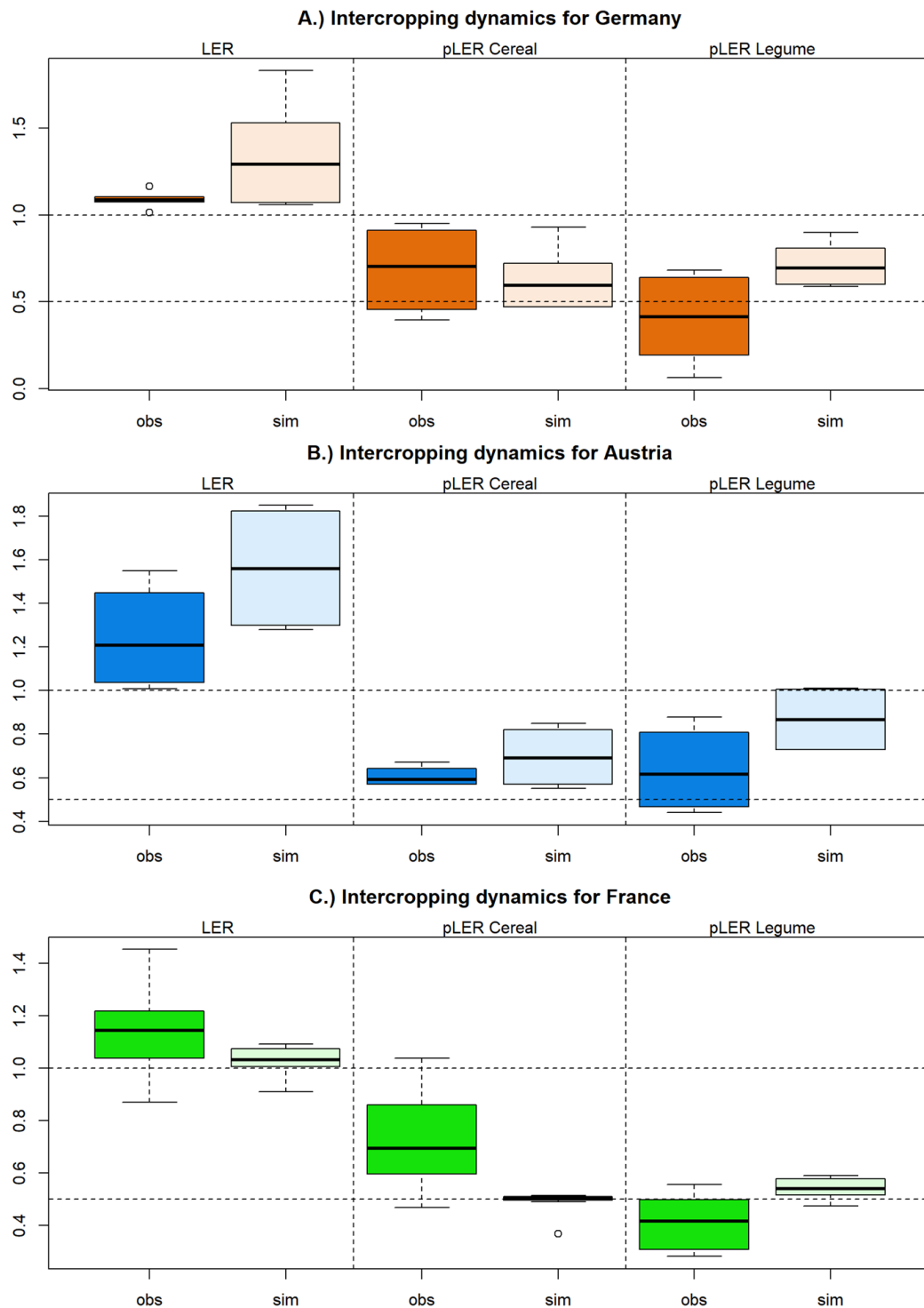


Figure 8. Boxplots of simulated and overserved LER and pLER values for the spring wheat an faba bean in Germany, for maize and soy in Austria and for durum wheat and pea in France



3. Multisite assessment of intercropping performance

As promised in the proposal, the calibrated model was used to quantify performances of intercrops in terms of grain production (yield, yield stability), ecosystem services (nutrient budgets, water fluxes and GHG emissions) under well-chosen soil-climate combinations representative of 3 EU (+1 African) crop production areas (D4.4 and D4.5). The results are based on submitted or under-preparation papers from the project (de Freitas et al., submitted; de Freitas et al., in prep; Winten et al., in prep)

3.1 Intercropping to save nitrogen and its impact on N balance in Sub-Saharan Africa

A multi-site simulation experiment was conducted using the STICS intercrop model to evaluate the agronomic and environmental performance of sorghum–cowpea intercropping across four representative sites of the Sudanian–Sahelian zone of West Africa over a 30-year historical climate period (Figure 1) (de Freitas et al., submitted) . Simulations covered a wide range of nitrogen fertilization levels (0–200 kg N ha⁻¹) under both sole sorghum and intercropping systems. For each site and year, the amount of mineral nitrogen required to achieve a productivity target corresponding to 80% of the water-limited yield potential of sole sorghum was calculated (Figure 9). Productivity was assessed both in terms of energy (kcal) and protein production, allowing the quantification of the nitrogen savings associated with intercropping while accounting for interannual climatic variability.

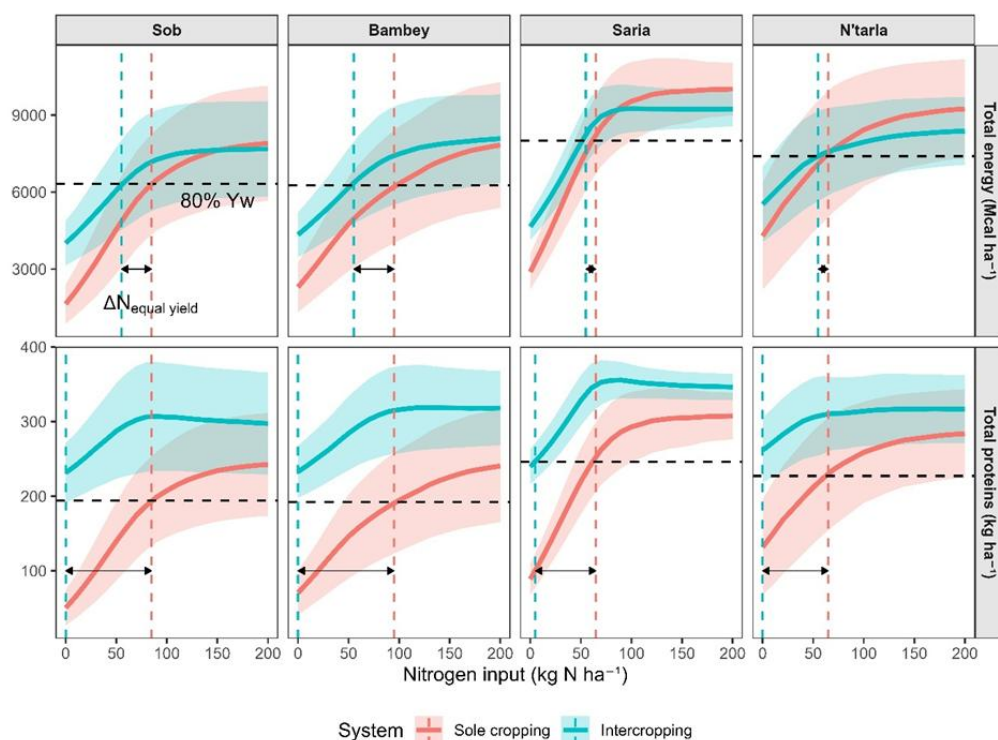


Figure 9. Average nitrogen input required to reach energy and protein productivity target corresponding to 80% of sole sorghum water-limited productivity (YW, black dashed line). Simulations were performed on four West African sites over 30 historical years.

The simulations demonstrated a substantial potential of sorghum–cowpea intercropping to reduce mineral nitrogen requirements while maintaining high productivity (Figure 10). Across the four sites, intercropping reduced fertilizer requirements by an average of 21 kg N ha⁻¹ when the productivity target was expressed in terms of energy, and by 73 kg N ha⁻¹ when expressed in terms of protein. Nitrogen savings varied considerably among sites, ranging from 3 to 43 kg N ha⁻¹ for energy production and 53 to 98 kg N ha⁻¹ for protein production, reflecting differences in climatic and soil conditions. The probability of achieving positive nitrogen savings was also high, particularly for protein production, where intercropping reduced nitrogen requirements in more than 98% of simulated years across all sites. These results confirm that cereal–legume intercropping can substantially decrease dependence on synthetic nitrogen fertilizer while maintaining agricultural productivity under a wide range of environmental conditions.

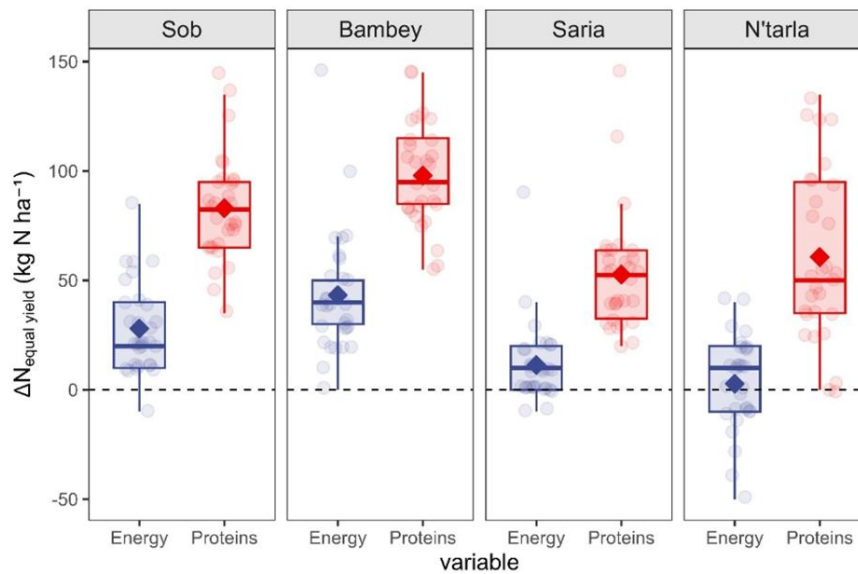


Figure 10. N fertilisation saved in intercropping compared to sole cropping when targeting the same 80% of energy and protein potential production.

Beyond fertilizer savings, the simulations provided insights into the nitrogen and water cycles that underpin the performance and environmental sustainability of intercropping systems (Figure 11). Intercropping consistently improved nitrogen use efficiency (NUE) by producing more energy and protein per unit of nitrogen applied, with energy-based NUE increasing by 6–35% depending on the site. This improvement was primarily driven by biological nitrogen fixation by cowpea, which contributed 51–69 kg N ha⁻¹ through atmospheric N₂ fixation and increased total crop nitrogen uptake by approximately 65% compared with sole sorghum. At the same time, intercropping enhanced water use efficiency (WUE), particularly under low to moderate nitrogen inputs, through greater canopy transpiration and reduced non-productive soil evaporation, thereby converting a larger proportion of rainfall into crop production.

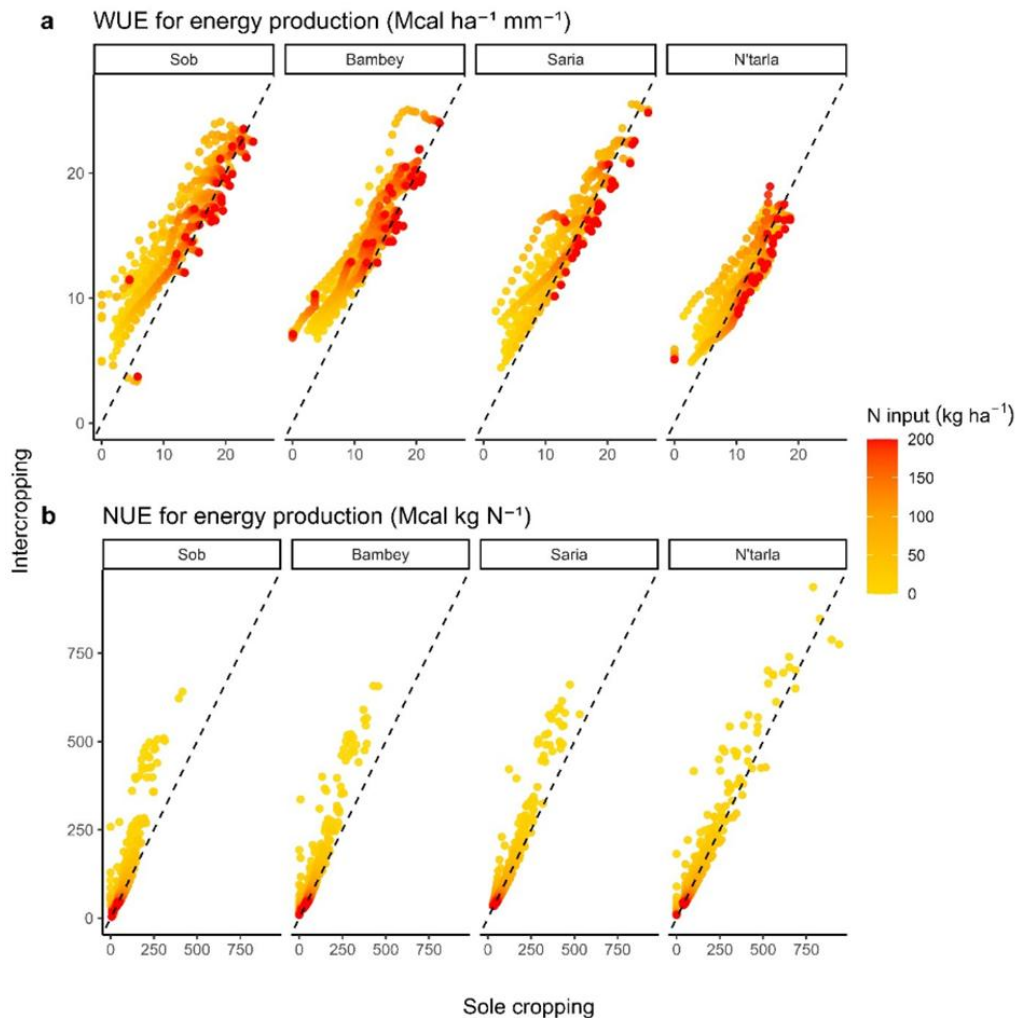


Figure 11. Water use efficiency and nutrient use efficiency of intercropping versus sole cropping across 30 years and a range of fertilisation rates.

The simulations also enabled the assessment of potential environmental impacts associated with nitrogen cycling (Figure 12) (de Freitas et al., in prep). While intercropping slightly increased simulated nitrate leaching under equivalent fertilizer application rates due to higher soil water drainage, these increases remained relatively small ($+0.7$ to $+4.9 \text{ kg N ha}^{-1}$ depending on the site). Importantly, because intercropping achieved comparable production with substantially lower fertilizer inputs, the overall nitrogen losses per unit of production are expected to decrease compared with sole cropping. The modelling framework therefore provides a comprehensive assessment of both agronomic performance and environmental indicators, demonstrating that sorghum-cowpea intercropping can simultaneously improve resource-use efficiency, reduce fertilizer dependency, and contribute to more sustainable nitrogen management in West African cropping systems.

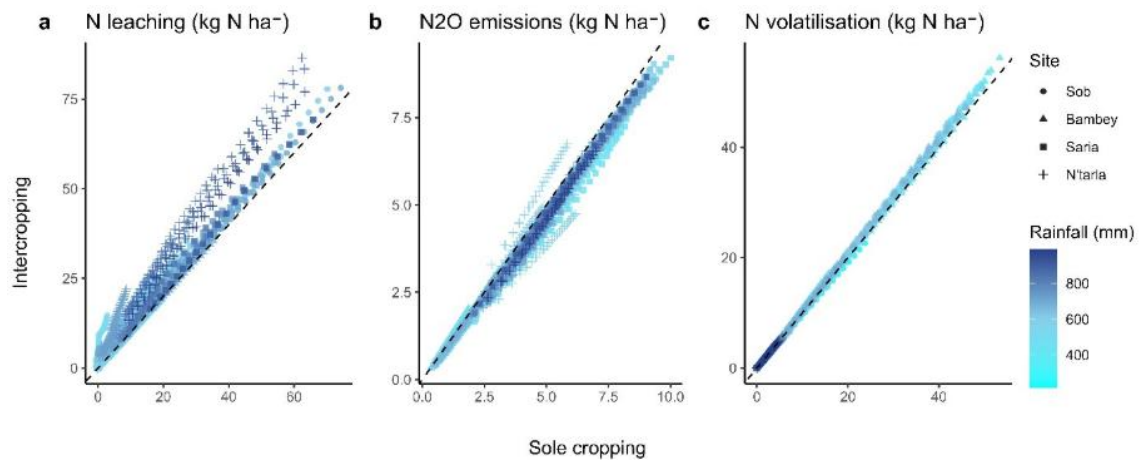


Figure 12. Comparison of a) N leaching) N2O emissions and c) N volatilisation between sole sorghum and sorghum-cowpea intercropping across sites

3.2 Intercropping in Europe (multi-site assessment)

Three regions have been selected for the multi-site assessment of climate variability from 1990 to 2020: North Rhine-Westphalia in Germany; eastern Austria; and Haute-Garonne in France. These three regions align with the locations of the calibrated sites. The weather data was extracted from ERA5 (ECMWF Reanalysis Version 5) , and the soil data was extracted from the SoilGrids dataset by ISRIC (International Soil Reference and Information Centre). ERA5 is a single-level dataset developed by the Copernicus Climate Change Service (Hersbach et al., 2018). Both data sets have a resolution of 3 km and were only considered when the grid cell contained at least 10% agricultural area. Figure 13 shows the grid points for the German and Austrian regions. The simulations contain various management scenarios showing the date of sowing (early or late), the date of fertilisation (early or late) and the dosage of fertiliser (0%, 50% or 100%). The simulation results are shown in deliverable D4.5 but we who below some services and disservices results from the 3 calibration sites (Figure 14).

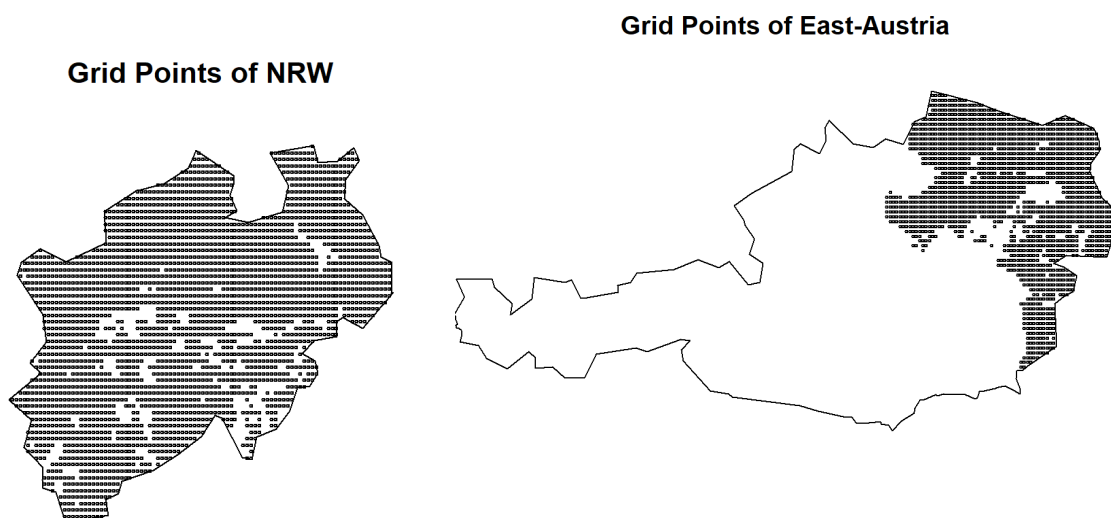


Figure 13. Grid points for the multi-site simulations in North Rhine Westphalia (Germany) and the eastern region of Austria.

Figure 14 shows the simulated cumulative nitrous oxide (N₂O) emissions from sole and intercropping systems, plotted against each other. The cereals from the three sites exhibit a more linear trend than the legumes, which are much more dispersed. The figure also shows that the Austrian site has the highest emissions, while the French crops have the lowest. Generally, there is a tendency towards lower emissions in intercropping, although this is not very pronounced. Since there are actual N₂O emissions for the German site, these can be compared. Observations show that simulated N₂O emissions are often overestimated. It should be noted that the soil was not calibrated for these measurements. Additionally, measuring N₂O in the field is challenging and subject to high variability over time and across soil property variations on a small scale. As there are no N₂O measurements for the other two sites, the validity of these simulations remains unknown.

To further assess the ecosystem (dis-) services in intercropping a TOI-like (Transgressive Over-yielding Index) metric for soil water content (SWC) is shown in figure 14B for the German and Austrian site. The French simulations were excluded because they included irrigation as management. The goal with the SWC-TOI is to compare the intercropping treatments on their merits with sole crops, without interference of management. The SWC-TOI is defined as follows:

$$SWC_{TOI} = \frac{SWC_{intercropping}}{\max(SWC_{cereal}, SWC_{legume})}$$

A SWC-TOI > 1 would mean that the mixture has a higher SWC than both sole crops. Figure 14B shows the simulated SWC-TOI. For the German site it shows that the median SWC-TOI resides at 1 at the top and intermediate soil layer in 2023 and 2024. This means that there is no difference between the intercropping and the sole crops, according to the median. However, these medians are (almost) always the identical to the maximum value. Thus, there are a lot of points below 1, meaning that the intercropping had a lower SWC than the sole crops. For the deepest soil layer, the median is below 1, again indicating a lower SCW in the intercropping case. A similar trend can be seen for the Austrian SWC-TOI. The only difference is that it shows a few points above 1. This result from both sites shows a median SWC at 1 for the top and intermediate soil layer and below 1 for the deepest layer. Thus, this can be interpreted that intercropping has the same SWC like sole crops in most cases, but with a trend for lower SCWs in the intercropping. The SWC plays an ambivalent role as a ecosystem service. Since a high SWC is good for plant growth, it might also promotes N₂O emissions and N-leaching (if it is higher than the field capacity). So, the trend for lower SWC could mitigate these N-losses while causing a higher water stress in intercropping.

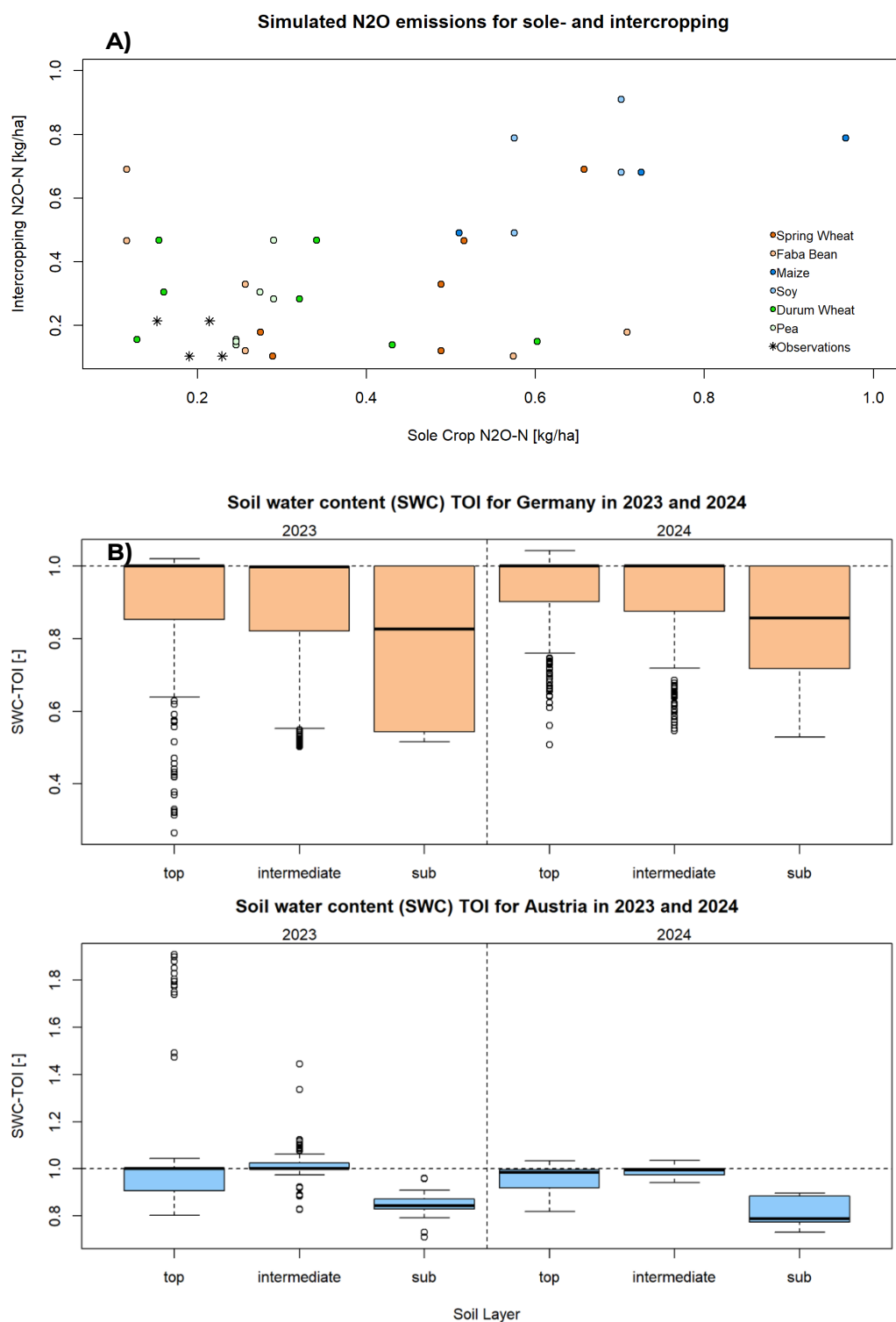


Figure 14. A) Simulated cumulative N₂O emissions in sole- and intercropping for the crops of the sites in Germany, Austria and France. The observed values from the German dataset are also marked with asterisk. B) simulated soil water content (SWC-) TOI for the simulated site in Germany and Austria

Conclusion

This deliverable demonstrates that the STICS intercrop model is capable of reproducing the main processes governing cereal-legume intercropping across contrasting environments in Europe and Sub-Saharan Africa. Despite remaining challenges in simulating legume performance under highly variable conditions, the model provides a robust framework for evaluating intercrop productivity, resource-use efficiency, and environmental impacts.

The multi-site simulations highlight the potential of intercropping to contribute to sustainable agricultural intensification. In West Africa, sorghum-cowpea intercropping substantially reduced mineral nitrogen fertilizer requirements while improving nitrogen- and water-use efficiencies. In Europe, the simulations suggest potential environmental benefits, including a tendency towards lower N₂O emissions under some conditions, while identifying trade-offs that require further validation through field measurements.

Overall, the validated STICS model provides a valuable decision-support tool for assessing intercropping systems across diverse agroecosystems and for exploring management strategies that enhance productivity, reduce dependence on synthetic nitrogen fertilizers, and improve the resilience and sustainability of agricultural production.

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INTERCROP VALUES



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