MODELING THE IMPACTS OF CONSERVATION AGRICULTURE ON HYDROLOGICAL PROCESSES AND CROP YIELD USING THE SWAT MODEL

A STUDY CASE IN THE HUPSEL CATCHMENT, EAST NETHERLANDS

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PREFACE

This thesis contains the findings of internal research undertaken at the University of Twente within the Civil Engineering and Management department with a specialization in Integrated Water Management. This research originates from the drought problem experienced by the farmer in the eastern part of the Netherlands with the help of Waterboard Rijn en Ijssel (WRIJ). Hopefully, the results of this study, with all its limitations and findings, could benefit many people. This thesis also marks the end and beginning phases of my life where I can proudly say that I have progressed this far with much new knowledge gained not only as a student and graduate but also as a human being and citizen of the world. Indeed, I would have never reached the point of finishing this thesis and master's without the help and support of others.

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SUMMARY

Drought is a severe issue that may have various adverse effects on agriculture. The types of droughts, such as hydrological and agricultural, are caused by a lack of precipitation. Additionally, as global warming levels rise, the frequency and severity of droughts will continue to rise on both a continental and worldwide scale. Poor rainwater partitioning contributes significantly to drought because it results in less productive rainfall (used by the plants) and less soil moisture, which could also lead to agricultural drought. An alternative agricultural practice might be utilized to deal with the droughts by improving rainwater partitioning. Alternative agricultural practices such as residue management (mulching), minimal soil disturbance (tillage), and crop rotation are all included in conservation agriculture (CA). In order to overcome inadequate rainfall partitioning, conservation agriculture focuses on minimizing runoff, soil evaporation and increasing soil water content or soil moisture. There is still minimal research on conservation agriculture as a potential drought solution, and there is even less research on how agricultural conservation methods affect crop productivity, hydrology, and the response to climate change. In order to address drought, the purpose of this thesis is to model the effects of conservation agriculture practices on hydrology and agricultural productivity of a rainfed agriculture area, which in this case is the Hupsel catchment located in the East of the Netherlands since this location experience droughts conditions in recent years.

To accomplish the study's goal, a baseline scenario is first created using a crop-water model that covers both crop growth and hydrological model. This study used the Soil and Water Assessment Tool (SWAT) model to simulate the baseline scenario using historical climate data to match the agricultural practices practised in the study area. It is crucial for the CA impact assessment because it allows comparisons between the baseline and the various CA practice scenarios. Additionally, the accuracy of the baseline scenario is evaluated by comparing the model's output with the readily accessible observed data related to hydrology and agricultural productivity. Next, the CA practices are modelled individually and combined to assess their impacts on hydrology (surface runoff, percolation, evapotranspiration, and soil moisture) and agricultural productivity (crop yield). These practices were compared to the baseline scenario under the same historical climate condition to see the effects further. Similarly, the last part of this study aims to model the CA practices under future climate change scenarios provided by The Royal Netherlands Meteorological Institute (KNMI'14), specifically for the Netherlands. Thus, the results of this step will be compared to the baseline scenario (under the historical climate condition) to see the response of CA practices toward the future climate change condition.

The result of the first step following conventional agriculture, the agriculture currently practised in the Hupsel watershed, was adequately modelled using the SWAT+ model. The model was calibrated and tested using daily observed streamflow, and then the model's performance was then assessed using a performance metric, Nash-Sutcliffe Efficiency (NSE). The model performed both quantitatively (NSE>0.65) and qualitatively performed well. In addition, the model predicted a yearly crop output comparable to the observed data from the Netherlands. Therefore, the model can be accurate enough to simulate agricultural yield and hydrology in the study area. Next, the results of the second step indicate that generally speaking, the CA practices have little influence on agricultural productivity (crop yield) and hydrological fluxes. The hydrological fluxes connected to the system's water loss (such as surface runoff, baseflow, and soil evaporation) are most significantly increased by crop rotation practices, whereas mulching has the reverse effect. On the other hand, it was found that the no-tillage method only affected surface runoff while barely showing any change for the other hydrological fluxes. Furthermore, mulching is observed to have the highest reduction in hydrological drought severity, while crop rotation and combination of CA practices scenarios favour lowering the agricultural drought severity. As for the last part, it was found that future climate conditions increased all hydrological fluxes in general, except for a slight decrease in soil water relative to the baseline scenario under the historical climatic condition. The practice of mulching significantly affects plant transpiration, having the most significant effect compared to the other scenarios under the future climate condition

represented by the WL scenario (warm and low influence of air circulation). It also exhibits the most significant decrease in soil evaporation but little change in percolation or surface runoff. Contrarily, the practice of crop rotation has a different effect on evapotranspiration than the practice of mulching while simultaneously having the most significant rise in surface runoff and percolation compared to the other activities. Regarding crop yield, mulching and a combination of CA practices scenarios increased corn yield under future climate conditions. In contrast, the other practices have almost no effects. On the other hand, CA practices have no effect on the amount of grass yield under the conditions of future climate change, whether they are used individually or together as one scenario. Similarly, mulching was still observed to have the most positive effect on reducing the hydrological drought severity. At the same time, crop rotation and a combination of CA practice scenarios provide less agricultural drought severity.

There are several limitations to the study. For instance, the unavailable parameters within the SWAT+ toolbox, values of the variables (such as Manning value) and databases (e.g., plants, soil, tillage) are less accurate in representing the actual condition in the Netherlands, and no specific mulching operation. The methodology and results of this study can be used as a reference for further study but still needs improvements to get proper output. The recommendations to improve this study vary, such as choosing the Green & Ampt method to get an accurate output of infiltration that is essential for modelling the CA practices, using licensed software to help the calibration and sensitivity analysis, and exploring other cropping systems along with other possible best management practice such as strip cropping and contouring.

1. INTRODUCTION

1.1 BACKGROUND

Drought is a concerning problem that can affect agriculture in several ways and have different impacts. Various types of droughts that can affect the agricultural sector have been identified: meteorological drought, agricultural drought, hydrological drought, and the subsequent effect of socio-economic drought (Liu et al., 2016). A study by Wilhite & Glantz (1985) stated several characteristics and differences between each type of drought. For instance, agricultural drought happens when the soil moisture content is insufficient for the plants during the growing phase. In contrast, hydrological drought is when the river flow is lower than the standard value or decreases the aquifer level. The study by Cornelis et al. (2019) stated that agricultural and hydrological drought is the most common type of droughts occurred due to the lack of precipitation. However, the occurrence of hydrological and agricultural drought depends on several factors. One of the factors is the buffering capacity of heterogeneous soil and groundwater storage, which can be improved with a better agricultural farming system and water management (Cruz et al., 2021).

According to the new IPCC report (AR 6) and JRC Technical Report for the EU, the frequency and intensity of droughts will continue to increase at both global and continental scales with increasing global warming levels. The area affected by the increase in droughts frequency and severity will be expanded in the future with increasing global warming (IPCC, 2021). Based on Figure 1, the southern part of the European continent will expect an increase in drought frequency and global warming. Furthermore, the Netherlands is projected to have an increase in drought frequency by 38% at 3˚C warming while also the most substantial rise in drought losses (e.g., economic loss) along with the surrounding countries in Europe (Cammalleri et al., 2020). On the contrary, the northern part of Europe will have less drought frequency with increasing global warming.

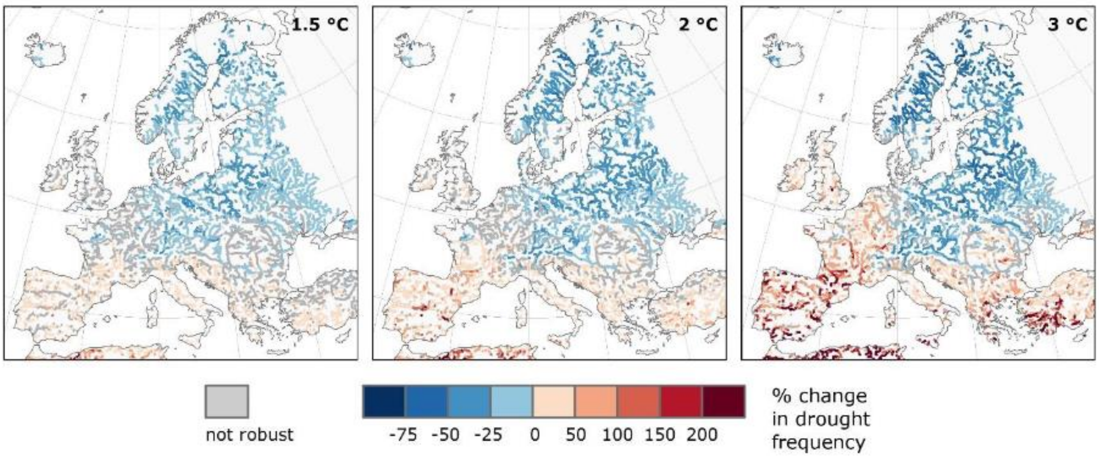

Figure 1. Projected change in drought frequency for different warming levels and baseline (1981-2010) climate (Source: Cammalleri et al. (2020))

Both hydrological and agricultural drought have their effect on the environment. Hydrological drought will affect the flow of the rivers and the decline of groundwater level, which in the end may lead to the water availability for the surrounding area, including irrigation for the agricultural land. A study by Telak et al. (2020) shows that particular agricultural practice, in this case, tillage impacts soil properties and hydrological responses such as significantly increasing soil water content while also significantly increasing the water holding capacity. This implies that the soil will tend to be saturated and thus will affect into faster rainfall-runoff that leads to sudden high peak discharge. In a sense, this will inevitably become one factor contributing to the occurrence of drought. Faster rainfall-runoff means that the water cannot infiltrate or percolate through the soil, leading to declining groundwater levels. This will inevitably cause a lower river base flow(Abdullahi & Garba, 2016; Weber & Perry, 2006). In addition, agricultural drought will have several impacts, such as reducing crop productivity, increasing crop production costs, and even increasing economic stress for farmers (van Duinen et al., 2015). This will become an even bigger problem for rainfed agricultural land that only depends on the amount of rainfall infiltrated into the soil and is stored there to be used by the plants later (Z. Liu & Jin, 2016). Therefore, agricultural practices are an essential factor to be considered in the increasing events of drought due to climate change, especially for rainfed farmland.

To cope with the droughts caused by rainfall deficit which eventually leads to agricultural and hydrological drought, alternative field management strategies could be applied by looking at the different possible strategies. Identifying the potential alternative agricultural practices can be performed by understanding the process of water loss in agricultural soils. In this case, soil moisture is one of the factors that contribute to agricultural and hydrological droughts. Low water retention capacity is primarily caused by poor rainwater partitioning, rainwater that mainly turns into water loss through runoff and seepage instead of being stored and then used by the plants. This condition leads to a lower productive amount of rainfall and reduces the amount of soil moisture (Cornelis et al., 2019). In another way, the green water (rainwater available for the plant to use) is less than the available rainfall due to the surface run-off, percolation, and soil evaporation. It can be seen in Figure 2, the illustration of the important hydrological fluxes and storage that affect the rainwater partitioning, which also has an impact on green water availability.

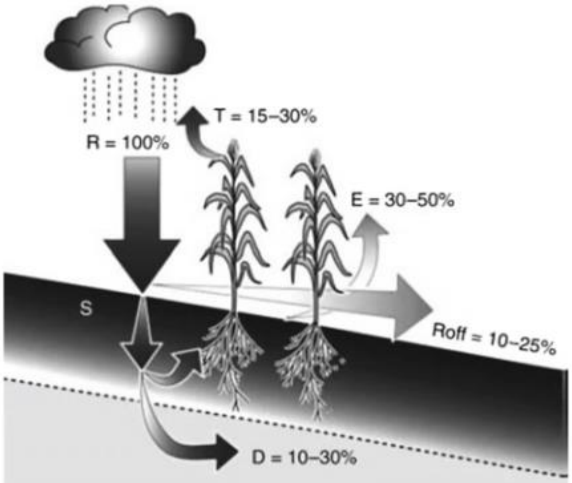

Figure 2. Rainwater partitioning, whereas Rainfall (R), Runoff (Roff), Deep percolation (D), Evaporation (E), Transpiration (T), and Rootzone water storage (S)
(Source: Rockström et al., 2002))

Conservation agriculture is an alternative farming system currently rising in popularity among farmers worldwide. This is in accordance with increasing people's awareness of climate change, environmental quality, and sustainable agriculture (Li et al., 2011). In general, conservation agriculture (CA) is essential in situ intervention that aims for better soil and water management, reducing the negative impacts of conventional agriculture, and resilience against changing climate (Assefa et al., 2018). This system includes several practices such as minimum soil disturbance (tillage), residue management (mulching practice), and diversified crop rotation. To overcome poor rainwater partitioning, CA strategy that focuses on reducing the runoff, soil evaporation, and increasing the soil water content or soil moisture is needed (Lal, 2008). This system also is in line and considers the principles of soil water management: increasing water infiltration, decreasing runoff, and reducing soil evaporation. Several studies reported various benefits of conservation agriculture systems, such as an increase in infiltration rate, higher hydraulic conductivity, reduced soil evaporation, reduced run-off, improved water-use efficiency, and increased crop yield (Abdallah et al., 2021; Bombino et al., 2021; Busari et al., 2015; Miller et al., 2002). These benefits cover the hydrological aspects on top of increasing agricultural productivity that can be a solution for coping against the drought (Assefa et al., 2018). Based on an extensive literature study, Table 1 shows the summary of the impacts of CA practices based on various papers that have been cited.

Table 1. List of different farm field management practices under conservation agriculture with respect to their impacts on hydrology and agricultural productivity

Conservation agriculture practices	Implementation	Explanation	Impact	
			Hydrology	Agricultural productivity
Soil disturbance (tillage)	Minimum or no tillage	Reducing or removing mechanical manipulation of soil characteristics	Increase infiltration rate, higher hydraulic conductivity, and increased soil moisture retention	Improved root development, more efficient water and nutrient use, and increased yield
Residues management practice	Organic mulching	Spreading various materials to cover the soil surface	Improved infiltration capacity, reduced soil evaporation, and reduced surface run-off	Higher green water productivity and increased crop yield
Cropping system	Diversified crop rotation	A sequence of different crops grown overtime in the same paddock	Increase water holding capacity and soil aggregate stability	Improved available nutrients, increased plants' resilience against disease, and increased productivity

Furthermore, there is still minimum knowledge and modelling related to the impacts of implementing conservation agriculture, especially in Europe. Europe is behind compared to the other countries in terms of conservation agriculture (CA) implementation, with only 25% of its arable land (Kertész & Madarász, 2014). To be more specific for the comparison between different areas, South America leads the CA implementation by covering 45% of the CA area in the world, followed by North America with 32% (Jat et al., 2013). On the other hand, Europe only covers 1% of the world's CA area and is far less compared to both South and North America. The small amount of CA implementation in Europe is clearly in accordance with the number of research related explicitly to CA conducted in Europe, which is also limited compared to other areas. Therefore, research and implementation of CA are considered to be minimum in Europe, especially in the Netherlands.

1.2 RESEARCH GAP

Assefa et al. (2018) compared the CA system to traditional conventional tillage only under drip irrigation technology. They modelled the CA impacts using the APEX model, which focuses on assessing several hydrological and agricultural indicators. However, they did not individually cover the impacts of CA practices and specifically conducted the study on irrigated agricultural land. Furthermore, there are still minimum studies that modelled the impacts of the three collaborative practices under CA in Europe, while many studies related to this topic are conducted outside of Europe (Abdallah et al., 2021; Assefa et al., 2018; Jat et al., 2021; Li et al., 2011; Patil et al., 2016). Additionally, other studies also tried to model the impacts of CA practices with the focus on how the individual practices under conservation agriculture affect agriculture productivity and hydrology (Bowles et al., 2020; Busari et al., 2015; Iqbal et al., 2020; Lobb, 2008; Montenegro et al., 2013). Even though various researchers have used the SWAT model for best management practices, they are mainly focused on the impacts from the perspective of water quality and sediment transport (Rocha et al., 2015; Santhi et al., 2001; van Liew et al., 2007; Zettam et al., 2022). Several researchers have used the SWAT model for assessing various best management practices.

However, they are mainly focused on the impacts of climate change from the perspective of water quantity and quality with minimum attention to crop yield (Parajuli et al., 2016; Woznicki, Nejadhashemi, & Lawrence, 2010; Woznicki, Nejadhashemi, Smith, et al., 2010). It can be concluded that there is still no study specifically focused on conservation agriculture practices' impacts on both hydrology and crop yield as well as their implications under climate change conditions in the Netherlands, especially in a rainfed land, with the focus on the combined measures of conservation agriculture.

1.3 RESEARCH OBJECTIVE AND SCOPE

The goal of this master thesis is to model the impacts of conservation agriculture practices on hydrology and agricultural productivity on rainfed agricultural land to cope with droughts and climate change. Furthermore, this thesis will be conducted in a rural area located in the east of the Netherlands, specifically in the Hupsel catchment, which mainly consists of a rainfed agricultural area, and various problems related to the drought events are encountered by the farmers in this area such as fast runoff and low soil moisture due to the frequency of drought events (Hesselink, personal communication, 19 January 2022). This problem causes lower crop yield and harms the ability to cultivate the crops in this area. Coping with drought, in this case, refers to minimizing the adverse effects of drought on both hydrology and crop yield in the area. Since many indicators can be explored in hydrology, this study is further limited to assessing the CA impacts on surface runoff, percolation, evapotranspiration, and soil moisture. The reason for focusing on these indicators is because rainfed agriculture depends on the infiltrated rainfall that forms as the soil moisture, which in most cases of high surface runoff, low infiltration, and high evapotranspiration will reduce the amount of rainfall infiltrated into the soil (Rockström et al., 2010).

In this study, the crop-water model, namely the SWAT model, is used to model the impacts of different farming practices. To be more specific, the newest version of the SWAT model, namely the SWAT+ model, is used, which includes more improvements compared to the last version (SWAT 2012). The reason for choosing the SWAT model over the other crop-water models is its various advantages. The SWAT model, compared to other crop-water models, such as the APEX model, is basically similar in terms of the theoretical basis of the model. For instance, both models use the same routing method in terms of hydrological modelling and also derive the crop growth modelling from EPIC. In terms of its practical implementation, the SWAT model is widely used and known worldwide to be used in modelling broad topics. For instance, various researchers have used the SWAT model to model the impacts of best management practices, crop growth, and climate change impacts (Khalili et al., 2021; Q. Liu et al., 2021; Rocha et al., 2015).

The CA impacts are modelled using SWAT+ since this model can simulate hydrology and crop growth in a system that includes several modules related to the agricultural practices suitable for this study (Bieger et al., 2017). CA practices are modelled individually and combined, which means that all three main practices, namely no soil disturbance (no-tillage), residue management (mulching), and crop rotation, are assessed while being implemented in the study area. Those practices will be assessed in a scenario-based simulation that consists of individual and combination of all practices to be compared with the baseline scenario, which is the scenario referred to as the current farming system used in the study area. Then, the baseline scenario and CA practices are modelled with respect to historical and future climate data. The reason for using historical and projected climate data is to assess the CA impacts under dry, wet, and average conditions using historical climate data (further to see the CA practices under different climate conditions). In contrast, projected climate data will give the future implication of CA implementation for the hydrological processes and agricultural productivity.

1.4 RESEARCH QUESTIONS

To achieve the research objective, several research questions need to be answered:

1. To what extent does the baseline scenario represents the farming practices used in the study area?

The first research question aims to create a baseline scenario to reflect the farming practices currently used in the study area through simulation using historical weather data. The baseline scenario, through the SWAT model, is an essential part of the CA impact assessment since the baseline scenario is used to compare with the other CA practices scenarios. Furthermore, the accuracy of the baseline scenario is appraised by comparing the model's output with the available observed data related to the hydrology and agricultural productivity of the Hupsel area.

2. How do the individual and combined practices under the CA farming system affect the hydrology and agricultural productivity compared to the baseline scenario under the historical climate conditions?

In this research question, several aims will be explored. Firstly, the CA practices, namely, no-tillage, residue management (mulching), and crop rotation, are modelled individually to assess their impacts on hydrology and agricultural productivity. Then, based on the individual CA practices simulations, the most impactful practice is identified. Furthermore, the combination of all the CA practices is also modelled and assessed for its impacts on hydrology and agricultural productivity. Lastly, the impacts of individual and combined CA practices are compared with the baseline scenario under the same condition using historical weather data.

3. How do the individual and combined practices under the CA farming system affect the hydrology and agricultural productivity compared to the baseline scenario under future climate conditions?

The aims of this research question are similar to the previous question, but the impacts will be assessed under future climate conditions. Comparison will also be sought between the individual and combined CA practices with the baseline scenario using the projected weather data further to assess the implication of CA implementation in the future.

1.5 REPORT OUTLINE

The thesis report starts by explaining the study area and describing the model used in chapter 2. This includes the description of the Hupsel catchment area and SWAT model covering the material used in this study. Chapter 3 provides the research methodology applied in this study to answer the research questions and describe the data used. Chapter 4 presents the results for generating the baseline scenario, modelling the impact of CA practices using historical climate data, and also under the future climate scenarios. Chapter 5 discusses the results based on the limitations, comparison with other studies, practical implications, and generalization of the method and results. Lastly, chapter 6 presents the conclusion and this study's recommendations.

2. STUDY AREA AND MODEL DESCRIPTION

2.1 STUDY AREA

The study area is the Hupsel catchment, a hamlet in the municipality of Berkelland. This area is located between Eibergen and Groenlo, consisting of several sub-catchments. Figure 3 shows the Hupsel catchment along with the elevation and slope of the area. Leringbeek (Hupselsebeek) is located on the south side. Droughts have reportedly occurred in this area, compounding with the area's slope that causes rapid drainage during rainfall. This becomes a problem due to less water percolating through the soil compared to the previous years in this area. Several hydrological processes, such as percolation and runoff, along with the soil's physical characteristics, will affect how much water will be percolated and how much will become surface runoff. Furthermore, many waterways are already dry. Deep watercourses lie on the highest parts. Therefore, these problems become the primary driver of desiccation in this area. Desiccation becomes even more concerning because the area in Hupsel is mainly agricultural land use.

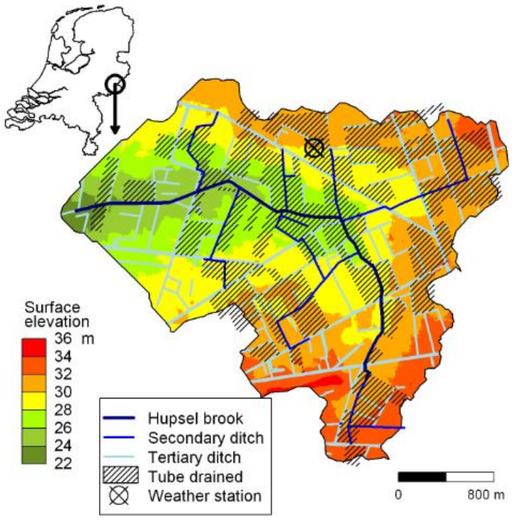

Figure 3. The Hupsel catchment in the east of the Netherlands
Source: (van der Velde et al., 2009)

The catchment area is approximately 6.5 km^2 with an elevation range of 22 to 35 m a.s.l and a mean slope of 8% (van der Velde et al., 2009). The land use of this area is mostly allocated to grassland covering 59% of the catchment area, 33% consists of crops mainly for cultivating maize, 3% forest, and 5% built-on areas (Brauer et al., 2011). The Hupsel catchment is dominated by the loamy sand type of soil with an average of more than 60% sand content on top of an impermeable clay layer (Brauer et al., 2014; BRO, 2022). Furthermore, the typical farmers in this area are livestock farmers that depend on the grassland and maize as their source of animal feed. In contrast, no irrigation water is supplied to this area or only depends on rainfall as the primary water source (rainfed agriculture). Based on a meeting with Waterboard Rijn en Ijssel (WRIJ), responsible for the Hupsel catchment, the farmers mainly use common machinery for the farming process (Hesselink, personal communication, 19 January 2022). This common machinery is essential for the tillage operation for their land. Furthermore, only one crop is cultivated in the same area all the time, namely grass and maize only.

Additionally, even though some farmers have started to incorporate the idea of mulching practice, there is still the minimum application of mulching observed in the catchment area. Therefore, it can be concluded that the common farming system implemented in the Hupsel catchment is the conventional system. This is due to the extensive machinery usage for tillage observed in this catchment. Furthermore, the catchment only cultivates one crop and has no mulching that matches the characteristics of the conventional farming system (Fisher, 2021; Mylonas et al., 2020).

In this case, the farmers themselves have been trying to come up with several solutions and suggestions on their own to tackle the desiccation problem and the waterboard consultation. There are mainly two measure categories to tackle this problem: in-stream and off-stream measures. In this case, the solutions implemented are mainly related to measures in the ditches or the in-stream measures. They aim to make the flow becoming slower so could give the water time to further percolate through the soil, which can be seen that the current solutions are more focused on technical infrastructure-based solutions. Therefore, another solution from the perspective of off-stream measures, such as an alternative agriculture farming system, could be used to help the desiccation problem in this area further. To be specific, conservation agriculture practices along with technical solutions could be the answer to further slowing the runoff and increasing the soil moisture in the area.

2.2 SOIL AND WATER ASSESSMENT TOOL (SWAT) MODEL

2.2.1 General Model Description

The SWAT model has several advantages and disadvantages that should be considered. Advantages such as the SWAT model has the capability of generating the required database quickly through its interface, uses readily available inputs that can be extracted from the accompanying database (related to various variables in the SWAT model), is computationally efficient, and is suitable for a long-term impact study (Neitsch et al., 2011). Furthermore, SWAT also provides an extension to integrate with open-source GIS software and is supported with various additional software that can improve the productivity of the model. On the other hand, the disadvantages of the SWAT model are that it uses a simpler version of the EPIC model compared to other crop-water models, such as the APEX model. It is less accurate than the APEX model in scale resolution, and it can only model a single crop in one HRU (Neitsch et al., 2011; Saleh, 2004; Tripathi & Gosain, 2013). Furthermore, since the SWAT model uses a reduced version of the EPIC model that excluded minor features of the EPIC model, those features are not essential for this master thesis topic. Additionally, the advantages of the APEX model over the SWAT model are not essential for this master thesis since the needed features and components for assessing the impacts of different farming practices are also available in the SWAT model.

SWAT (Soil and Water Assessment Tool) is a distributed hydrological model based on the water balance concept. Using digital elevation data, the modelled watershed is separated geographically into sub-watersheds. Sub watersheds are further split into lumped, non-spatial hydrologic response units (HRUs), which comprise all places within a subwatershed with comparable landscape features (Y. Wang et al., 2019). Furthermore, SWAT is a physically-based semi-distributed model that requires specific input related to weather, soil properties, topography, vegetation, and land management within the watershed (Neitsch et al., 2011). Then, the physical processes associated with the input data will be modelled by SWAT, such as water movement, sediment movement, crop growth, nutrient cycling, etc.

The newer version of SWAT, namely the SWAT+ model, is a newly redesigned version of SWAT that was created to solve current and future issues in water resource modelling and management, as well as to fulfil the demands of an ever-growing global user community (Bieger et al., 2017). SWAT+ provides greater watershed discretization and setup flexibility than prior SWAT versions (Bieger et al., 2019). SWAT+ was chosen as the crop-water model for this study based on its features and benefits. In particular, the SWAT+ model can cover water balance, crop growth, and a database of farm practices for further assessment of different farming practices.

The water balance is the main driving force for everything in the watershed under the SWAT model (Neitsch et al., 2011). The simulation of a watershed's hydrology may be divided into two essential parts. The land phase of the hydrologic cycle is the first part. The quantity of water, sediment, nutrient, and pesticide loadings to the main channel in each sub-basin is controlled by the land phase of the hydrologic cycle. This includes components such as Rainfall (P), Evapotranspiration (ET), Surface Runoff (Qs), Lateral Flow (Ql), Base Flow (Qb), and four storages (Marhaento et al., 2017). The second part of the hydrologic cycle is the water or routing phase, the passage of water, sediments, and other materials through the watershed's channel network to the outlet. In general, the land-phase cycle and routing phase schematization of the SWAT model used in this study can be seen in Figure 4.

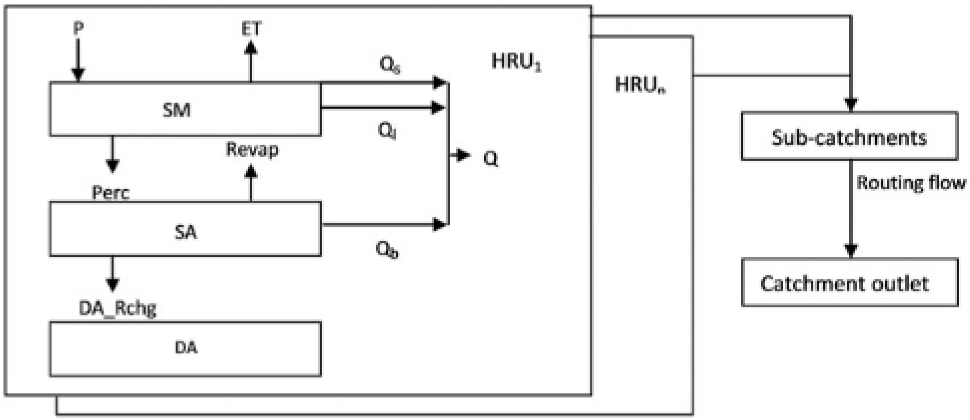

Figure 4. The SWAT model structure.
DA = deep aquifer; ET = evapotranspiration; HRU = hydrological response unit; Qb = base flow; Ql = lateral flow; Qs = surface runoff; SA = shallow aquifer; SM = soil moisture
(Marhaento et al., 2017)

2.2.2 Surface Runoff

The SWAT model offers the Green & Ampt infiltration (1911) and the SCS curve number method to estimate surface runoff (Neitsch et al., 2011). The SCS curve number approach was utilized in this study because it calculates surface runoff as a function of the permeability of the soil, the kind of land used, and the preexisting soil water conditions. When the land use is known, the approach is simple and offers a consistent basis for predicting the quantity of runoff under various land uses and soil types. Furthermore, this method strongly depends on CN, the curve number, a function of soil permeability, land use, and antecedent soil water conditions. The limitation of using the SCS curve number method is that it cannot directly simulate the infiltration, which in this case needs to be manually calculated from the other fluxes provided by the method. Thus, infiltration can only be simulated using the Green & Ampt method, which requires sub-daily precipitation data as input for the modelling process. A more detailed description of the surface runoff calculation is given by Neitsch et al. (2011).

2.2.3 Evapotranspiration

The total transpiration from vegetated surfaces and evaporation from rivers, lakes, and bare soil is known as evapotranspiration. The actual values of transpiration and evaporation are estimated independently using the SWAT model. The prospective evapotranspiration (PET), the amount of water that might evaporate and transpire if adequate water is available, is used to determine the actual evapotranspiration. SWAT may estimate the daily PET using one of three techniques: Penman-Monteith, Hargreaves, or Priestley-Talor (Neitsch et al., 2011). This study used the Hargreaves method to calculate the daily evapotranspiration (ET), which only requires daily maximum and minimum temperature (˚C). The actual evapotranspiration is the sum of soil water evaporation and transpiration by vegetation. Soil water evaporation was estimated using exponential functions of soil depth [mm] and water content [-]; a detailed description of these functions is given by Neitsch et al., 2011.

2.2.4 Soil-Water Interaction

Water can travel through the soil in several ways, including lateral movement in the profile, percolation, removal from the soil via evaporation or plant absorption. The kinematic storage model offered by Sloan et al. (1983) calculates the lateral movement through the soil. This model mimics three-dimensional subsurface flow based on slope, length, and hydraulic conductivity. The percolation for each soil layer in the profile is calculated using the storage routing algorithm within the SWAT model. Neitsch et al. (2011) provide a more thorough explanation of the interaction between soil and water.

2.2.5 Groundwater

Both shallow and deep aquifers are included in the SWAT model. The quantity of water moving into the soil zone in reaction to water shortages, groundwater flow, recharge entering the shallow aquifer, and water pumped out of the aquifer make up the shallow aquifer water balance. The deep aquifer water balance comprises the quantity of water pumped out of the deep aquifer and the amount of water that percolates from the shallow aquifer into the deep aquifer, which is not included in this study. SWAT uses various empirical and analytical methodologies to consider all of these elements of the groundwater distribution (Neitsch et al., 2011).

2.2.6 Plant Growth and Crop Yields

SWAT's plant growth component is a reduced version of EPIC's plant growth model (Neitsch et al., 2011). As in EPIC, plant growth can be inhibited by temperature, water, nitrogen, or phosphorus stress. Phenological plant development is based on daily accumulated heat units, potential biomass is based on a Monteith method based on radiation use efficiency, a harvest index is used to calculate yield, and plant growth can be inhibited by temperature, water, nitrogen, or phosphorus stress. Detailed root growth, micronutrient cycling, toxicity responses, and simultaneous growth of multiple plant species in the same HRU are all parts of the EPIC plant growth model that were not included in SWAT.

2.2.7 Soil Nutrients

The three most crucial minerals for plant development are nitrogen, phosphorus, and potassium. Three main types of nitrogen are stored in the soil: organic nitrogen linked to humus, mineral forms stored by soil colloids, and nitrogen in solution. In SWAT, nitrogen can be introduced to the soil using fertilizer, manure, or residue, fixation by symbiotic or non-symbiotic bacteria, and rain. Plant absorption, leaching, volatilization, denitrification, and erosion are the processes that remove them from the soil. Manual by Neitsch et al. (2011) provides a more thorough explanation of soil nutrients.

2.2.8 Practical Application of SWAT Model

The SWAT model is considered a possible model for assessing the impacts of different farming practices since it is possible to incorporate and simulate the practices, namely tillage, mulching, and crop rotation, in the SWAT model (Neitsch et al., 2011). Tillage re-distributes residues, nutrients, pesticides, and microbes across the soil profile. The time of the tillage operation (could be in a format of Julian day or fraction of base zero potential heat units) and the type of tillage operation are both essential. Throughout the year, the user can change the curve number in the HRU. New curve number values can be inputted in a plant operation, tillage operation, and harvest and kill operation. For these activities, the curve number entered is moisture condition II, which is the average soil moisture. SWAT updates the inputted value daily to account for changes in water content. Furthermore, the user can also change the Manning value (roughness) representative to the tillage operation in the HRU. In terms of residue management (mulching), the users can incorporate this practice by defining the initial residue cover relative to every plant that the users intend to have mulch on. One of the several operations, such as harvest and kill operation, can automatically incorporate the crop residue right after it has been harvested. In this case, the SWAT model also uses the crop residue as input for the nutrient cycle (Nitrogen and Phosphorus) by simulating the decomposition of organic residue. The residue also affects the soil organic matter (SOM) of the soil since SWAT is also simulating the SOM through a one-pool SOM sub-model developed by Kemanian & Stöckle (2010). Therefore, the crop residue will impact not only the roughness of the soil but also the nutrients and SOM within the soil. Lastly, crop rotation practice can be easily incorporated into the SWAT model by defining the specific rotation schemes under the management operation section of the SWAT model.

3. METHODOLOGY AND DATA

This section will explain the methodology used to answer the research questions and needed data for this master thesis study. This master thesis consists of three parts that will be elaborated in this section, answering respective research questions.

3.1 GENERATING BASELINE SCENARIO

The three main preparation data, the digital elevation model (DEM), land use map, and soil map, are processed in the GIS environment. As the output from the GIS environment, the HRUs and the chosen historical climate data are used to model the catchment area in the SWAT+ model. In addition, to further generate the baseline scenario representing the conventional agriculture practices in the study area, the land use management and the operations schedules are adjusted and checked in accordance with the actual condition implemented in the Hupsel catchment area. After that, the sensitivity analysis, calibration, and validation processes are conducted to improve the model performance by comparing it with the available observed flow data. Several statistical metrics are used to assess the model's performance during the calibration and validation processes. The statistical metrics that are being used are the ones that will be mentioned in section 3.1.6. Lastly, the model that has been through those processes generates outputs that can be used for comparison purposes in the second question. The overall methodology can be seen in Figure 9.

3.1.1 Watershed Delineation

The three primary preparation data, digital elevation model (DEM), land use map, and soil map, are processed in the GIS environment. DEM data is used to delineate the watershed to produce a watershed with additional streams data provided by the waterboard of the catchment to be included in the watershed delineation process. This way, the watershed delineation produced a more accurate result. Furthermore, the outlet of the catchment area is determined manually by following the coordinate of the streamflow measurement station in the Hupsel catchment. The result of the watershed delineation using the SWAT+ model can be seen in Figure 5, with a total area of 7.8 km^2 and 13 subbasins.

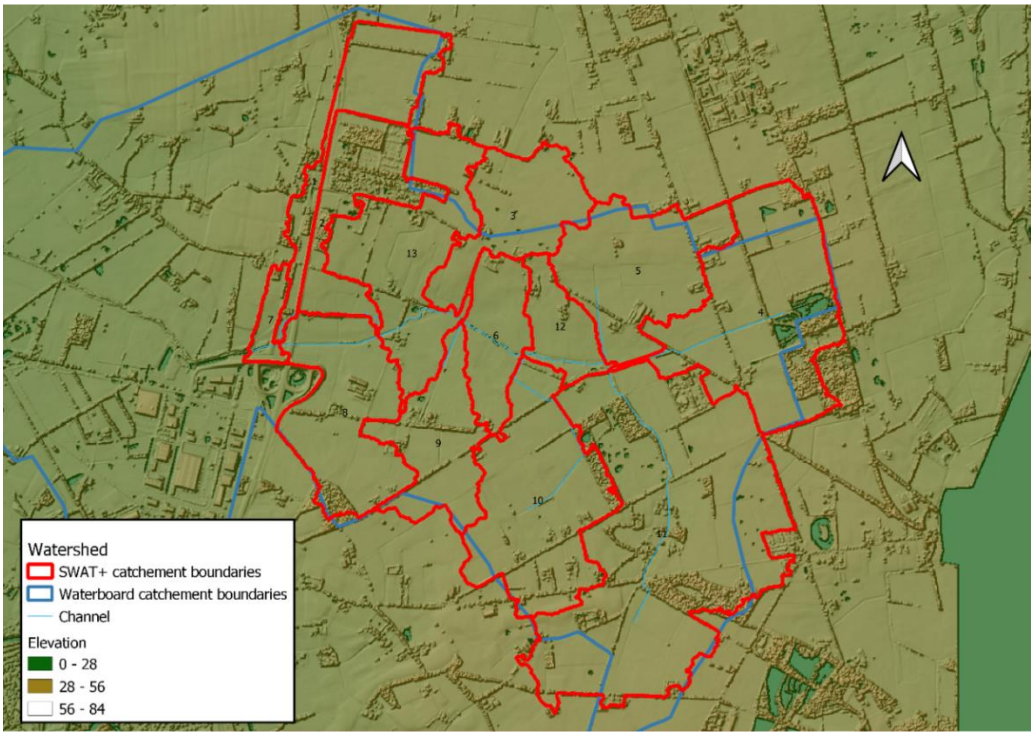

Figure 5. Watershed boundaries comparison between SWAT+ and waterboard

However, it can also be seen in Figure 5 that the watershed delineated due to the SWAT+ model was not the same as the watershed boundaries determined by the waterboard. The delineated watershed produced by the SWAT+ model overestimated the actual boundaries compared to the waterboard's. For instance, the north side of the delineated watershed by the SWAT+ model has the largest area overestimation compared to the other sides. According to the waterboard boundaries, the overestimated area should belong to another watershed whereas the water supposed to flow north instead of going south and discharged to Leerinkbeek. Regardless, the resulted watershed area produced by the SWAT+ model was still acceptable since it only overestimates small area and can still follows the actual watershed boundaries determined by the waterboard. Furthermore, such an overestimation could also be resulted from errors of the model and different approach on determining the boundaries. For instance, the SWAT+ model only follows the DEM as the main input for determining the boundaries while the waterboard was using higher resolution DEM along with checking and measuring the catchment area in-person. As for the other sides, they only overestimate the area way less compared to the north part. This is due to the SWAT+ model was using the road as the boundaries while the waterboard takes into account the orifice/culvert under the road and resulted with the difference between the two watershed boundaries.

3.1.2 Generating Chosen HRUs

Then, by including both land use map and soil map, a number of potential hydrological response unit (HRU) are identified. In order to generate HRUs that will be used for SWAT+ simulation, several settings are being adjusted according to the user preference. Slope classes are being determined by the users whereas for this study, the slope was divided into 5 classes (in %), which are 0-2, 2-5, 5-10, 10-20, and higher than 20. By using the percentage subbasins as the threshold, the users can determine and limit the number of HRUs that are going to be generated by the SWAT+. The reason to limit the number of HRUs is to have less computational demand for simulating SWAT+ while also focus on the intended land uses that are relevant to this master thesis study. Therefore, the threshold values for the inputs based on the percentage coverage of subbasins are determined as 10%, 10%, and 20% respectively for land use, soil, and slope. The respective percentage values for threshold were chosen to capture all of the land uses that are relevant for this study, which are corn and grassland. Therefore, every single corn and grassland land uses were being included in the simulations while also limit all the other land uses that have lower percentage area determined.

Based on the settings adjustment for choosing and limiting the number of HRUs, a total of 73 HRUs were being generated and chosen to be used in the simulation. From total of 16 land uses in the Hupsel catchment, only 5 land uses were included in the simulation. Those land uses are urban, grassland, corn, and two different types of forests. As for the other land uses that were excluded, their areas were being allocated and distributed evenly to the 5 land uses that were included in the simulations provided that they are in the same subbasins as the excluded land uses.

3.1.3 SPEI Index of the Historical Climate Data

In total there were 28 years of climate data from the period of 1994 to 2021 that were chosen to be used as the input for the simulation. The period was chosen due to its completeness and availability of the climate variables needed by the SWAT+ model and will further be explained in section 3.4. Thus, this set period of historical climate data that contains dry, wet, and average conditions are being used as the required climate data input for the SWAT+ model. The reason of identifying the historical weather data condition is to further help the assessment of the impact of the CA practices in different conditions. This way, the behavior of the farming practices can be seen based in three different conditions, namely dry, wet, and average. Therefore, the Standard Precipitation Evapotranspiration Index (SPEI) is used as an index to distinguish the conditions of the historical climate data (Vicente-Serrano et al., 2010). This index is chosen of all the other indices due to the input parameters utilized in this index are precipitation and evapotranspiration data, which makes it significantly simpler than other indices. Furthermore, SPEI will be more appropriate for usage in this master's thesis research area since the agricultural areas in the Hupsel region are mostly rainfed, making the SPEI index much more reliable than Standard Precipitation Index (SPI) in terms of determining the condition of historical weather data in the study site by using two variables. Finally, despite the fact that SPI appears to be more commonly used and only using one variable, SPEI is still a more robust drought index when compared to SPI (Pei et al., 2020). The chosen period of one year (to represent dry, wet, and average) from the historical climate data based on the SPEI index are used as the input climate data for answering the second research question.

The SPEI index calculation for the historical climate data that were used as input for the SWAT+ simulation is essential to give information regarding the drought on the different period. Based on the value of the SPEI index, the condition of every single year can be identified whereas the lowest negative value represent severe drought condition while positive value the other way around.The results of the SPEI index for the historical climate data can be seen in Figure 6. Moderate wet year period was only observed in the year of 2007 which indicated by the value of SPEI index around 1 to 1.49. On the other hand, the most severe drought condition was observed in 2018 with the value of SPEI index over -3. The drought condition was observed to be continuing in the following years until 2020 with severe dry condition. For the rest of the years are observed to have nor slight wet or dry years which means they are normal condition with the SPEI index value around -1 to 1. Therefore, the analysis of the wet-dry conditions in different period based on SPEI index were useful to further see how different practices under CA affect under different wet-dry conditions.

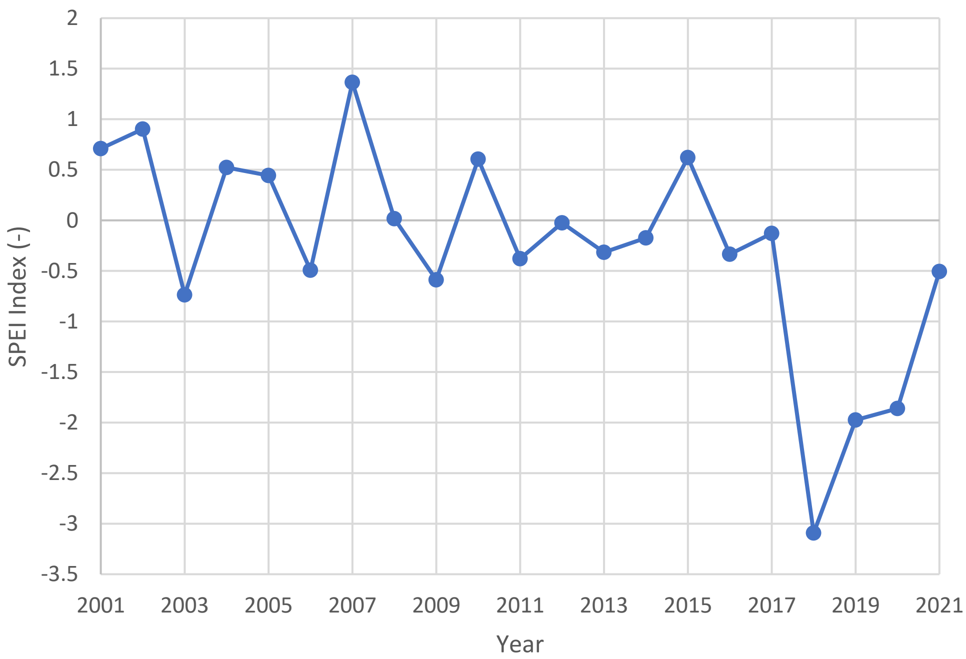

Figure 6. The SPEI Index for the historical climate period 2001-2021 used in SWAT+ simulation

3.1.4 Management Operations and Schedule of Baseline Scenario

Determining the management operations and schedules are crucial to get the actual representation of how the farmers operate in the Hupsel catchment area. Management operations and schedules became the main focus to be given more attention and details for this study. In this case, the conventional agriculture practices are still being adopted and implemented by the farmers in the area. For instance, the extensive use of machinery for tillage, no residue management, and no crop rotation. SWAT+ model provides various databases that cover all of the common and possible operations that can be implemented by the farmers, which include plants, tillage, fertilizer, grazing, etc. For instance, the tillage database includes various machines such as moldboard, field cultivator, bedder, and many more. The same goes for all the other databases. In addition, the users have two options for scheduling their chosen operations. It can be based on potential heat units or using julian day and the users can also determine the desired rotation years as well. In this study, the scheduling of the operations was determined by the julian day. This way, the operations were being scheduled at the same period for every single year during the simulation within the SWAT+ model. It can be seen in Figure 7 and Figure 8, the management operations and schedules were created by using databases provided with further consultation with the waterboard and common knowledge on the agricultural practices of a conventional system. In both figures, the column next to data refers to types of fertilizer application and harvest operation while last column represents the amount of fertilizer applied (kg/ha) and number of grazing days. Thus, the chosen management operations and schedules were implemented under the management operation section within the SWAT+ editor page to further implement the desired operations and schedules for the baseline scenario.

Operations

OPERATION	YEAR	MONTH	DAY	HU	DATA		
till	1	4	24	0	mldboard		0
fert	1	4	27	0	ceap_p_p	aerial_liquid	30
fert	1	4	27	0	urea	aerial_liquid	100
till	1	4	28	0	fldcult		0
plnt	1	5	1	0	corn		0
fert	1	5	21	0	urea	aerial_liquid	200
fert	1	7	25	0	urea	aerial_liquid	200
hvkl	1	9	25	0	corn	grain	0
till	1	9	28	0	chisplow		0

Figure 7. The baseline scenario management operations and schedules for corn landuse

Operations

OPERATION	YEAR	MONTH	DAY	HU	DATA		
fert	1	3	17	0	urea	aerial_liquid	100
fert	1	3	17	0	ceap_p_p	aerial_liquid	50
till	1	4	24	0	mldboard		0
till	1	4	28	0	fldcult		0
plnt	1	5	1	0	rnge		0
graz	1	5	20	0	beef_high		120
harv	1	10	28	0	rnge	grass_bag	0
till	1	10	31	0	chisplow		0

Figure 8. The baseline scenario management operations and schedules for grassland landuse

SWAT+ model provides a database that contains various tillage machinery that are commonly used by the farmers worldwide. This database contains details such as mixing efficiency and mixing depth for each of the machinery included in the database. Both variables related to a specific tillage machinery is important to help the SWAT+ model determines the distribution of residue, nutrients, pesticides, and bacteria (Neitsch et al., 2011). The tillage operations that were being implemented in both corn and grassland were based on the recommendation provided by the SWAT+ model for extensive tillage operations. The tillage machineries that were included namely moldboard and field cultivator before planting the seeds and chisel plow after harvesting the plants. As for the fertilizer, the amount and date of the application were adjusted so that the plants are having as minimum nutrient stresses as possible during growth but with a reasonable amount of fertilizer. Normally, the phosphate fertilizer is being implemented in the early phase of the crop growth and nitrogen at a later phase due to the phosphate is essential nutrient at the early phase of the crop growth (Grant et al., 2001). In case of the harvesting operation, corn and grassland have different types. For harvesting the corn, harvest and kill operation was chosen, which refers to turning a fraction of biomass into yield and turns the rest of the biomass into residue on top of the soil surface. On the other hand, harvest only operation was chosen for the grassland, means that a fraction of plant's biomass will be turned into yield and allows the plant to live and grows again. Lastly, grazing operation was also included in the grassland's list of operations for 120 days since grazing by the livestock are taking place in reality at the study area.

3.1.5 Sensitivity Analysis

In this study, the SWAT+ toolbox is used for conducting the sensitivity analysis and calibration of the SWAT+ model, which is an open-source tool that is able to help the users that specifically use the SWAT+ model. There are various available sensitivity analysis methods available in the SWAT+ toolbox. The Sobol method was used for the sensitivity analysis of the SWAT+ model for this study. Sobol method is a variance decomposition-based global and model-independent sensitivity analysis tool that can work with non-linear and non-monotonic models and functions (Nossent et al., 2011). This method was chosen because of its ability to incorporate parameter interactions and the relatively straightforward interpretation of its indices (C. Zhang et al., 2013). It has been demonstrated that Sobol's method's sensitivity indices are superior to other techniques at capturing the interactions between a large number of variables for highly nonlinear models, despite the method's demanding processing needs (Tang et al., 2007). In practice, the Sobol method has been used by several researchers as well on the topic of water management (Gatel et al., 2020). In the SWAT+ toolbox, the output of the Sobol method is the first-order index (sensitivity) that refers to the fractional contribution of a single parameter to the output variance, whereas a higher value (maximum 1.0) of the index indicates a sensitive parameter (Chawanda, 2021; X. Y. Zhang et al., 2015).

3.1.6 Calibration and Validation

Both calibration and validation of the SWAT+ model in this study was using different approach. The SWAT+ toolbox model, which uses the Dynamically Dimensioned Search (DDS) method to aid in the auto-calibration process, was used to conduct the SWAT+ model calibration (Chawanda, 2021). DDS is a type of algorithm that, in the best case scenario, converges to the global optimum or, in the worst case scenario, to the good local optimum (Xu et al., 2019). DDS is already a widely used approach for calibrating parameters (Tolson & Shoemaker, 2007). On the other hand, validation of the model was conducted by manually comparing the results of the model and the desired validation period from the historical climate data. Since the historical data could possibly have some missing values, only the available data were being used in the validation. This is clearly different compared to the calibration of the model as the SWAT+ toolbox requires a complete set of historical data for the calibration process.

The calibration and validation of the SWAT+ model was performed with respect to statistical metrics. In this study, various statistical metrics were used to help the calibration and assess the model's performance during the validation process. According to Moriasi et al., (2007), statistical metrics such as Nash-Sutcliffe efficiency (NSE), Pearson's correlation coefficient (r), coefficient of determination (R2), mean square error (MSE), and root mean square error (RMSE), Percent bias (PBIAS), and RMSE-observations standard deviation ratio (RSR). However, only three statistical metrics were used in this study which have the range oof values recommended by the paper, namely NSE, PBIAS, and RSR. NSE is a normalized statistic that determines the relative magnitude of the residual variance ("noise") compared to the measured data variance ("information") which shows how well the 1:1 line is fit by the observed versus simulated data display (Nash & Sutcliffe, 1970). NSE has a range of $-\infty$ to 1.0 (inclusive), with NSE = 1 being the ideal value. The linear relation between observed and simulated data is measured by the correlation coefficient, which has a range of -1 to 1. No linear connection exists if r = 0. A perfect positive or negative linear connection arises if r = 1 or -1. Similar to this, R2 represents the percentage of the variation in the measured data that the model explains. R2 has a range of 0 to 1, and higher values imply lower error variance (Santhi et al., 2001; van Liew et al., 2007). MSE and RMSE are important because they show the amount of inaccuracy in the units (or squared units) of the relevant ingredient, which helps with the interpretation of the outcomes, whereas values of 0 indicate a perfect fit. PBIAS calculates the simulated data's average propensity to be greater or smaller than the corresponding observed data. Low magnitude values indicate accurate model simulation, and the ideal value of PBIAS is 0.0. Model underestimation bias is shown by positive values, and model overestimation bias is indicated by negative values (Gupta et al., 1999). So that the generated statistic and reported values can apply to varied elements, RSR utilizes the advantages of error index statistics and includes a scaling/normalization factor. RSR ranges from a big positive number to the ideal value of 0, which denotes zero residual variation or RMSE and hence faultless model simulation. The performance of the model simulation improves with decreasing RSR.

The calibration and validation of the agricultural output (crop yield) was not done in this study due to no data and information related to it in the Hupsel catchment. However, the agricultural output of the calibrated and validated model from the hydrological part still needs to be compared with the available recorded crop yield data in different resolution or location. For instance, the average yield in the country (Netherlands) or even in the world but with similar climate condition as in the study area.

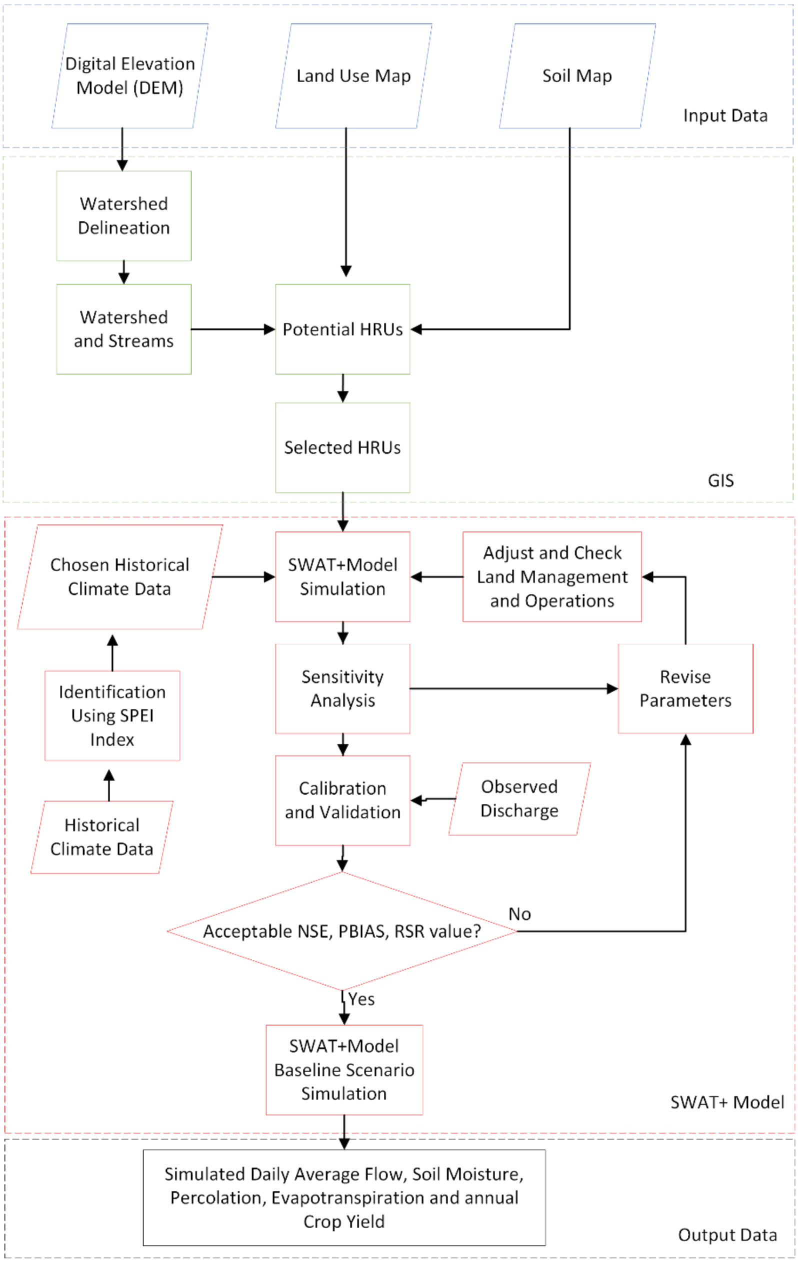

Figure 9. Methodology for generating baseline scenario in SWAT+ model

3.2 MODELLING THE IMPACTS OF CA PRACTICES USING HISTORICAL CLIMATE DATA

In this section, the impacts of individual and combined CA practices are assessed in scenario-based simulation for answering the second research question. Several scenarios for the simulation of CA practices can be seen in Table 2. In total there are 10 scenarios including the baseline scenario. This scenario has been simulated in the previous research question (conventional agriculture practices) which include extensive tillage, no residue management (no-mulching), and growing only one crop.

Table 2. List of scenarios for CA impacts modelling

Scenario	Agriculture Practices	Climate Data
Baseline	Conventional Agriculture	Historical
1	No Tillage	Historical
2	Residue Management	Historical

3	Crop Rotation	Historical
4	All CA Practices	Historical
5	Conventional Agriculture	Projected
6	No Tillage	Projected
7	Residue Management	Projected
8	Crop Rotation	Projected
9	All CA Practices	Projected

For modelling the CA practices impacts on hydrology and agricultural productivity, the baseline scenario that has been generated for answering the first research question is used as the starting point. In order to incorporate and adjust different CA practices in the SWAT+ model, the land use management and operations schedule are changed in accordance with intended scenario that want to be simulated. Similar way of adjusting the CA practices in SWAT+ model as shown in the Figure 7 and Figure 8 can also be used. Thus, the process of adjusting the land use management and operations schedule are repeated until all of the scenarios using historical climate data have been simulated.

Additionally, the effects of CA practices should be assessed by looking at the bigger picture of all the focused fluxes to prevent misleading conclusions toward droughts. Furthermore, the analysis should also be connected to the context of droughts, which in this case are hydrological and agricultural droughts, instead of only focusing on one. Therefore, simple indicators related to hydrological drought and agricultural drought are used in this study to further give indications of whether CA practices have positive or negative effects toward the droughts. The indicators that were used are the Water Stress Ratio for agricultural drought and Standardized Streamflow Index (SSFI) for hydrological drought. These indices were chosen due to the input needed to calculate them can be easily provided by the output of the SWAT model without any further need of additional variable. The water stress ratio is in fact similar to the Evaporative Stress Index (ESI) that considers both potential and actual evapotranspiration, whereas the value of 1 means that there is no evapotranspiration (high water stress) and 0 indicates that actual evapotranspiration occurs at the same rate as the potential value (Narasimhan & Srinivasan, 2005; Schyns et al., 2015). On the other hand, SSFI is basically similar to Standard Precipitation Index (SPI) which also uses the same classification range to give indication of the drought severity from the streamflow perspective (Modarres, 2007). The SSFI can be calculated by depending on the difference of the streamflow mean divided with the standard deviation for a given period, which more detailed description and explanation given by Vicente-Serrano et al., (2012).

3.2.1 No-tillage Scenario

The scenario 1 (no-tillage) was implemented in the SWAT+ model through adjusting the specific tillage operations in the baseline scenario. Therefore, three different tillage operations were changed into zerotillage operation. This way the variables related to tillage operation, namely mixing efficiency and mixing depth, were automatically adjusted to represent the no-tillage operation. Furthermore, other variable besides the tillage operation needs to be adjusted as well. In this case, Manning's roughness coefficient for overland flow also was adjusted to represent the no-tillage with no residue condition from previously being conventional tillage with no residue condition. This approach has also been implemented by G. Wang et al., (2014) for modelling both conventional and no tillage conditions. Furthermore, according to Bonta & Shipitalo (2013), the curve number of no-tillage practice on corn was observed to be reduced around 10-30% compared to the conventional tillage practice. Since the SWAT+ model does not provide a specific condition of tillage with reduced curve number or even a feature to update the curve number, this study was implementing the reduced curve number for no-tillage practice manually by adjusting the calibrated value of CN2 parameter to the desired percentage of reduce. This way, the SWAT+ model could cover the possible impact of no tillage practice as can be seen in Table 1. For instance, having lower curve number for no-tillage means that it has higher infiltration which also have effect on more water being available for the plants and possibly increase the crop yield.

3.2.2 Residue Management (Mulching) Scenario

There are several settings related to operations, schedules, and parameters to properly model the mulching scenario in SWAT+ model so that it can cover possible impacts on hydrology and agricultural productivity. In case of incorporating the residue management practice (mulching) for scenario 2, it was implemented by defining the initial residue for the specific crop in SWAT+ model. However, there is no specific mulching operation that can be used to directly implement mulch in the farmland. This is due to the SWAT+ model need the user to also consider the supply of mulch needed to be included in the simulation. This way, the simulation would be more practical as well in reality since the farmers should also need to secure the supply of mulch needed to be applied in the farmland. Thus, instead of specific mulching operation, SWAT+ model provides the users to schedule an operation of grass_mulch type under the harvesting operation, which refers to harvesting a plant but then instead of removing biomass from the farmland, the operation makes it to be distributed as residue on the soil surface. Therefore, this specific operation is used in this study to further model the residue management in the farmland. However, the supply of mulch still needs to be determined in order for the grass_mulch operation can be implemented. A paper by Sith et al., (2019) gives an approach of implementing mulch in the SWAT+ simulation by growing a specific crop outside of the growing period of the main crop to be used for the supply of mulching practice. In practice, a certain crop such as grass is grown right after the harvesting operation of the main crop and then harvest it through grass_mulch operation later on several days before the start of the preparation for the next growing period of the main crop. This way, the farmers will have the supply of residue needed to be used for the mulching operation. This study, implement the same approach for the residue management (mulching) scenario and chose rye grass for the mulch suppy on the corn farmland.

On the other hand, the grasslands do not need any additional crop to be used as residue for mulching. Instead, they will be supplied with their own grass through the grass_mulch operation as the residue. Furthermore, other variables such as manning value and curve number of both corn and grassland should be adjusted. As for the corn, its manning value was adjusted to no-tillage with residue since there is no value for conventional tillage with residue while the grasslands were adjusted to range with cover (residue) value. Lastly, only the curve number for corn was adjusted to the row crops with residue as there is no specific curve number representing the grasslands with cover. Based on the settings, the possible impacts as in Table 1 such as reduced soil evaporation and runoff while also increase the crop yield was covered in the model represented by the specific lower curve number for mulching condition and also the amount of residue on the soil surface.

3.2.3 Crop Rotation Scenario

Scenario 3 (crop rotation), which alternating the crop grown in the same field each year, can only be implemented in the area that cultivates maize since the other areas are mainly for grass. This due to the rules and regulation in the Netherlands that most dairy farmers in our region, make use of 'derogation' (in dutch: derogatie) (Gerner, personal communication, 24 May 2022). It means that they can apply more manure of the cows to their fields (on sandy soils 230 kg N (nitrogen)/ha) than the European maximum standard (170 kg N/ha). The obligation is that they have at least 80% of their land in grassland and at most 20% arable land. In this case, 33% area in the Hupsel catchment belongs to arable crop. Corn is very productive and gives a good combination with grass for feeding and milking the cows, so that's the reason that most of the time corn is chosen as the arable crop Therefore, approximately 33% of the area belong to corn in the Hupsel catchment (as mentioned in 2.1) was implemented by the crop rotation practice. This is due to the rest of Hupsel catchment area (mainly grasslands) cannot be rotated with other crops since it needs to be grasslands based on the law and regulations. Furthermore, the rotation crop chosen for this study is further explored along by looking into the possible crop to be cultivated. The alternative crops to be chosen was closely discussed with water authority and experts who know the area as well to fit in the required climate and usefulness for the farmers in the area (Gerner, personal communication, 24 May 2022). Based on the discussion with the water authority, *tricitale* was chosen as the alternative crop for the rotation purpose. This crop was chosen due its suitability with the Netherlands' climate, can be used as animal feed, and there are some recorded observations of the specific crop yield in the Netherlands. The details of the management operations and schedules of this scenario is basically the same as in baseline scenario (Figure 7) but include the exact same operations in the second rotation year for *tricitale* cultivation.

3.2.4 Combined CA Scenario

Lastly, scenario 4 (all CA practices) was simulated by incorporating all of the management operations and schedules used in the scenario 1, 2, and 3 with also the respective variables settings as well, such as the manning value, curve number, and initial amount of residue. The details of all the management operations and scenario for scenario 1 to 4 can be seen in Appendix A Management Operations and Schedules of the CA Scenarios. After all scenarios and land treatment have been simulated, the output of those scenarios was assessed on the basin spatial scale and both monthly and annual temporal scale such as how impactful the individual CA practices are compared to each other and how impactful the combined CA practice is compared to the baseline scenario. The overall methodology of this section can be seen in Figure 10.

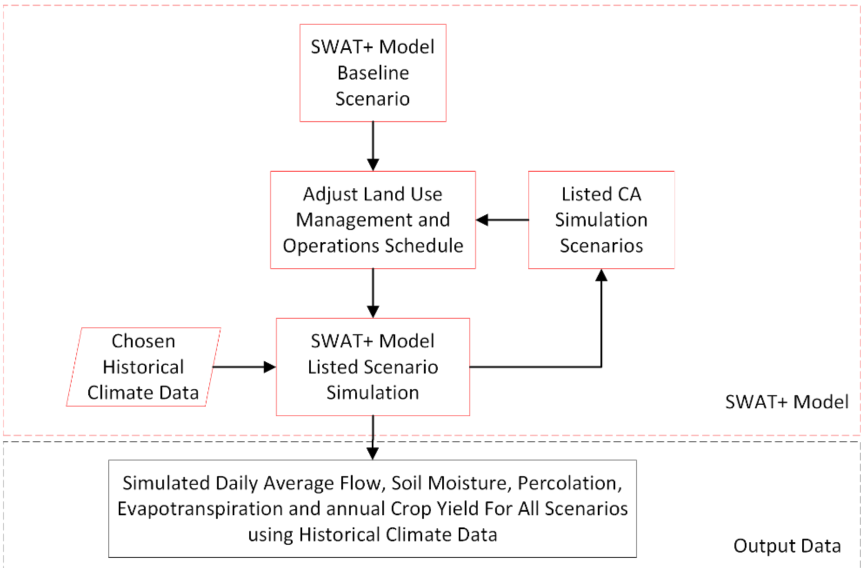

Figure 10. Methodology for modelling the impacts of CA using historical climate data

3.3 MODELLING THE IMPACTS OF CA PRACTICES USING PROJECTED CLIMATE DATA

In principle, similar steps as in the second research question are required for answering the third research question. However, the only different is using different input climate data as in the second research question. Instead of using historical climate data, the third research question used projected climate data as input for the modelling of conservation agriculture practices. In this study, the projected climate data are provided by the KNMI '14 climate change scenarios (Attema et al., 2014). The reason of choosing the KNMI '14 climate change scenarios was because it provides prediction of possible future climate change or condition specifically for the Netherlands instead of worldwide scale. Therefore, the KNMI '14 climate change scenario is preferred to be used instead of output from global climate models (GCMs) provided in the IPCC report since the climate change analysis is conducted in the

Netherlands. The KNMI ’14 scenario is the updated version of the older version (KNMI ’06) and it translates the IPCC 2013 report to the situation in the Netherlands.

The KNMI ’14 climate change scenarios is capable of predicting future climate condition in the Netherlands focusing on the climate condition of 2050 and 2085 (Attema et al., 2014). Furthermore, KNMI ’14 capable of providing several scenarios of possible climate conditions in the Netherlands based on two main factors influencing the climate change, which are global mean temperature increase and change in air circulation pattern. Since KNMI'14 scenarios are based on the various IPCC scenarios for future emissions of greenhouse gases and pollutants, global mean temperature is the main factor that distinguish the climate change scenarios in KNMI ’14. There are two classifications regarding the global mean temperature increase according to the KNMI ’14 scenarios, namely G (stands for *Gematigd*, Dutch for moderate) and W (stands for warm). On the other hand, the change in air circulation pattern is also considered to have a substantial influence on climate change according to KNMI ’14 and thus has been distinguished into two different classifications, which are L (stands for low) refers to the small influence of air circulation, H (stands for high) refers to the large influence of the air circulation. Westerly winds occur more frequently in the winter in the H situations. Compared to the L scenarios, this results in milder and more humid weather. In the H scenarios, high-pressure systems have a bigger impact on the weather during the summer. These high-pressure systems generate stronger easterly winds than the L scenarios, which suggests warmer and drier weather for the Netherlands.

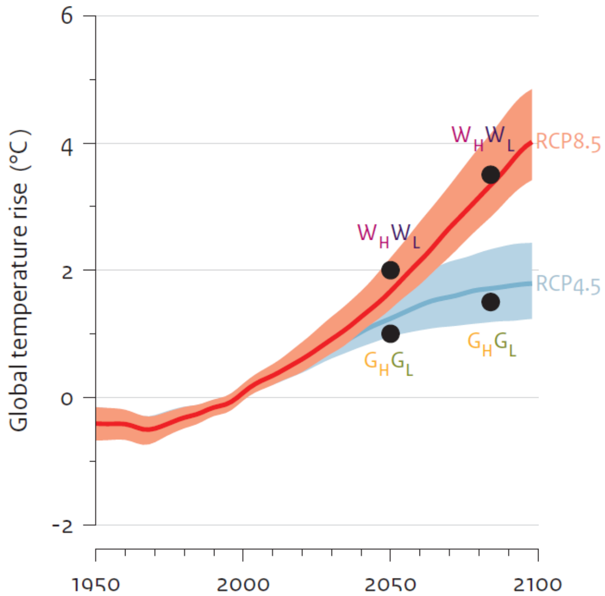

Figure 11. Comparison between KNMI '14 scenarios and IPCC 2013 emission scenarios
(Source: Attema et al., 2014)

In total, there are four different scenarios provided by KNMI ’14 that were derived from the main factors that have been explained previously, namely G_L, G_H, W_L, and W_H. It can be seen in Figure 11, how the four scenarios of KNMI ’14 are compared to the representative concentration pathway (RCP) in terms of global temperature rise. The W_L and W_H scenarios are following the RCP 8.5 pathway while G_L and G_H scenarios are corresponding with the RCP 4.5 pathway. Furthermore, each of the scenarios in KNMI ’14 are based on the reference condition of observed climate data in De Bilt measurement station from the period of 1981 to 2010 and then transformed to future prediction using 12 climate variables including solar radiation, temperature, and precipitation. In addition, 22 relevant indicators are also included for user application of the future predicted climate condition. Furthermore, the projected climate change condition of the various KNMI ’14 scenarios provide the change values of the climate condition in annual and seasonal scale. The projected climate conditions are also in a form of 30-year dataset (due to the reference period is also a 30-year dataset) that focused on the climate condition around 2050 and 2080. The projected climate condition in the Netherlands can be seen in Table 3. The climate variables included in Table 3 are the ones that are used for the input climate data of the SWAT+ model.

Table 3. KNMI'14 projected climate change for the Netherlands
Source: (Attema et al., 2014)

Season	Variable	Indicator	Climate 1981-2010 = reference period	Scenario change values for climate around 2050 (2036-2065)			
				G_L	G_H	W_L	W_H
Global temperature rise:				**+1 ˚C**	**+1 ˚C**	**+2 ˚C**	**+2 ˚C**
Change in air circulation pattern:				**Low value**	**High value**	**Low value**	**High value**
Year	Temperature	mean (˚C)	10.1	1	1.4	2	2.3
	Precipitation	mean amount (mm)	851	4%	2.50%	5.50%	5%
	Solar radiation	solar radiation (KJ/cm^2)	354	0.60%	1.60%	-0.80%	1.20%
Winter	Temperature	mean (˚C)	3.4	1.1	1.6	2.1	2.7
	Precipitation	mean amount (mm)	211	3%	8%	8%	17%
	Wind	mean wind speed (m/s)	6.9	-1.10%	0.50%	-2.50%	0.90%
Spring	Temperature	mean (˚C)	9.5	0.9	1.1	1.8	2.1
	Precipitation	mean amount (mm)	173	4.50%	2.30%	11%	9%
Summer	Temperature	mean (˚C)	17	1	1.4	1.7	2.3
	Precipitation	mean amount (mm)	224	1.20%	-8%	1.40%	-13%
	Humidity	relative humidity (%)	77	-0.6	-2	0.1	-2.5
Autumn	Temperature	mean (˚C)	10.6	1.1	1.3	2.2	2.3
	Precipitation	mean amount (mm)	245	7%	8%	3%	7.50%

There are several things that need to be considered in order to properly use the KNMI ’14 climate change projection in this study. Firstly, the climate data used as the reference period for the KNMI ’14 projection were observed in De Bilt measurement station. Secondly, the reference period of the climate data is 1981-2010 which needs to be considered as the other measurement station in the Netherlands might have different available recorded climate data. Therefore, both spatial variation (due to observed climate data of the reference period being measured in one station) and temporal variation (due to the availability of the recorded climate data) of the projected climate data needs to be addressed. In this case, the spatial variation of the reference period climate data can be neglected with the assumption that the change values will be the same all over the Netherlands. Thus, the same projected change values are also being used for the analysis in the Hupsel catchment. Furthermore, the temporal variation of the reference period climate is addressed through a scaling procedure relative to the available period of the climate data. By using later period than the reference period means that the climate change values will be less compared to the 1981-2010 as the reference period. In practical, the median of the reference period used by the KNMI, 1995, has a time difference of 55 years while the median of the available historical climate data (2001-2021) used in this study, 2011, has a time difference of 39 years toward the intended year of projection 2050. Thus, using the difference in the span of years, the change values for climate condition in 2050 relative to the climate data used for this study was scaled by multiplying with 0.71. Following the assumption and scaling procedure, the change values can then be used for generating series of the future climate condition (through implementing the change values to the historical climate data used in previous research question) in the study area and then became the input data for scenario simulations as mentioned in Table 2. In addition, the CO_2 fertilization effect due to the increased amount of CO_2 concentration in the future should be incorporated in the SWAT+ model by adjusting the concentration of CO_2 in the parameter within SWAT+ model (Neitsch et al., 2011). Since the KNMI'14 scenarios are comparable with the RCPs (Figure 11), the CO_2 concentration can be assumed to have similar values. According to van Vuuren et al., (2011), the concentration of RCP 8.5 and 4.5 are 550 and 450 ppm respectively, whereas those number are used to adjust the CO_2 concentration parameter in the SWAT model during the simulations under future climate data. The output from the scenario simulations are assessed and compared to each other on their respective impacts on hydrology and agricultural productivity indicators. The overall methodology of answering the third research question can be seen in Figure 12.

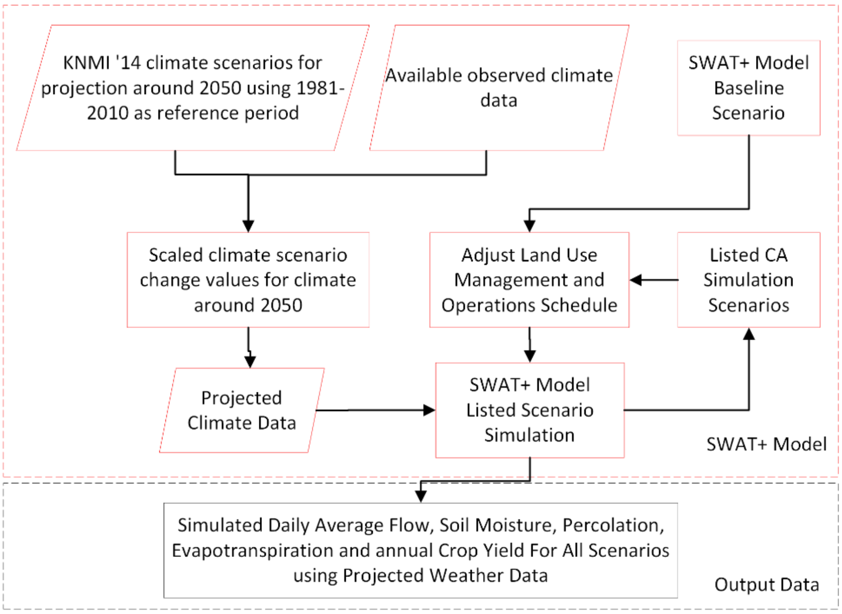

Figure 12. Methodology for modelling the impacts of CA using projected climate data

3.4 DATA

There are several data needed for this study includes both the preparation data in GIS environment and the input data for SWAT+ modelling. There are three main geospatial data needed in GIS environment. Firstly, the Digital Elevation Model (DEM) is obtained from the waterboard data portal (AHN, 2022). Secondly, land use map for the Netherlands is provided by the waterboard but with older version, which is the LGN 7 representing the land use of 2012 in the Netherlands (WRIJ, 2022). Thirdly, to identify the soil within the Hupsel catchment area, a soil map data is obtained from the BRO website that covers the latest version of soil map in the Netherlands (BRO, 2022). The DEM data is in the resolution of 5 m for further preparation and identification of the watershed characteristics in the GIS environment along with the streams data that can be burned in the DEM for more accurate watershed delineation process. Therefore, data related to watershed area of Hupsel catchment from the waterboard, then those data are to be prioritized to be used since it is way more accurate compared to the other open-source data. Furthermore, the input climate data for SWAT+ model of the study area are obtained from website of The Royal Netherlands Meteorological Institute (KNMI) by extracting the Hupsel meteorological station data. The climate data includes precipitation, temperature, wind speed, relative humidity, and sunlight radiation which spans from 1989 to 2021. Lastly, the observed data for calibration purpose used the observed daily flow data for Hupsel catchment provided by the waterboard (WRIJ, 2022). The observed flow data is measured using a type of H-flume at the catchment outlet which has been measured from 1976 which were used by other studies as well (Brauer et al., 2011, 2018; van der Velde et al., 2009). Thus, it can be seen in Table 4 for the summary of the required data in this master thesis along with the resolution, description, and source of the dataset being used in the modelling the impacts of CA by using SWAT+ model.

Table 4. Data used for CA impact modelling using SWAT+ model

Data	Resolution		Description	Source
	Spatial	Temporal		
DEM	5 m	2021	Elevation	(AHN, 2022)
Streams	Vector	2021	River streams in the area	(WRIJ, 2022)
Land use	25 m	2012	Land use classes	(WRIJ, 2022)
Soil data	1:50,000	2021	Soil properties	(BRO, 2022)
Climate data	1 station	Daily (1989-2021)	Precipitation, temperature, humidity, solar radiation, wind speed	(KNMI, 2022)
Observed flow	1 station	Daily (1976-2021)	River flow	(WRIJ, 2022)
Climate change projection	1 station	Annual and Seasonal (2050)	Climate change values of the projected period	(KNMI, 2022)

Before the dataset can be used for modelling using the SWAT+ model, several data need to be processed first. This due to several reasons such as the SWAT+ model use a specific format for its input data, specific databases are being used in the SWAT+ model, different coordinate reference system of the geospatial data, data format to be used in the GIS environment, availability, and completeness of the dataset. All the geospatial data that are being used as the input of SWAT+ model in the GIS environment should be using the same coordinate reference system. Therefore, all related data that has spatial reference were adjusted or converted into using the common projected coordinate reference system used in the Netherlands, in this case is the Amersfoort/RD New (EPSG:28992). This also includes the streams data obtained from the waterboard website. However, instead of only need to have the same projected coordinate reference system, the streams data also need to be converted into a polyline format since it was initially in a format file of polygon.

Databases that are being used by the SWAT+ model are various such as USGS LULC, NLCD 1992, and NLCD 2001/2006 for the land cover codes. On the other hand, the soil classification codes used by the SWAT+ model are also limited to the US STATSGO, US specific area soil properties, and FAO soil codes. Therefore, the given initial format of the obtained land use and soil map data needed to be adjusted so that they can have the same format accepted by the SWAT+ model. The land use data, namely the LGN7 data provided by the waterboard, has different codes compared to the SWAT+ database, and the descriptions are also in Dutch. Thus, the description of the land use cover in LGN7 needs to be translated and assign the corresponding land cover codes that are being used by the SWAT+ model database. In this way, the model will be able to read and determine the correct land use cover during the process of creating HRUs in the SWAT+ model. Similarly, the soil map obtained from the BRO web page needs to follow the same procedure but, in this case, since the database of soil properties used by the SWAT+ model is specifically for US soils, it needs to be replaced by a global soil database. In this study, the FAO soil database is used to replace the US soil database within the SWAT+ model. After that, the soil lookup file is created by matching the soil properties given by the Netherlands' soil map with the soil properties provided in the FAO database. Since the format of the soil map properties and the FAO database are different, only limited variables of soil characteristics can be matched with each other. For instance, only the sand, clay, silt, bulk density, and carbon content variables are being used for the matching purposes and identifying the type of the soil that will be used in creating HRUs in the SWAT+ model. Following the processing procedures, the land use and soil lookup file format that is being used in the SWAT+ model can be seen in Appendix B Land use and Soil Lookup Table.

4. RESULTS

4.1 BASELINE SCENARIO FOR MODELLING CA IMPACT

4.1.1 Sensitivity Analysis

SWAT+ model has to be calibrated in order to create a realistic representation of the study area. Prior to model calibration, a sensitivity analysis must be carried out to identify the parameters that have the greatest impact on the variable of interest in the watershed, such as hydrological fluxes and crop growth. Nearly 140 parameters from the SWAT+ model are available and included in the simulation, although not all of them are significant or have any bearing on the calibration procedure. As a result, by removing the parameters that were determined to be insensitive, sensitivity analysis aids in reducing the number of parameters in the calibration process.

Table 5 lists the parameters that the SWAT+ toolbox software's Sobol algorithm was used to assess, along with a brief description of each parameter. The SWAT+ model makes use of a wide range of factors to mimic multiple aspects of a single watershed, including agricultural growth, streamflow, sediment transport, and water quality. This research, however, focuses solely on the variables that affect how the Hupsel catchment's streamflow and crop growth are simulated. This is because only observed streamflow is accessible as the observed data that may be utilized for calibration. The variables listed in Table 5 are the ones that have the greatest impact on a watershed's hydrological fluxes out of all of them. Common sensitive parameters based on multiple papers were utilized as starting points for the sensitivity analysis of the model in order to assist in further narrowing down the parameters that may be included in it (Guo & Su, 2019; Khalid et al., 2016; Khatun et al., 2018; Marhaento et al., 2017; Nazari-Sharabian et al., 2020; Pulighe et al., 2021; X. Zhang et al., 2015).

Table 5. Results of the sensitivity analysis using the Sobol Method

Group	Name	Change type	1st Order Sensitivity	Description	Rank
hru	cn2	percent	0.73567	Initial SCS runoff CN for moisture condition II	1
rte	bd	percent	0.50751	Channel bulk density (g/cm3)	2
sol	awc	percent	0.22011	Available water capacity of the soil layer (mmH2O/mm soil)	3
sol	bd	percent	0.16839	Soil bulk density (g/cm3)	4
hru	perco	percent	0.10321	Percolation coefficient	5
sol	z	percent	0.03813	Depth from soil surface to bottom of layer (mm)	6
aqu	alpha	replace	0.01325	Baseflow alpha factor (1/days)	7
sol	k	percent	0.01045	Saturated hydraulic conductivity (mm/hr)	8
hru	snomelt_lag	percent	0.00819	Snowmelt lag coefficient	9
hru	canmx	relative	0.00499	Maximum canopy storage (mm)	10
hru	cn3_swf	percent	0.00039	Pothole evaporation coefficient	11
hru	esco	replace	0.00008	Soil evaporation compensation factor	12
aqu	revap_co	replace	0.00003	Groundwater "revap" coefficient	13
hru	slope	percent	-0.00031	Average slope steepness in HRU	14

hru	snomelt_max	replace	-0.00076	Maximum snowmelt temperature (˚C)	15
hru	snofall_tmp	replace	-0.00163	Snowfall temperature (˚C)	16
hru	epco	percent	-0.00251	Plant uptake compensation factor	17
hru	snomelt_tmp	replace	-0.01163	Snowmelt base temperature (˚C)	18
hru	snomelt_min	replace	-0.02598	Minimum snowmelt temperature (˚C)	19
hru	petco	percent	-0.67753	Potential evapotranspiration coefficient	20

The sensitivity study included a total of 20 parameters, including parameters from the HRU, Routing, Soil, and Aquifer groups. Additionally, the Sobol technique was used to create about 1000 iterations for the sensitivity analysis. With this many iterations, it is clear that the most sensitive parameter for this model is CN2, also known as the curve number. Since CN2 influences the flow in the catchment region, its sensitivity was the highest as predicted. For instance, a high CN value results in greater surface runoff and less infiltration. The second-most sensitive parameter, bulk density, which has a significant influence on the soil's properties and structure and may, in turn, have an impact on damping depth, soil water content, and water infiltration. The soil water storage between soil moisture levels at field capacity and the permanent wilting point is controlled by the soil layer's available water capacity. The percentage of percolation from the root zone that flows to the saturated zone is then determined by the percolation coefficient. The other parameters had an influence on the calibration procedure even if they weren't as sensitive as the ones that have been described. A more sensitive parameter is represented by a greater value of first-order sensitivity. Thus, the results of the sensitivity analysis were then used to calibrate the SWAT+ model by including all of the 20 parameters in it.

4.1.2 Calibration and Validation

As a consequence of the sensitivity analysis, 20 SWAT+ parameters were calibrated in accordance with the lists in Table 6. Different techniques were used to adapt these variables. According to Table 6, there were three different change types for the calibration process, namely percent, relative, and replace. Percent change refers to calibrating the parameter by increasing or decreasing the value by a certain percentage determined by the users. This way, different values of parameters representing HRUs were changed relative to its initial value. Relative type of change administers an exact value to be added or subtracted to the initial value of the parameter. Lastly, the replace change type basically replace the initial value of the parameter into a specified value determined by the user. However, it needs to be considered whether a parameter could be changed by using replace type or not since it basically a change type that changes the values of a certain parameter in every single HRU into the value determined. Therefore, a parameter such as CN2 should not be changed by using replace type since it carries spatial variations in the catchment area. Therefore, all of the change type implemented for each of the parameters (Table 6) have already been given appropriate change type to avoid losing any spatial variations during the simulation process.

Table 6. Best values of the calibrated parameters

Group	Name	Change type	Best Value
hru	cn2	percent	-8.701
rte	bd	percent	-5.295
sol	awc	percent	-18.322
sol	bd	percent	25.535
hru	perco	percent	79.216
sol	z	percent	-5.479

aqu	alpha	replace	0.918
sol	k	percent	57.230
hru	snomelt_lag	percent	27.437
hru	canmx	relative	-0.703
hru	cn3_swf	percent	-28.060
hru	esco	replace	0.007
aqu	revap_co	replace	0.049
hru	slope	percent	33.538
hru	snomelt_max	replace	3.258
hru	snofall_tmp	replace	-0.013
hru	epco	percent	-39.904
hru	snomelt_tmp	replace	3.845
hru	snomelt_min	replace	5.833
hru	petco	percent	-24.192

Using historical climate data from the years 2011 to 2021 as input, the baseline scenario for this study was calibrated. The calibration time was selected for two major reasons. First off, there are no missing data for any part of the recorded time in the observed flow in this period. In this way, the calibration period may be completed with as little as the necessary number of observed flows, negating the need for any imputation or filling in of missing values. Secondly, the specific period was chosen due to the obtained land use data was also dated from the condition of the Hupsel catchment in 2012. On the other hand, the validation process was using the data from the period of 2001 to 2010 by using only the available observed data without any interpolation or filling method for replacing the missing values. In addition, 5 years of the historical climate data (1994-1998) were used as the warm-up period for the SWAT+ simulation. Based on 3000 iterations (for calibration), the result of both calibration and validation processes can be seen in Figure 13, with an outlier of 3.3 m^3/s (observed) and 2.9 m^3/s (simulated) on the 26th August 2010. Furthermore, the performance of the model in both calibration and validation periods based on several statistical metrics can be seen in Table 7.

Table 7. The baseline scenario model performance based on several statistical metrics

Objective Functions	**Calibration (2011-2021)**	**Validation (2001-2010)**
NSE	0.653	0.692
MSE	0.002	0.003
RMSE	0.048	0.057
PBIAS	-2.97%	-9.61%
r	0.810	0.835
R^2	0.656	0.697
RSR	0.589	0.534

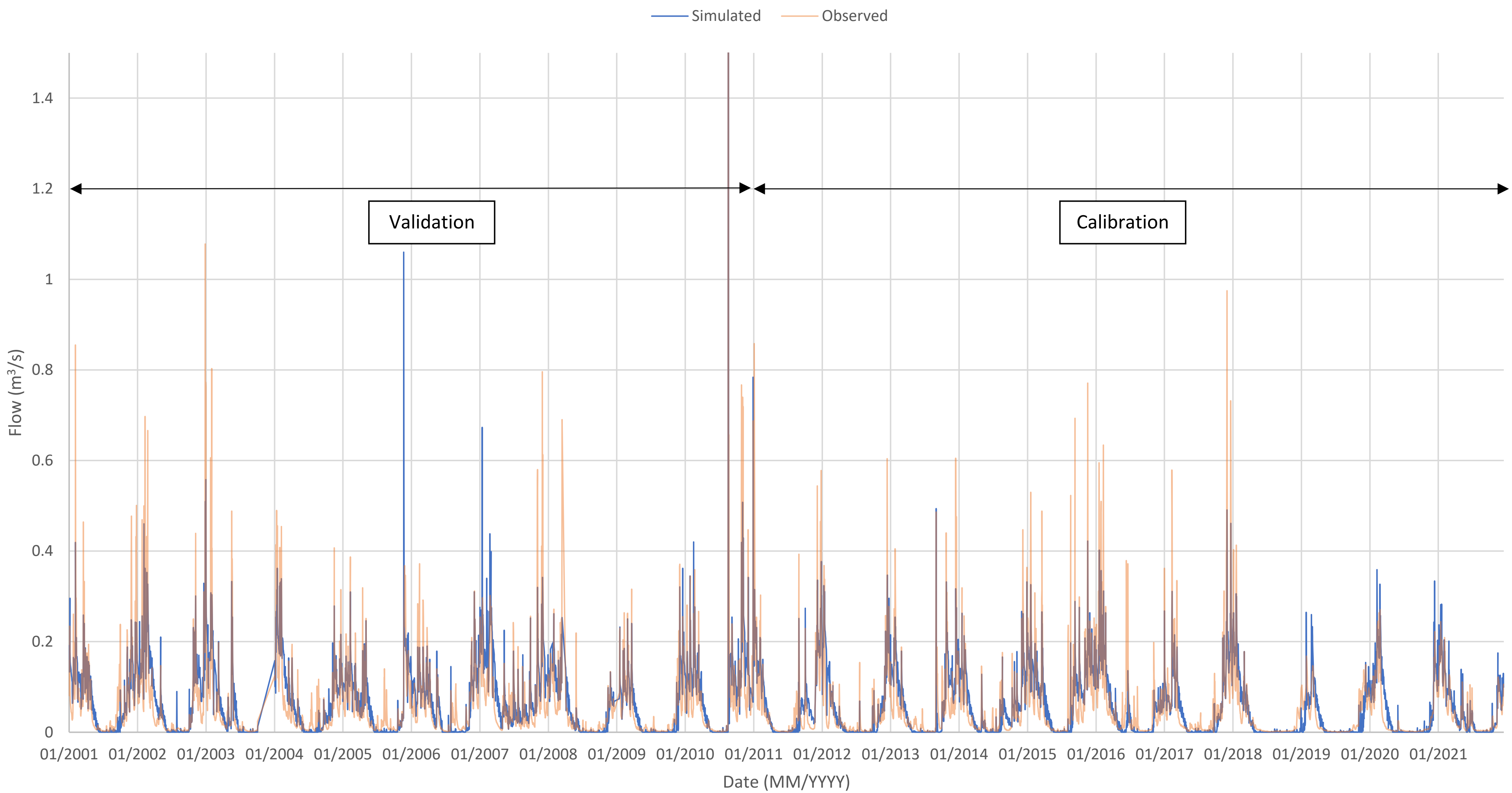

Figure 13. Comparison between simulated and observed flow in the calibration (2011-2021) and validation (2001-2010) period

According to Table 7, there are 7 statistical metrics used for assessing the model performance in both calibration and validation processes. However, this study focused on three main objective functions, which are NSE, RSR, and PBIAS. Following the recommendation by D. N. Moriasi et al. (2007), the model performance in both calibration and validation process can be considered as good performance from the perspective of NSE ($0.65<NSE<0.75$) and RSR ($0.5<RSR<0.6$). Furthermore, PBIAS values in both calibration and validation were even considered as very good performance ($PBIAS<\pm10\%$). Despite the good and very good performance of the statistical metrics according to a reference paper (quantitative analysis), the model should also be assessed from the qualitative perspective to prevent misleading performance. For instance, a PBIAS value closer to 0% quantitatively has a near-perfect comparison between simulated and observed values while it can also because there are a lot of overestimations that have been compensated with a lot of underestimations from the simulated model. Thus, both calibration and validation were analyzed qualitatively as well based on the comparison between the simulated and observed flow in Figure 13.

In the calibration period, it can be seen that the model has simulated the flow by following the pattern of the observed flow in the Hupsel catchment. During the winter season, the model produced high flows and have the same order of magnitude as the observed flow. Furthermore, the simulated flow cannot fully capture the peak flows and tends to underestimate them. In contrary, the model performed really well during the summer period by producing similar flows as the observed ones and follow its pattern as well. Apart from the model performance in seasonal variability, the model simulated longer recession during the transition from winter to summer period compared to the observed value that have faster recession period. This can clearly be seen in Figure 13 especially the seasonal transition in 2019 and 2020. As for the validation period, the model behaved similarly to the calibration period by capturing the seasonal variations while also still underestimating the peak flows. The difference in recession period can also be noticed here but not as clear as in the calibration period. Nevertheless, the model performed quite well by capturing the main pattern of the observed model and thus can also be considered acceptable in terms of its model performance qualitatively.

4.1.3 Agricultural Output

The output of the agricultural part based on the calibrated and validated model can be seen in Figure 14. Since this study only focused on both corn and grassland land use, the agricultural output from other land uses was not included in the analysis. The average crop yield for the corn land use ranged between 6 to 8.5 tons per hectare and for grassland was around 1.5 to 2.3 tons per hectare. Based on the recorded crop yield of corn in the Netherlands by CBS, it has an average of 10 tons per hectare. However, even though the simulated crop yield has the same order of magnitude as the observed yield, there is indeed still a quite significant difference between each other. This is due to the crop yield that was simulated by the SWAT+ model was the dry weight of the crop yield while the recorded crop yield data was the fresh weight or the weight right after the crop has been harvested. A paper by Mialyk et al., (2022) gives conversion coefficient (0.87) that can be used to translate the fresh weight into dry weight matter for corn, which means that the actual average of the recorded corn yield in the Netherlands was 8.7 tonne dry matter per hectare annually. This indicates that the simulated corn yield was similar with the actual recorded yield in the Netherlands. Furthermore, the annual average of the grass yield in the Netherlands was observed to be around 4 tons per hectare of fresh weight (FAOSTAT, 2022). Then, the fresh weight of the grass yield was converted into the dry matter weight by multiplying the fresh weight with 0.25 since the fresh yield has around 75% of moisture content and it needs to be around 15% to be considered as a dry matter weight (Undersander & Saxe, 2022). Thus, the actual annual average of grass yield in the Netherlands was observed to be around 1 tons dry matter per hectare. Based on the comparison between simulated and available observed crop yield data of both corn and grass, it can be seen that both crops have simulated crop yield that are close to the observed amounts in the Netherlands.

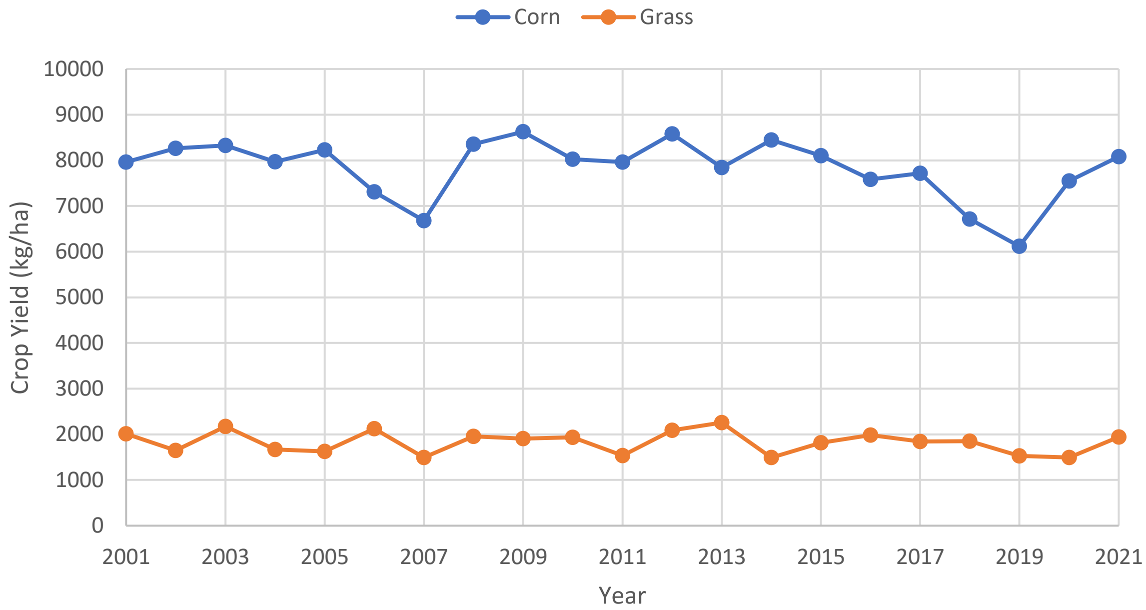

Figure 14. Annual crop yield in the Hupsel catchment

Despite the good accuracy of simulating the crop yield, there are two factors that could affect the differences in simulating the crop yield. Firstly, the harvest index could be the main factor of the difference in observed and simulation of the crop yield. Higher harvest index represents higher crop yield which depends on the cultivar of the crop itself. Knowing the advancement of agriculture technology in the Netherlands there is a possibility that crops cultivated here has been in a sort of breeding process that has a high harvest index. This way, the harvest index of crop provided in the SWAT database is lower than the actual harvest index of corn in the Netherlands and thus would lead to a lower simulated yield. Secondly, the harvest efficiency of the actual farmers in the field could also be different with the simulated crop yield since different machinery used for harvesting the crops would also lead to different harvest efficiency. Regardless, the main interest of this study is to see the relative impact of CA practices whereas getting the absolute exact amount of observed crop yield was less important. Thus, the calibrated and validated SWAT+ model for baseline scenario can be used for further CA analysis from the agricultural output part.

4.2 IMPACTS OF CA PRACTICES IN HISTORICAL CLIMATE

In this section, the result of different scenarios of CA practices are given based on the SWAT+ model simulations using the historical climate data. The SWAT+ model has simulated the scenarios for 21 years starting from 1st January 2001 and ending on 31st December 2021. Impacts of CA practices on hydrology will be given in section 4.2.1 followed by the result of CA practices' impacts on crop yield in section 4.2.2. Furthermore, no tillage and mulching practices were implemented to approximately 90% of the catchment area since it was applied to both grasslands (60% of the area) and corn (30% of the area). On the other hand, since grassland cannot be implemented by the crop rotation, only 30% of the catchment area was implemented with crop rotation practice.

4.2.1 Hydrological Fluxes

In Table 8, the values of different annual average hydrological fluxes in the baseline scenario are presented along with the relative changes of various scenarios representing the CA practices. The table provides the soil evaporation and plant transpiration individually instead of as one flux, namely the actual evapotranspiration. This way, the different CA practices can be assessed separately. Furthermore, the percolation given in Table 8 refers to the amount of water that percolates from the unsaturared zone (soil profile) to the saturated zone (unconfined aquifer). In terms of assessing the CA practices impact on hydrology, looking at the amount of water infiltrating into the soil (infiltration) would have given more evidence on the effect of whether the practices can help the plants during the drought condition or not. However, the amount of water infiltrated into the soil profile cannot be directly modelled by the current method chosen in the SWAT+. Seepage refers to the amount of water from unconfined aquifer that percolates to the deep aquifer (confined aquifer) while revap or capillary rise refers to the water from unconfined aquifer that percolates upwards to the soil profile which mainly become the water for plant uptake or evaporation. Therefore, along with storage in the water system, namely soil water content, the indication of whether there is more water being used by the plants or loss from the water system can be seen. In addition, the amount of the soil water content presented in Table 8 refers to the average water content in the soil profile. In Table 8, NT refers to no tillage, M is mulching, CR is crop rotation, and CA is the combination of conservation agriculture practices.

Table 8. Annual average of hydrological fluxes and storage with the relative change in different scenarios

Annual Hydrological Fluxes	**Baseline Scenario (mm)**	**Relative Change (%)**			
		Scenario 1 (NT)	**Scenario 2 (M)**	**Scenario 3 (CR)**	**Scenario 4 (CA)**
Precipitation	750	-	-	-	-
Surface Runoff	34	-12%	-3%	3%	-11%
Lateral Flow	0	3%	0%	0%	4%
Percolation	269	1%	-1%	3%	3%
Transpiration	192	-2%	8%	-10%	0%
Soil Evaporation	231	1%	-6%	4%	-3%
Baseflow	215	1%	-1%	4%	3%
Revap	38	0%	0%	0%	0%
Seepage	13	1%	-1%	3%	3%
Annual Storage					
Soil Water	153	0%	0%	1%	1%

It can be seen in Table 8, scenario 2 (mulching) and scenario 3 (crop rotation) have the higher impact on the hydrological fluxes in general while both scenario 1 (no-tillage) and scenario 4 (All CA) can be considered to have almost no effect on hydrological fluxes except the surface runoff. This result was according to the expectation since mulching practice incorporate residue and thus have higher organic matter that leads to increase the roughness. In addition, considerably high effects on the surface runoff in scenario 1 and 4 was due to actual curve number being reduced as part of the modeling for tillage operation. Despite the relative change on the surface runoff was higher than the other fluxes, the actual runoff that was being reduced was around 6 mm annually and considered to be minimum to have any effects on the other fluxes. However, the surface runoff relative change also gives the implication of how much water being infiltrated into the soil with negative relative change of surface runoff means that more water is being infiltrated. Surprisingly, scenario 4 (All CA) expected to have had similar impact as scenario 2 as it also has mulching practice being implemented as well. The reason that scenario 4 (All CA) have less impact compared to scenario 2 was influenced by the effect of the crop rotation (scenario 3) practice, which was observed to have the opposite relative change compared to scenario 2 (mulching). Thus, the impact on hydrological fluxes provided by the mulching practice was being compensated due to the crop rotation practice in scenario 4 (All CA).

Scenario 2 (mulching) observed to have effects on reducing the amount of surface runoff, percolation, baseflow, seepage, and soil evaporation with the latter having the highest reduction though the effects were observed to be low. Furthermore, there is barely any change of soil water content. Instead of increasing the soil water content, the amount of water that have been reduced (see Table 8) by mulching practice was allocated to be used by the plants hence increase the amount of transpiration. This implies that the mulching practice allows the plants to have more available water especially by reducing the soil evaporation. Compared to the other scenarios, mulching practice provides cover to the soil and prevent increase of soil temperature which lower evaporation. The decrease in percolation caused by more water uptake by the plants and thus reduced the flux from the unsaturated zone to the saturated zone. Due to the decrease in percolation, other hydrological fluxes that depends on percolation, such as baseflow and seepage, were observed to be decreased as well. Lastly, there is observed to be no change in the capillary rise or the revap flux. There are several reasons of no change in capillary rise or revap. Two of the reasons are because there is no change in periods when the material overlying the aquifer is dry and the depth of the plants root are not deep enough to uptake water directly from the aquifer under saturated conditions.

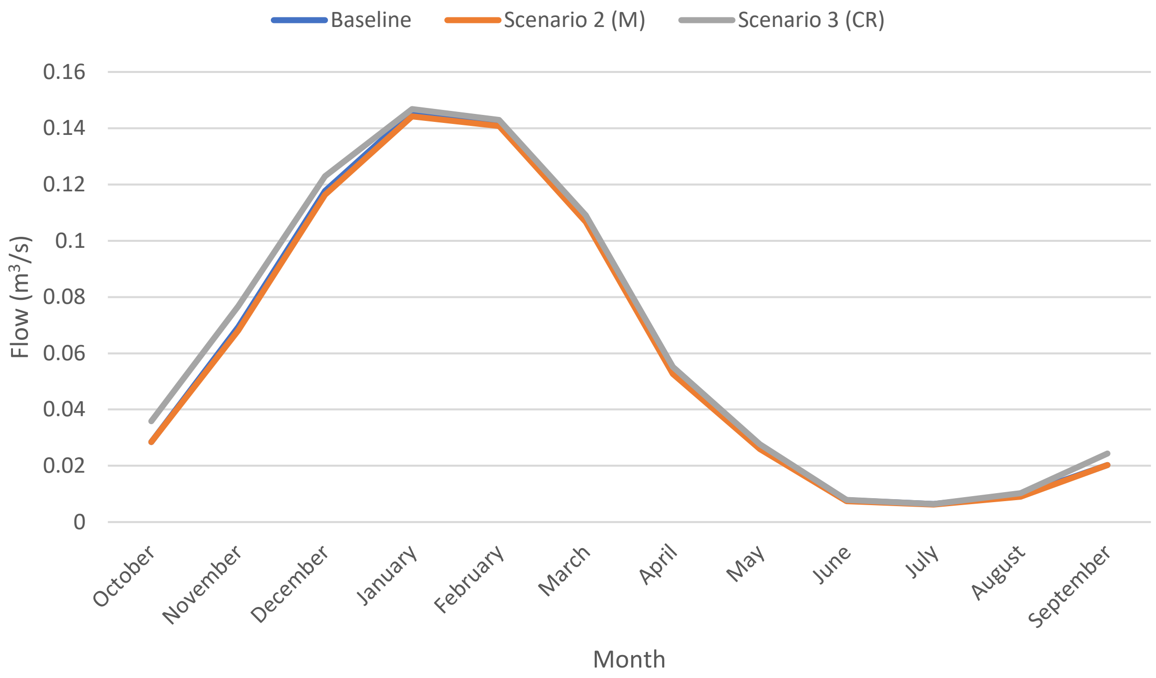

Figure 15. Monthly average streamflow of different scenarios in Hupsel catchment

Figure 15 shows the monthly average of streamflow for baseline, scenario 2 (mulching), and scenario 3 (crop rotation) since these scenarios observed to have more relative change compared to the other scenarios. The figure provides the result based on the Netherlands' hydrological cycle which starts from October to September. This way the seasonal variations of the streamflow can be clearly seen which differentiate between the winter and summer season. According to Figure 15, the difference between scenarios can hardly be seen due to the small relative change as mentioned in Table 8. Despite the small impacts of the practices, the increase of streamflow in scenario 3 (crop rotation) can still be noticed especially during the winter season. On the other hand, almost no difference can be identified during the summer season. Similarly, scenario 2 (mulching) impacts can hardly be identified even in both seasons.

As for the other hydrological fluxes, the impacts of the scenarios are compared by looking at the monthly average similar as the streamflow. Only the focused hydrological fluxes in this study, namely surface runoff, percolation, plant transpiration, soil evaporation, and soil water content (storage), that were being assessed and only both scenario 2 (mulching) and 3 (crop rotation) were compared to the baseline scenario. The figures of comparison for different scenarios on the fluxes and storage can be seen in Appendix C Monthly Average Hydrological Fluxes of Mulching and Crop Rotation Under Historical Climate Condition. In general, the impacts of the different scenarios can be hardly seen in the fluxes and storage. However, only both soil evaporation and plant transpiration impacts can be clearly seen. According to the figures in Appendix C, the increase of plant transpiration was observed in all months except from May and June with the highest increase was seen in March. Similarly, the decrease of soil evaporation is present as well in all months except May and June. Furthermore, smaller impacts of reducing the soil evaporation was observed during the winter season following the drop of temperature. On the other hand, the impact of reducing the soil evaporation was observed to be increase approaching the summer season and has the biggest impact on August.

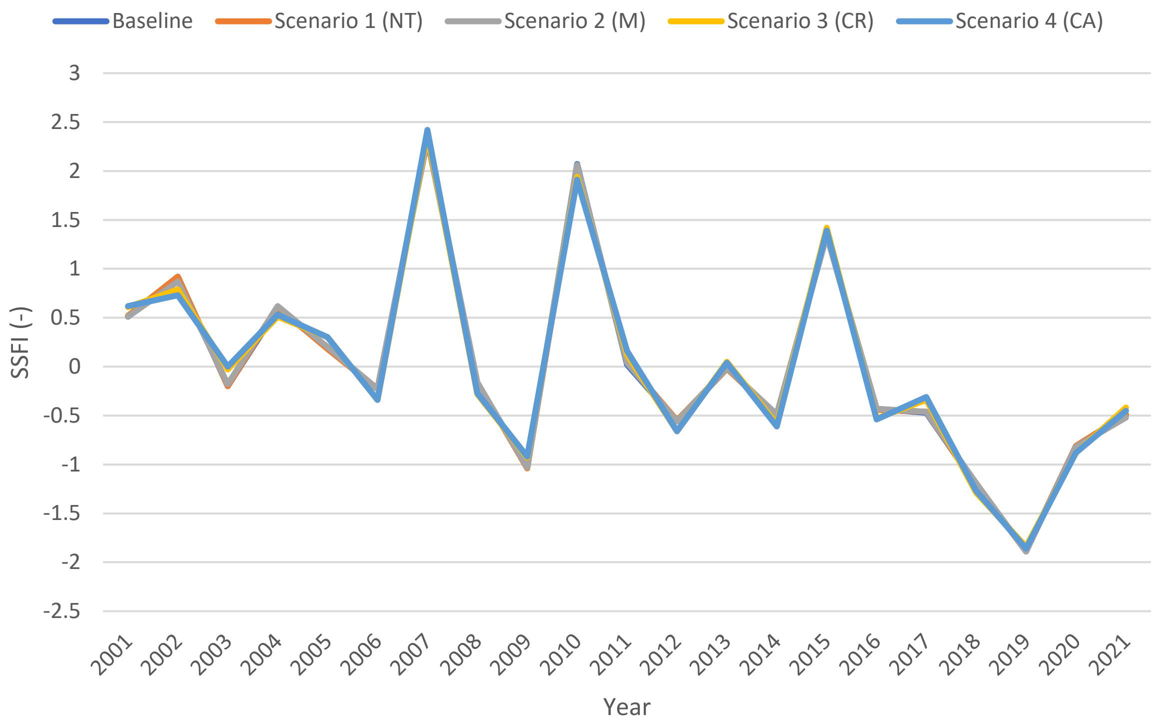

Figure 16. SSFI values of different scenarios in Hupsel catchment

To see the indication whether CA practices effects are positive or negative toward the hydrological drought, the SSFI values for each year of the simulation are used (Figure 16). It can be seen that in general the CA practices have small effects toward hydrological drought since there are minimum difference between the lines that can be observed visually. However according to the numbers, only scenario 2 (mulching) that quantitatively reduce the hydrological drought severity by increasing the value of SSFI around 0.02 relative to the baseline scenario throughout the years. On the other hand, both scenario 3 (crop rotation) and scenario 4 (all CA) are in general decreased the SSFI values by 0.01 and 0.02 respectively. Thus, scenario 2 (mulching) have the highest positive effect toward reducing the hydrological drought severity compared to the other practices.

The different CA practices was also observed on their respective impacts under different climate conditions throughout the historical climate data used in the simulations. Figure 6 provides the wet-dry conditions of the historical climate data based on the SPEI index that was used for further addressing the impacts of CA practices in wet, normal, and dry years. The values of the relative change for different scenarios can be seen in Table 9 which covers the average of the whole historical climate data used (2001-2021), a wet year represented by the 2002, a normal year represented by the year that has the closest SPEI index value to 0 (2008), and a dry year represented by the year of 2018 that is considered as extreme drought according to the SPEI index. The year of 2002 was chosen instead of 2007 due to this year was growing triticale.

Table 9. The relative change of different CA scenarios compared to baseline scenario on hydrological fluxes and storage according to wet-dry periods

Period	Hydrological Fluxes and Storage (mm)	Relative Change (%)			
		Scenario 1 (NT)	Scenario 2 (M)	Scenario 3 (CR)	Scenario 4 (CA)
Wet	Surface Runoff	-8%	-5%	0%	-12%
	Percolation	0%	-2%	0%	-1%
	Soil Evaporation	1%	-8%	0%	-8%
	Plant Transpiration	-2%	13%	0%	14%
	Soil Water	0%	-1%	1%	1%
Normal	Surface Runoff	-7%	-1%	0%	-8%
	Percolation	1%	-1%	0%	-1%
	Soil Evaporation	1%	-3%	0%	-3%
	Plant Transpiration	-2%	5%	0%	6%
	Soil Water	0%	-1%	0%	-1%
Dry	Surface Runoff	-8%	0%	1%	-6%
	Percolation	0%	-2%	1%	-1%
	Soil Evaporation	1%	-9%	0%	-9%
	Plant Transpiration	-1%	10%	0%	11%
	Soil Water	0%	-1%	0%	-1%

According to Table 9, scenario 2 (mulching) has the most impact in general on the different wet and dry periods. The highest impact of scenario 2 (mulching) was observed during the wet period. For instance, it has higher relative change in the surface runoff, soil evaporation, and plant transpiration compared to the other periods. Scenario 3 (crop rotation) observed to have barely any change. Scenario 4 (All CA) was observed to have similar impact toward the hydrological fluxes by having slightly higher increase of plant transpiration in dry and normal year compared to scenario 2 (mulching). Scenario 4 (All CA) observed to have different direction of relative change compared to scenario 2 (mulching). This result could have been influenced by the impact of crop rotation that affect the response of the scenario 4 (All CA) toward the soil evaporation and plant transpiration.

Figure 17 and Figure 18 show the monthly streamflow of both scenario 2 (mulching) and scenario 3 (crop rotation) during the wet and dry period respectively. According to Figure 17, the difference can be hardly seen for both scenarios except the increase of streamflow around September for scenario 3 (crop rotation). This is due to the triticale that was being grown in the year (2007) provided lower amount of residue (from its biomass) on the soil surface compared to corn hence resulted in increase of streamflow. On the other hand, during the dry period, the impacts of both scenarios can hardly be seen and clearly have no impacts on the low streamflow observed from May to December (Figure 18). In general, both during wet and dry period, there is no intra-annual impacts observed.

Similarly, the effects of scenario 2 (mulching) and scenario 3 (crop rotation) are compared by looking at the focused monthly hydrological fluxes and storage in both wet and dry periods. The figures of different scenarios effects during wet and dry period can be seen in Appendix D Monthly Hydrological Fluxes of Mulching and Crop Rotation Under Historical Wet-Dry Climate Conditions. The mulching practice observed to have higher reduction in soil evaporation from January to May during both wet and dry period and August only during the wet period. Furthermore, mulching also observed to have higher impact on increasing plant transpiration from January to May and August to October during wet year, while during dry period, the impacts only observed from January to May. The mulching practices performs better during the wet period due to the mulch itself able to store water moisture which eventually could be used by the plants. In addition, the mulch also helps to entrap more water and make more water available for plant uptake. The reduction in soil evaporation from January to May in both wet and dry periods is because high amount of residue on the soil surface that provided cover for the soil compared to later months where the residues have been degraded completely and disappear from the soil surface. Therefore, the mulching practice can be concluded as the most impactful practice on hydrological fluxes compared to the other practices and has the highest impact during wet period and the first months of the year.

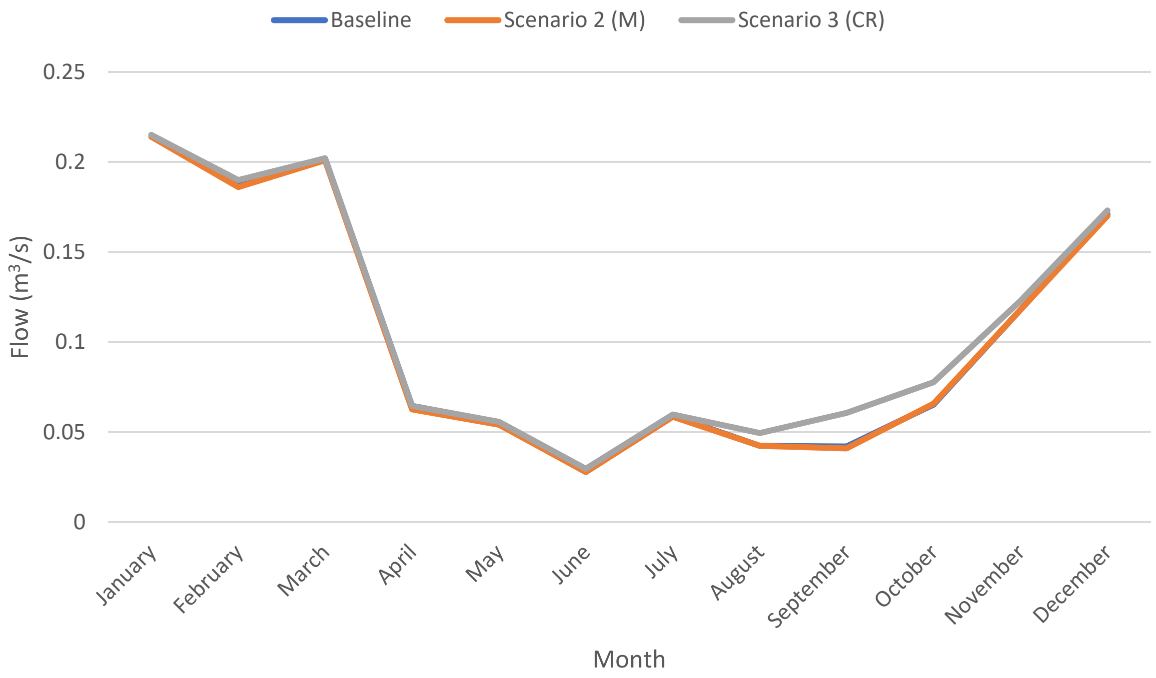

Figure 17. Monthly streamflow of different scenarios during wet year conditions

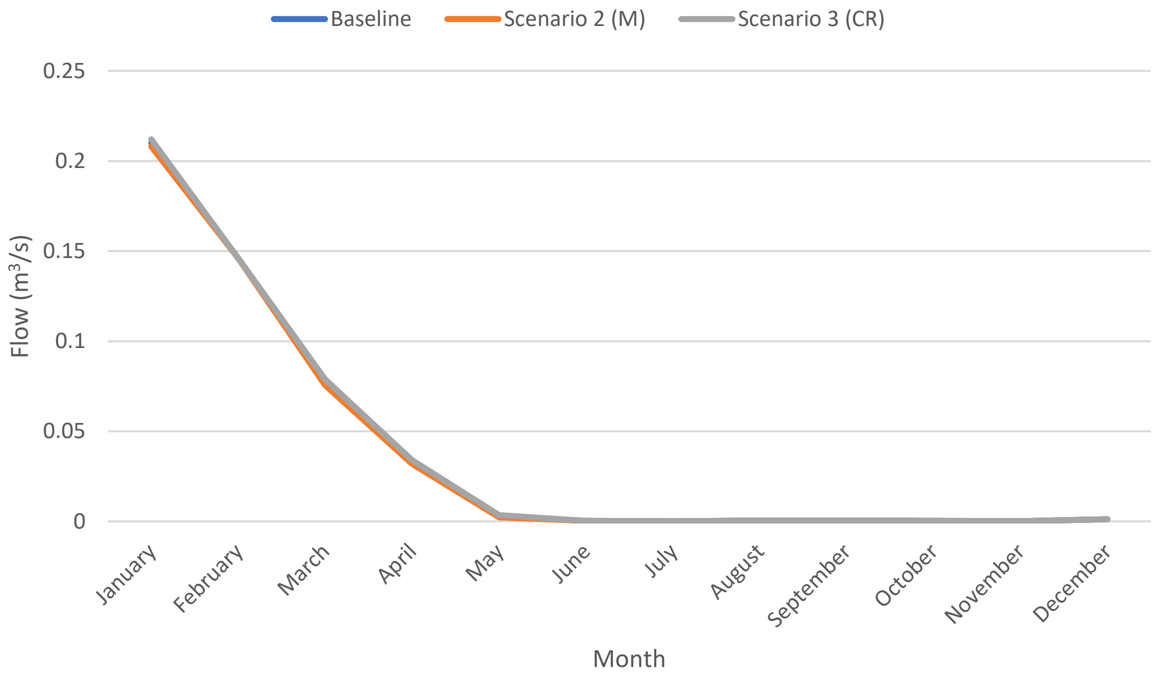

Figure 18. Monthly streamflow of different scenarios during dry year conditions

4.2.2 Crop Yield

Figure 19 and Figure 20 show the simulated agricultural output for various scenarios related to the different CA practices being implemented. Both figures represent corn and grass respectively as the annual average crop yield in the Hupsel catchment. However, Figure 19 shows both scenario 3 (crop rotation) and 4 (all CA) have lower crop yield in the odd years due to the crop being grown in those years was triticale instead of corn.

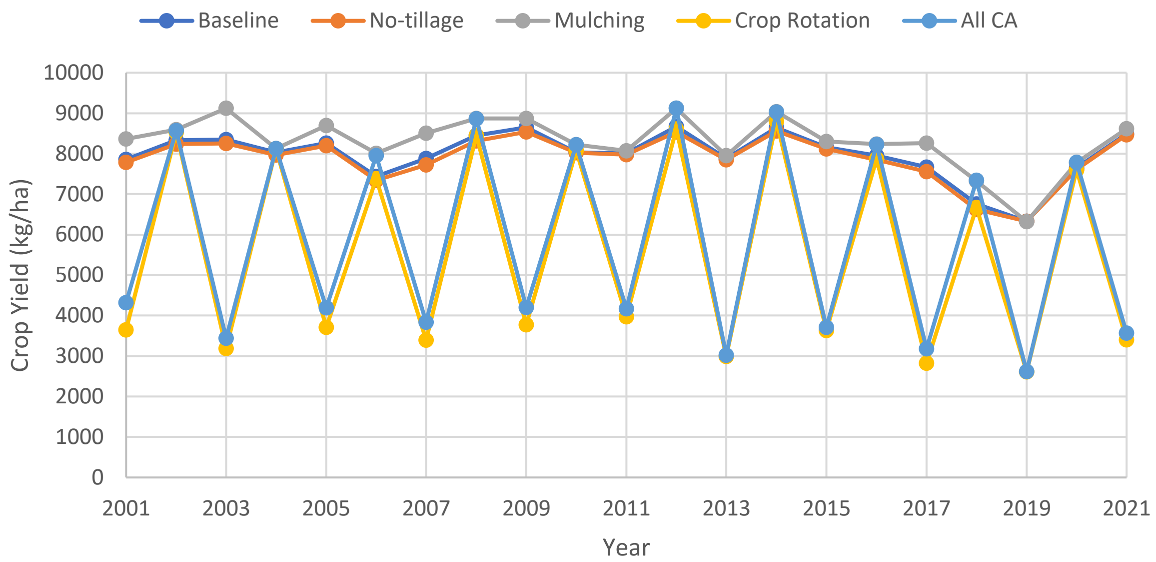

Figure 19. Annual average corn (even years) and triticale (odd years) yield in the Hupsel catchment

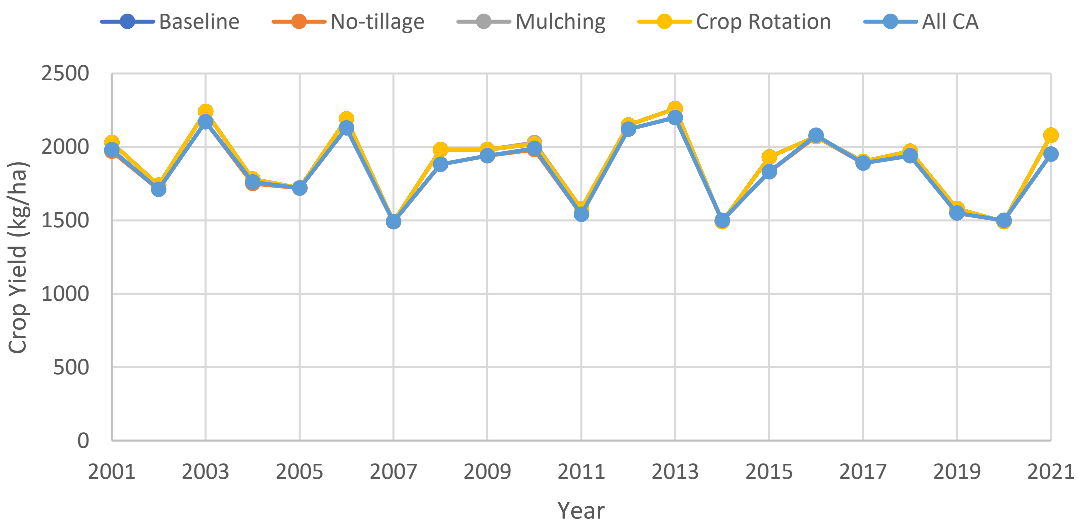

Figure 20. Annual average grass yield in the Hupsel catchment

According to Figure 19, it can be clearly seen that both scenario 2 and 4 (neglecting the triticale yield) that includes mulching practices have a higher crop yield along the simulation period compared to the other scenarios. In general, the implementation of CA practices was considered to have a positive impact toward increasing the crop yield. However, from the perspective of corn landuse, the implementation of no-tillage (scenario 1) practice was simulated to have a negative impact by lowering the crop yield though the impact was very small. This implies that the corn yield will be affected with respect to the distribution of nutrient along the soil profile. In this case, the baseline scenario has distributed the nutrients in the soil profile evenly which helps the plant nutrient uptake. On the other hand, no tillage practice was basically making the nutrients and residue to be the highest around the top profile of the soil which provides slower accessibility for the plant roots to perform its nutrient uptake. Furthermore, the crop rotation with triticale (scenario 3) observed to almost have no impact on the corn yield. Thus, mulching practice was observed to have the highest impact on the corn yield during the implementation of all CA practices in the corn landuse depicted by both scenario 2 (mulching) and scenario 4 (All CA) in Figure 19.

From the perspective of grasslands, it can be seen that there are, in general, only two lines representing the crop yield (Figure 20) with the highest crop yield represented by scenario 2 (mulching). The baseline scenario and scenario 2 (mulching) produced similar results while both scenario 1 and scenario 4 also observed to have the same case but lower. This implies that tillage operation has more impact in terms of increasing the crop yield compared to the other practices in the perspective of grasslands. Both scenario 1 (no-tillage) and scenario 4 (All CA) was observed to have a lower crop yield compared to the baseline scenario and scenario 2 (mulching) since the scenarios 1 (no-tillage) and 4 (all CA) were implemented by the no-tillage practice. The scenarios with no-tillage practice have a crop yield of around 2% less relative to the scenarios with conventional tillage practice. Therefore, tillage practice was observed to barely have any effect on the grasslands yield.

Furthermore, the effects of CA practices are being assessed by looking at the crop water ratio as an indication to see whether the practices have positive or negative impacts toward the agricultural drought. Figure 21 provides the total daily water stress ratio in Hupsel catchment due to the SWAT model calculates water stress ratio in a daily basis during the crop growth period. According to Figure 21, the CA practices are in general have small effect toward the agricultural drought severity represented by the lines that visually have the same pattern. However, there are several distinctive differences that can be seen during the period of 2003 and 2019. During these years, both scenario 3 (crop rotation) and scenario 4 (all CA) reduced the total water stress ratio quite significant compared to the other years especially 2019 since this year is considered as dry year. To be precise, both scenarios reduce the total water stress ratio by approximately 0.4 each year while the other practices have barely any effect in general. Therefore, only scenario 3 (crop rotation) and scenario 4 (all CA) that considered to have positive impacts toward reducing the agricultural drought severity based on water stress ratio.

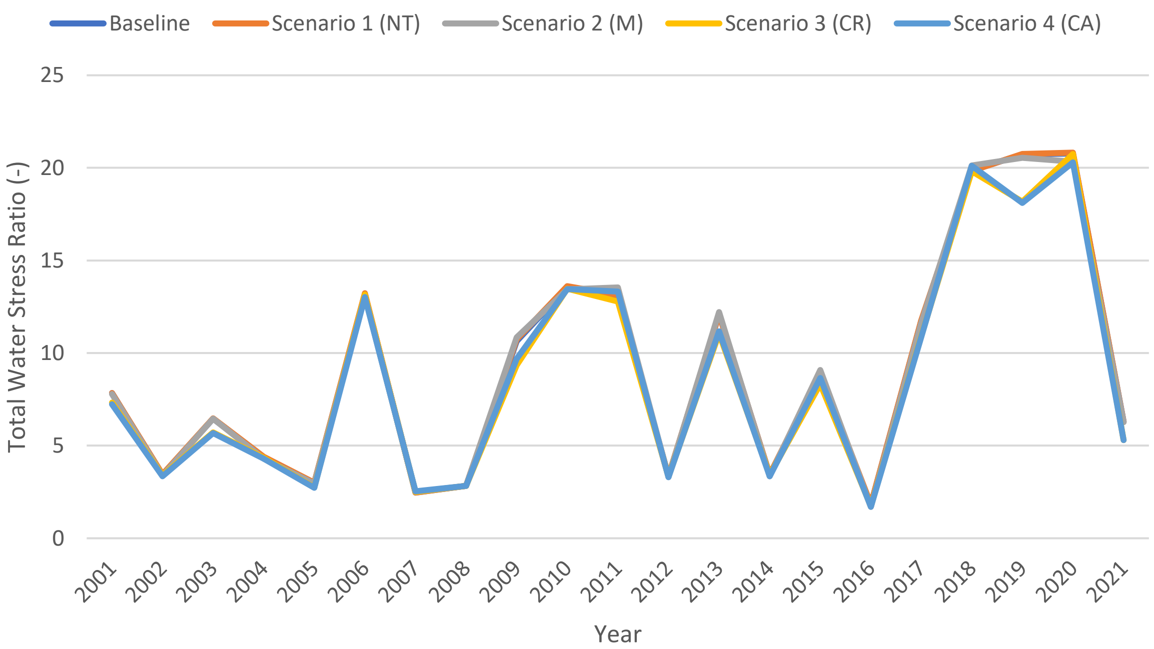

Figure 21. Total daily water stress ratio of different CA practices in a year during crops growing period

Table 10. The relative impact of different CA scenarios on crop yield and storage according to wet-dry periods

Crop	Period	Crop yield (kg/ha)	Relative change (%)			
			Scenario 1 (NT)	Scenario 2 (M)	Scenario 3 (CR)	Scenario 4 (CA)
Corn	2001-2021 (Average)	7995	-1%	4%	0%	4%
	Wet	8330	-1%	3%	2%	3%
	Normal	8560	-2%	5%	0%	5%
	Dry	6760	-2%	8%	-1%	9%
Grass	2001-2021 (Average)	1889	-2%	0%	0%	-2%
	Wet	1740	0%	0%	0%	0%
	Normal	1980	-5%	0%	0%	-5%
	Dry	1680	-2%	0%	0%	-2%

Similarly, to section 4.2.1, the different CA practices were also assessed on their respective impacts for different climate conditions. The mulching practice was observed to have constantly positive impacts on corn yield for each climate condition while it has no effect on the grasslands. Furthermore, it has the highest impact during dry conditions while the lowest impact was observed during the wet period. On contrary, no-tillage practice have negative impacts on the corn and grasslands yield while scenario 3 (crop rotation) observed to have barely any effect in different wet-dry climate.

4.3 IMPACTS OF CA PRACTICES IN FUTURE CLIMATE SCENARIOS

Table 11 provides the scaled climate change values to be used for the CA practices impacts using projected climate data. All of the available scenarios provided in Table 11, namely GL, GH, WL, and WH, were used in the simulations to compare between the conventional agriculture in historical and in the future conditions. The reason of including all climate change scenarios is to have more different possible conditions of climate change in the future and further assess the impacts of different CA practices under different climate change, which in this case are the global temperature rise and change in air circulation pattern. However, only one of the KNMI'14 scenarios was chosen to represent the projected climate data for further CA impact analysis on both hydrological fluxes and crop yield.

Table 11. Scaled change values for projected climate data around 2050

Season	Variable	Scenario change values for climate around 2050 scaled using input period			
		G_L	G_H	W_L	W_H
Global temperature rise:		+1 ˚C	+1 ˚C	+2 ˚C	+2 ˚C
Change in air circulation pattern:		Low value	High value	Low value	High value
Year	Temperature (˚C)	0.71	0.99	1.42	1.63
	Precipitation	2.84%	1.77%	3.90%	3.55%
	Solar radiation	0.43%	1.13%	-0.57%	0.85%
Winter	Temperature (˚C)	0.78	1.13	1.49	1.91

	Precipitation	2.13%	5.67%	5.67%	12.05%
	Wind	-0.78%	0.35%	-1.77%	0.64%
Spring	Temperature (˚C)	0.64	0.78	1.28	1.49
	Precipitation	3.19%	1.63%	7.80%	6.38%
Summer	Temperature (˚C)	0.71	0.99	1.21	1.63
	Precipitation	0.85%	-5.67%	0.99%	-9.22%
	Humidity	-0.43	-1.42	0.07	-1.77
Autumn	Temperature (˚C)	0.78	0.92	1.56	1.63
	Precipitation	4.96%	5.67%	2.13%	5.32%

4.3.1 Hydrological Fluxes

Firstly, the baseline scenario and scenario 5 (conventional agriculture) with different climate change scenarios were compared to each other to obtain the most impactful KNMI'14 scenario to be chosen as the representative future climate condition. The comparison was sought for all hydrological fluxes and storage (average soil water content).

Table 12. Comparison of hydrological fluxes and storage between historical (baseline) and projected condition of conventional agriculture practices (scenario 5)

Annual Hydrological Fluxes	Baseline Scenario (mm)	Relative Change (%)			
		GL	GH	WL	WH
Precipitation	750	3%	1%	4%	3%
Surface Runoff	34	2%	0%	2%	2%
Lateral Flow	0	8%	7%	11%	10%
Percolation	269	3%	1%	3%	2%
Transpiration	192	1%	1%	4%	3%
Soil Evaporation	231	2%	2%	3%	3%
Baseflow	215	4%	1%	3%	1%
Revap	38	2%	3%	4%	5%
Seepage	13	3%	1%	3%	2%
Annual Storage					
Soil Water	153	0%	-1%	-1%	-2%

According to Table 12, the hydrological fluxes were observed to have different responses toward the future climate change conditions. Both WL and WH scenarios observed to have more relative change compared to the others. This implies that global temperature rise was having more influence on the change in hydrological fluxes and storage. Higher relative change in general was observed under the WL scenario followed by the change in WH scenario. Despite having higher change compared to the other fluxes, lateral flow under the WL scenario observed to only contribute small amount toward the streamflow and thus less important for the comparison between scenarios. Based on the results of the relative change of the hydrological fluxes, the WL climate change scenario was chosen to represent the projected climate data used for assessing the CA practices on the hydrological fluxes. The reason of choosing the specific climate change scenario was because, in general, it has the highest relative change values for different hydrological fluxes. However, for the other fluxes, the difference between WL and WH was minimum with WH have slightly higher change, such as in Revap under WH has 1% higher compared to WL. Owing to this fact, WL was still chosen to represent the projected climate data since it also has the highest impact on corn yield even though the WH scenario has the highest effect on grass that will be explained in section 4.3.2.

Figure 22 shows the response of hydrological fluxes and storage to different CA practices in the future climate condition. The relative change provided in Figure 22 was based on the annual average of the focused hydrological fluxes according to the 21 years of simulation using SWAT+ data. Scenario 7 (mulching) observed to have the highest impact on both soil evaporation and plant transpiration compared to the other scenarios. Mulching practices increase the plant transpiration significantly while also reduce the soil evaporation. which means that higher plant transpiration would lead to the increased amount of water used by the plants supplied by the lowering of soil evaporation. However, scenario 9 (all CA) was observed to have lower impact compared to scenario 7 (mulching) provided that it also implements the mulching practice. Similar reason as mentioned in 4.2.1, the effect of crop rotation practice compensates the impact generated by mulching practice, whereas scenario 8 (crop rotation) have opposite change compared to the scenario 7 (mulching). In case of scenario 8 (crop rotation), increasing hydrological fluxes were observed such as in surface runoff, percolation, and soil evaporation while reduced the plant transpiration and soil water content. This means that higher simulated streamflow will be expected for scenario 8 (crop rotation) compared to the other scenarios in the future climate condition, which re-confirmed by Figure 23. In addition, scenario 6 (no-tillage) have the highest effect on reducing the surface runoff compared to the other scenarios but almost have no effects on the other fluxes.

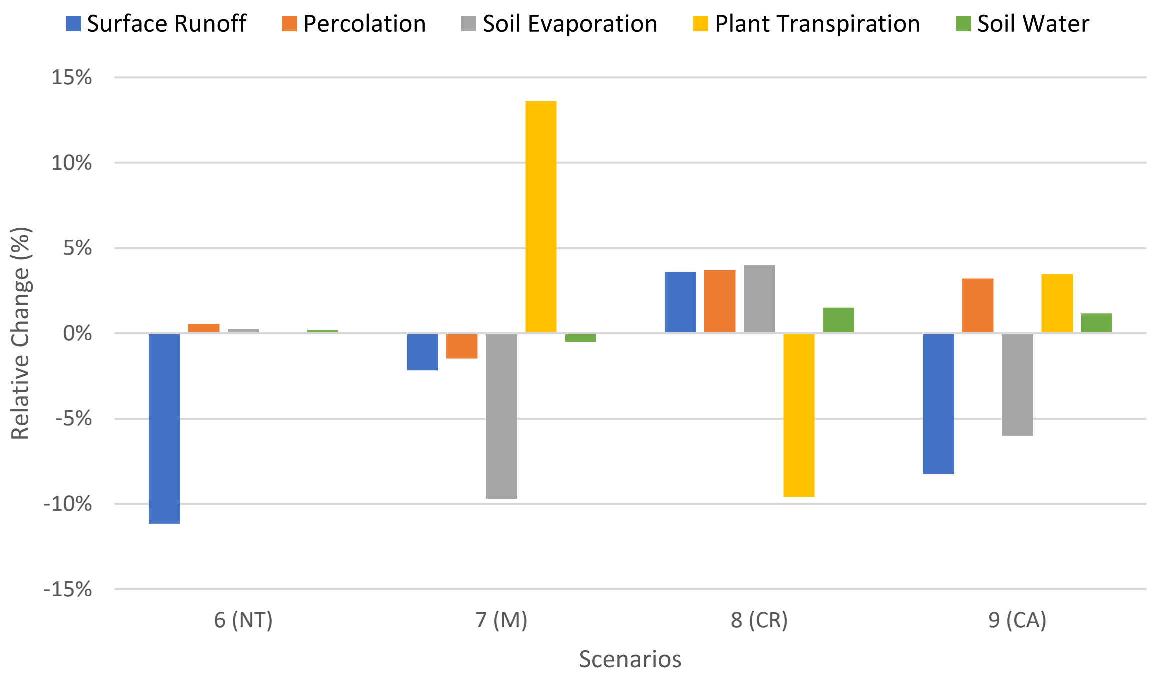

Figure 22. The change in hydrological fluxes in different scenarios using projected climate data relative to the scenario 5 (conventional agriculture)

Figure 23 shows both scenario 7 (mulching) and scenario 8 (crop rotation) compared to the scenario 5 (conventional agriculture). Only these scenarios were chosen to be compared with the scenario 5 (CT) using monthly average streamflow due to higher impacts observed in these scenarios compared to the other scenarios. According to Figure 23, scenario 8 (crop rotation) was observed to increase the streamflow from October to January while scenario 7 (mulching) did not have impact during this period. On the other hand, scenario 7 (mulching) observed to barely decrease the streamflow throughout the different months despite that it cannot be clearly seen visually in Figure 23. This is due to the presence of ryegrass grown right after harvest of the main crop while scenario 8 (crop rotation) did not have any plant grown outside of the main crops' growing period. As for the focused hydrological fluxes, namely the surface runoff, percolation, soil evaporation, plant transpiration, and soil water, the impacts of both mulching and crop rotation practices in the future climate condition based on the monthly average can be seen in

Appendix E Monthly Average Hydrological Fluxes of Mulching and Crop Rotation Under Future Climate Scenario. Impacts of CA practices observed in the figures were relative to the scenario 5, which is the conventional agricultural practices under future climate data. Both scenarios increased the surface runoff and percolation during the winter season, whereas the crop rotation practice has higher increase compared to the mulching scenario. Furthermore, the mulching scenario was observed to have higher reduction and increase in soil evaporation and plant transpiration respectively during the summer season. This is due to the growing period of the crop is within the summer season whereas mulching provides more impact on helping the plant to have more available water. On contrary, the crop rotation practice increases the soil evaporation during the winter period but then reduced it from May and June then increased it again from July to September. Lastly, the soil water content was observed to be decreased from May to September in both mulching and crop rotation practice.

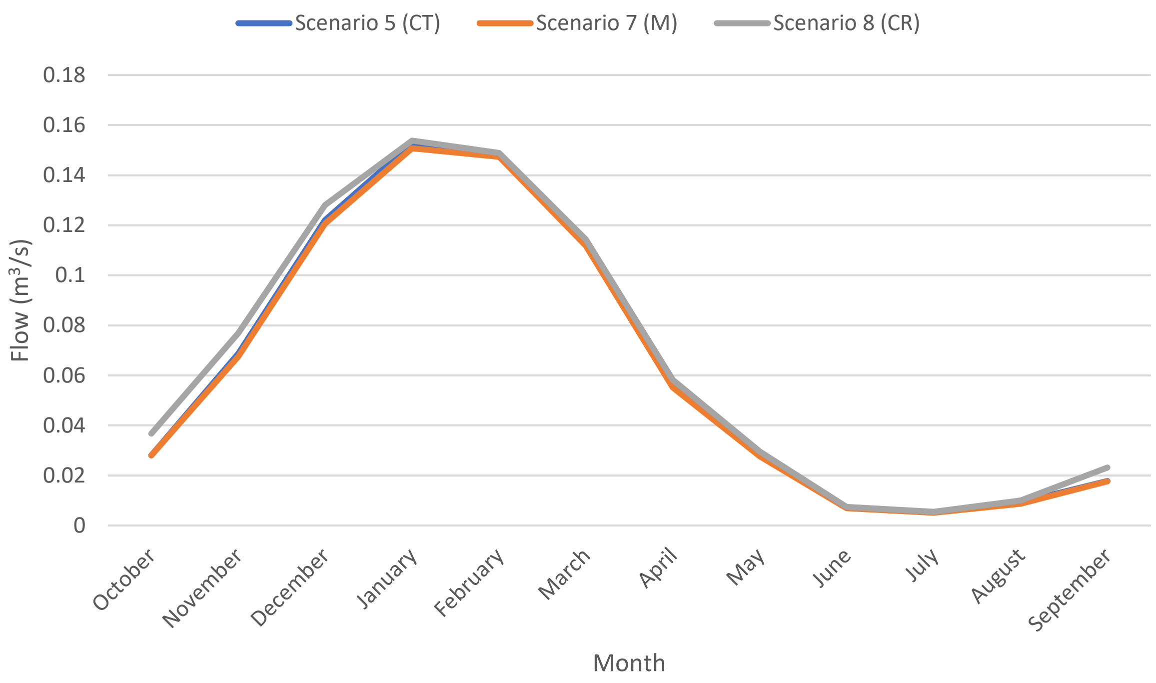

Figure 23. Monthly average streamflow of different scenarios based on future climate change condition (WL) compared to scenario 5 (CT) in Hupsel catchment

Figure 24 shows the SSFI values to provide indication of the effects of different scenarios under the future climate condition. In this case, similar condition as in Figure 16 was observed whereas the difference between the lines are minimum. Hence, the effects of CA pratices under the future climate condition considered to be minimal as well. However, there are still some distinctive differences that observed in certain years such as during the early years of simulation (2040-2044) and 2056. In general, scenario 7 (mulching) has the highest increases of the SSFI value which in other words reduces the severity of hydrological drought compared to scenario 6 (NT) and scenario 8 (CR) while scenario 9 (all CA) slightly reduce the SSFI value.

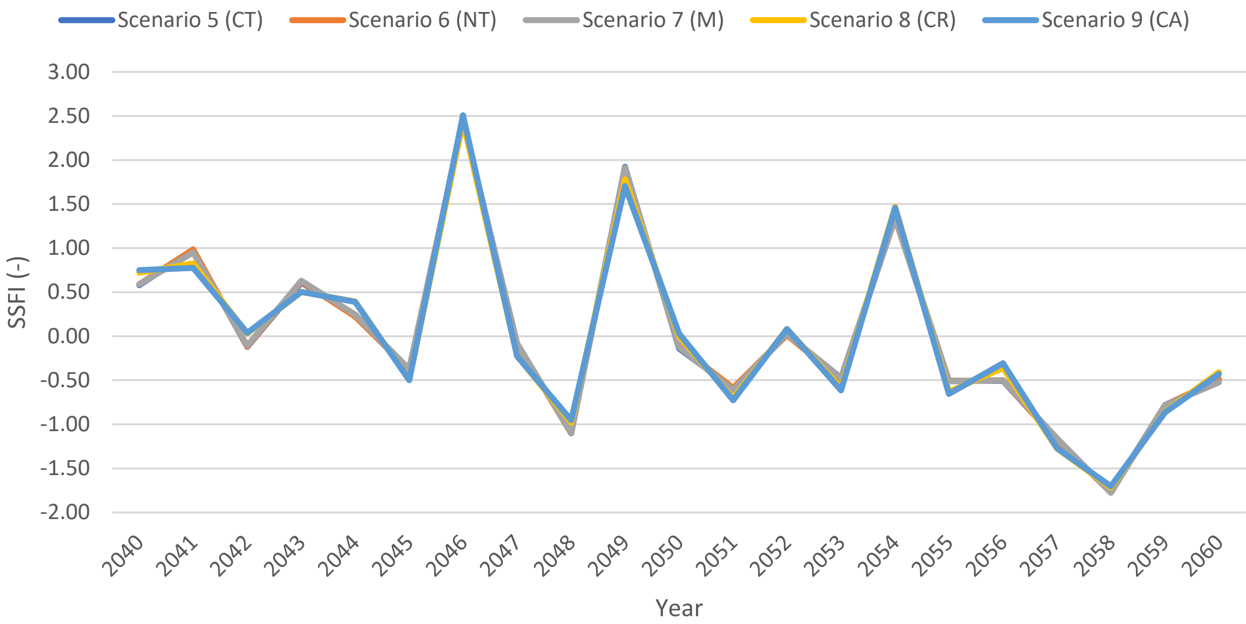

Figure 24. SSFI values of different scenarios under future climate condition (WL) in Hupsel catchment

4.3.2 Crop Yield

Similarly to section 4.3.1, the baseline scenario had been compared with scenario 5 (conventional agriculture) by all KNMI'14 climate change scenarios. This way, crop yield impact due to climate change according to the projection by KNMI '14 was assessed relative to the baseline scenario. The comparison between those scenarios can be seen in Table 13, whereas the crop yield given in the table was the average of 21 years simulation. Furthermore, the relative change presented in Table 13 refers to the change with respect to the baseline scenario (conventional agriculture in historical climate condition from 2001-2021) as the reference value.

Table 13. Comparison of crop yield between historical and projected conditions of conventional agriculture practices

Crop	Scenario	Average Crop Yield (kg/ha)	Relative change (%)
Corn	Baseline	7995	-
	Scenario 5 - GL	8085	1.13%
	Scenario 5 - GH	7998	0.03%
	Scenario 5 - WL	8180	2.31%
	Scenario 5 - WH	7973	-0.28%
Grass	Baseline	1889	-
	Scenario 5 - GL	1836	-2.80%
	Scenario 5 - GH	1763	-6.68%
	Scenario 5 - WL	1656	-12.32%
	Scenario 5 - WH	1584	-16.16%

According to Table 13, the crop yield of both crops, corn and grass, decreased under the projected climate change conditions. Corn was observed to have a decrease of crop yield in the WH scenario, where it has 2 ˚C increase in the global temperature with high air circulation change. This is due to the temperature increase that affecting the crop growth did not meet with its crop base and optimum temperature. Similar condition was observed in the grasslands whereas the crop yield was mainly reduced as well in the different climate change scenarios. However, the difference between corn and grass crop yield within the projected climate change condition was the grass observed to have higher decrease of crop yield compared to corn. Scenario 5 (conventional agriculture) with WH climate change scenario has the highest change with approximately reducing 16% of the grass yield annually. Thus, the grassland was observed to be more sensitive and prone toward the climate change condition. Additionally, the WL climate change scenario was chosen for representing the projected climate data used for assessing the impact of different CA practices in crop yield. The reason was due to WL climate change scenario has the highest impact on increasing the crop yield for corn. Even though WH scenario has larger decrease of crop yield for grassland, the difference between WL and WH was not significant and thus considered to be representative change for grass yield. Therefore, based on the crop yield simulation in the future climate change condition, the farmers in the Hupsel catchment will suffer with reductions in annual grass yield.

In Figure 25 and Figure 26, the annual average crop yield of the 21 years of simulations for both corn and grass are shown. For instance, comparing the scenario 7 (mulching) with Scenario 5 (conventional agriculture) will provide implication of the mulching practice impact in the future climate change condition relative to the current pratice in the Hupsel catchment area. Furthermore, the scenarios provided in the figures were conventional agriculture (CT), no-tillage (NT), mulching (M), crop rotation (CR), and all conservation agriculture practices (CA), which can also refer to the Table 2.

Figure 25 shows the difference between the crop yield simulated under projected climate data which can be clearly seen that scenario 5 (CT) have crop yield around 8000 kg/ha as a reference to be compared to the other scenarios. However, there are some positive results that can be observed in the implementation of CA practices' result of the crop yield under the projected climate data. Both scenario 7 (mulching) and scenario 9 (all CA) observed to have higher crop yield compared to the other scenarios under the projected climate data. Those scenarios provide positive results by increasing the corn by approximately 2000 kg/ha despite the future climate change condition of higher temperature. On contrary, Figure 26 shows that in general, the practices of CA barely have any impact on reducing or increasing the grass yield under the climate change conditions in the future. This is due to the grass are more sensitive toward the increase of temperature under the climate change condition despite the increasing CO_2 concentrations.

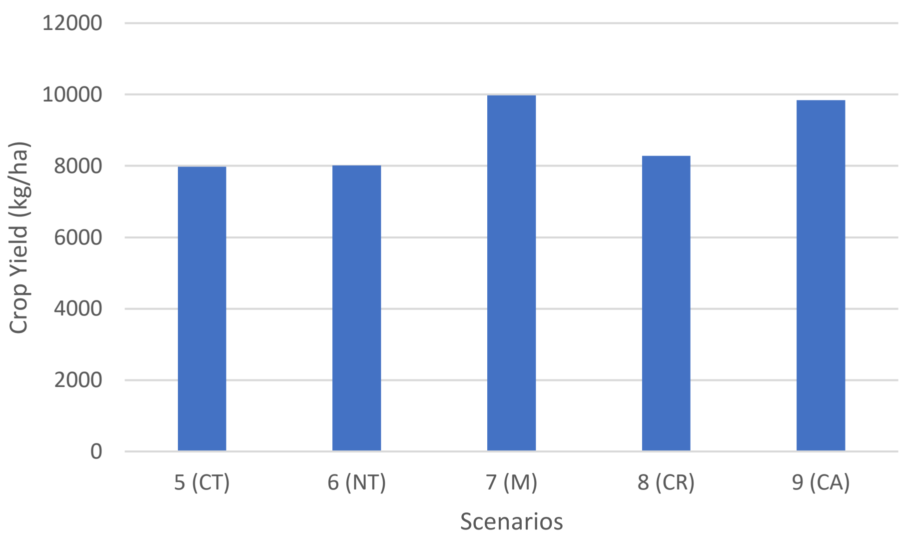

Figure 25. The annual average corn yield of different scenarios

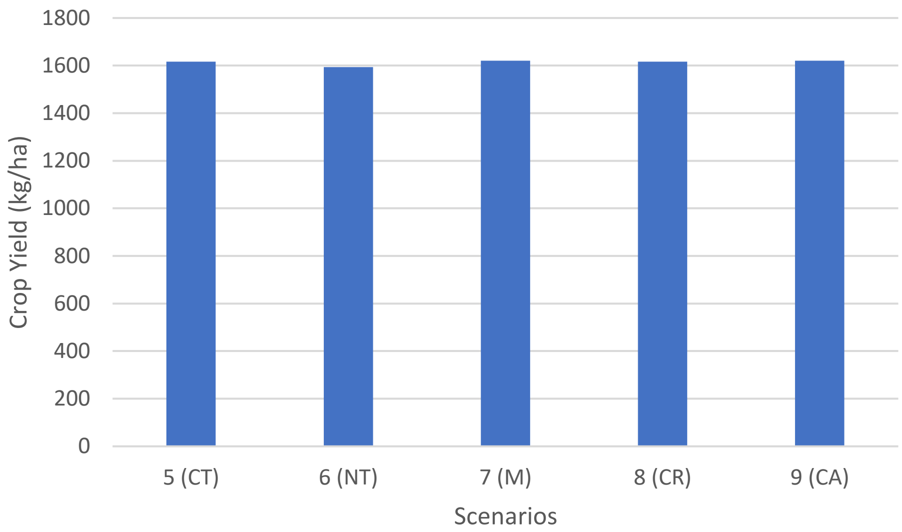

Figure 26. The annual grass yield for different scenarios

According to Figure 27, the total daily water stress ratio of different CA scenarios under the future climate condition have also small effect that can barely observed visually. In this case, the lines that represent different scenarios are even closer and more similar compared to Figure 21. The only year that observed to have a quite significant effect was in 2058 with both scenario 9 (crop rotation) and scenario 9 (all CA) are reducing the total water stress ratio. In addition, both scenarios are reducing the total water stress ratio approximately 0.3 on average each year. On contrary, scenario 6 (NT) and scenario 7 (M) are observed to almost have no effect on either decreasing or increasing the total water stress ratio throughout the simulation years. Thus, based on the water stress ratio, only scenarios 3 (crop rotation) and 4 (all CA) were assessed to have favorable effects on lessening the severity of the agricultural drought.

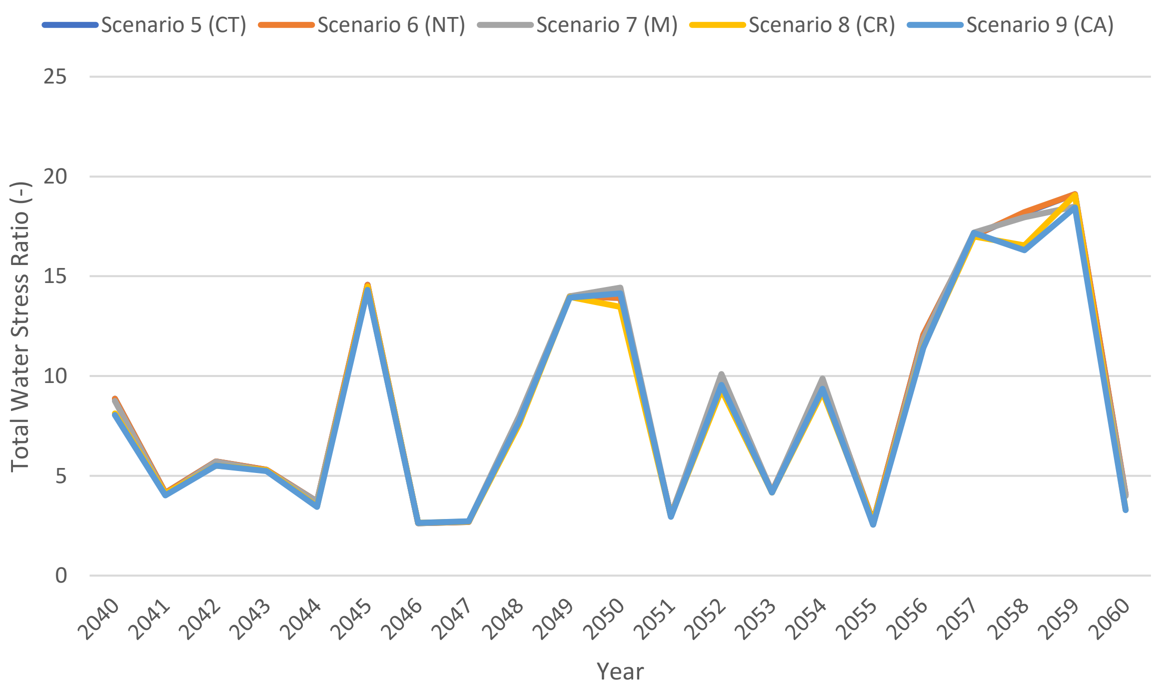

Figure 27. Total daily water stress ratio of different CA practices in a year during crops growing period under future climate condition (WL)

5. DISCUSSION

5.1 EVALUATION AND LIMITATIONS OF THE RESULTS

The limitations of the current study may affect the conclusions on the effects of CA practices on hydrology and agricultural productivity. The evaluation of the results are described in this part along with the effects of limitations on the results will be assessed as well.

The result of the calibrated and validated SWAT+ model shows that the model is performing well enough to simulate the observed streamflow quantitatively and qualitatively. This is following the aims of the first research question to generate a baseline scenario that represents the Hupsel catchment area. However, the qualitative analysis of the model indicated that there is longer recession of the simulated streamflow compared to the observed streamflow during the transition from winter to summer season. This is because the model simulated considerably low surface runoff and lateral flow while it has the baseflow as the main contribution toward the streamflow. Having higher baseflow compared to the surface runoff implies that the catchment area of the simulated model is dominated by the influence of groundwater. Furthermore, the soil properties of the catchment area in the model are mainly dominated by sand which means that the soil has high infiltration rate and low surface runoff. Thus, most of the precipitation are being infiltrated into the soil and slowly flow into the main channel as baseflow. Hence, it has longer recession simulated by the model instead of a fast response through surface runoff.

Low surface runoff simulated by the model is due to mainly two reasons. Firstly, the average curve number simulated by the model was around 59, whereas the number is a function of soil permeability, landuse, and antecedent soil water conditions (Neitsch et al., 2011). In this case, the low curve number was mainly dominated by the influence of soil permeability where the soil properties in the Hupsel catchment is dominated by the sands as mentioned in section 2.1. Having higher sands content in the soil means that the water will be easily transmitted through the pores between the particle of sands. Secondly, the Hupsel catchment mainly consists of agricultural landuse which covers around 90% of the whole area (60% grasslands and 30% corn). In addition, there is a small part of forest in the catchment area as well. Therefore, it has considerably high Manning value and low curve number within the area which generate low surface runoff. Furthermore, the high simulated baseflow was mainly coming from the simulated percolation. The water that percolates into the saturated zone was mainly transformed into baseflow due to the presence of an impermeable clay layer in the deep aquifer (Brauer et al., 2014). This statement is supported by the small amount of seepage simulated by the model, which can be seen in Table 8. The reason behind the unexpected result of having higher baseflow was because the limitation of SWAT+ toolbox (used in sensitivity analysis and calibration) related to the aquifer components. There are only two aquifer parameters were included in the calibration mainly due to the other parameters were not available to be used from the beginning. Aquifer parameters such as gw_delay that affect the lag of water percolation and *gwqmn* which control the amount of baseflow by determining the depth of water threshold in the unconfined aquifer. These parameters highly influence the amount of baseflow especially the latter which control the threshold of shallow groundwater height that affect when the water is being turned into baseflow or further increase the depth of the groundwater.

In this study, the conservation agriculture (CA) practices were further simulated based on the historical climate data to see the different impacts of the practices individually and all together on hydrology and agricultural productivity. The CA practices, represented by different scenarios, were observed to have a small impact on hydrological fluxes and crop yield. In case of the no-tillage practice, only the surface runoff was affected while there is hardly any impacts observed on the other hydrological fluxes and minimum impacts toward the crop yield. In other words, the reduction of surface runoff also means that the more water is being infiltrated into the soil. Despite the quite significant reduction of surface runoff was observed, the other fluxes were just slightly affected due to the actual amount of the water reduced from the surface runoff were really small compared to the other fluxes, such as the percolation and baseflow. According to the SWAT+ database, the manning value for no tillage is 0.07 while conventional tillage has 0.09. Clearly, the small difference in the manning value is another reason that influence no tillage practice toward the hydrological fluxes, especially the surface runoff where it supposed to have the higher impact due to no-tillage practice. In addition, no-tillage practice is expected to have significant impact on both hydrology and agricultural productivity according to several papers (Busari et al., 2015; de Medeiros Barbosa, 2015; Jat et al., 2021; Sharifi et al., 2016). The result of this study covers the reduction of surface runoff and hence increase the infiltration rate but does not provide the expectation of increased soil water capacity. Possible reason was because the no-tillage practice was implemented on its own in this study while the other studies are always include mulching along with the no-tillage practice. This implies that implementing the no tillage practice only, would lead to limited impact toward the hydrological fluxes and agricultural productivity, as the main aim of having no-tillage is to retain the roughness of soil surface.

The mulching practice was simulated to have the highest impact toward hydrological fluxes and crop yield compared to the other practices. In terms of the hydrological fluxes, the mulching practice impacts was mainly observed only outside and around the first 20 days of the crop growing period. This is closely related to the management operations and schedules being implemented in the scenario to represent the mulching scenario. The only source of mulch for the practice was coming from the rest of the crop biomass right after the harvest operation and grass that was solely being grown outside the growing period of the main crop. Therefore, the highest amount of residue (mulch) was observed right after the crop harvest and then gradually reduced due to decay, which in this case the residue was completely run out during most of the plant growth stage. Furthermore, the grass that is grown to provide mulch can only provide small amount of residue and it can only be applied on top of the soil surface before planting the main crop. From the practical perspective, mulch is being implemented whenever the crop has been planted and the temperature is starting to rise. This way, the mulch can provide cover of the soil surface to prevent water loss from soil evaporation. Therefore, the difference in the implementation of the actual mulching practice and in the SWAT+ model caused the impact being mainly observed outside of the crop growing period. Despite the small change of mulching practice, the increase in crop yield and reduction in both surface runoff and evapotranspiration was in accordance with the expectation while it has the opposite for the change in rest of the hydrological fluxes. This is due to the reduced amount of surface runoff and soil evaporation was directly being used by the plants instead of being stored or increased toward the other fluxes. Furthermore, the current practice being implemented in the SWAT+ model for representing the mulching practice was overlapping with another cropping system, which is intercropping that has its own impact toward hydrology and crop yield (Huss et al., 2022). However, even though this study focused on mulching part, the modelling scheme only allows mulching practice to be implemented along with the intercropping practice. This way, there are also some possible effects of intercropping being included in the mulching scenario such as lower water availability and nutrients for the main crop as the available amount of water and nutrients in the soil are being used by the cover crop as well. In addition, there is hardly any impact of mulching toward the grasslands due to the small amount of residue that can be allocated on the soil surface. The only supply of residue that grasslands can get was from the grass that was being grown in the grasslands itself.

As for the crop rotation practice, the result indicates small opposite impact compared to mulching practice. This is due to the substitute crop for corn (triticale) has lower biomass growth. Therefore, it requires less water and nutrients compared to the corn, while the rest of the available water become loss from the system and turns into surface runoff, percolation, and soil evaporation. Furthermore, the management operations and schedules of the crop rotation could affect hydrology and crop yield in the actual practice. For instance, having longer rotation cycle leads to higher crop yield due to increased variation in shoot and root characteristics, biological and chemical traits, which were not covered by the SWAT model (Jalli et al., 2021). In addition, there is still minimum study on crop rotation between corn and triticale since different combination of crop rotation could lead to different outcomes due to agroecological complexity between the crops.

The results of the CA practices in the future climate change conditions show that in general, the hydrological fluxes and corn yield were increased while the grass yield was reduced. This effect can be clearly seen in the higher streamflow observed during the winter season while there is small decrease during the summer season compared to the historical climate condition. Higher streamflow during winter season is closely related to the increase in temperature and precipitation which means that winter become wetter. As for the lower streamflow during summer period was because the increased temperature that affect the increase of soil evaporation while the precipitation was reduced. Therefore, mulching practice was observed to have significant impact by storing more available water for the plants. This can be seen with significant increase in plant transpiration and soil evaporation in the future climate condition. Furthermore, the reduced amount of crop yield in the future climate condition was mainly because the increased temperature that affect the plants growth despite the increasing amount of rainfall.

5.2 COMPARISON WITH OTHER STUDIES

There is still minimum study related to modelling the impacts of conservation agriculture especially in the European continent. Therefore, this study was only compared to other studies that focused on modelling the conservation agriculture by using a crop-water model that looks on the impact on either or both hydrology and agricultural productivity. There are only two studies to be used as comparison for this study. The first one is study by Assefa et al., (2018) which focuses on modelling the impact of conservation agriculture on hydrology and water management in Africa using the APEX model. The other study is Parajuli et al., (2013) that focused on the impact of both crop rotation and tillage on crop and sediment yield by using SWAT model in US.

Firstly, the performance of the model used in the study will be compared. In this case, the comparison was sought specifically between the performance of the model in this study with the study by Parajuli et al., (2013) as they also used the SWAT model with similar soil condition and land use. Despite the difference in study location, the aim of the comparison is to see the accuracy of the model to be used for modelling the impacts of the practices. Study by Parajuli et al., (2013) able to get more accurate with the NSE value around 0.7 in the calibration and validation part compared to this study with only 0.65 NSE value. However, they calibrated their model by using monthly timestep instead of daily. According to Adla et al., (2019), the daily rainfall-runoff processes are not adequately characterized by the monthly-calibrated model, despite it being able to represent trends reasonably accurate in monthly discharge data. Therefore, the daily-calibrated model was preferred since it captures the daily variance of the streamflow hence more accurate model.

In terms of the hydrology, the conservation agriculture practices modelled by Assefa et al., (2018) provided widely various impact that depends on soil conditions, crops, and operational management and schedules. For instance, there is also minimum impact observed on the hydrological fluxes of sweet potato and cucumber in one of their locations. These results indicate that the unseemly small impact of CA practices in this master study is closely related to the types of the soil, crops being grown, and also the proper management schedules. However, compared to the other results presented by Assefa et al., (2018), the impact of CA practices in this study is indeed very small with only the mulching practice that has similar impact. For instance, they observed that CA practices especially mulching practice reduce the soil evaporation at some catchment area with similar order of magnitude as in this study while also reduce the surface runoff. On the other hand, study by Parajuli et al., (2013) provided the impact of the tillage and crop rotation on crop yield, whereas they simulated the crop yield to have two or even three times higher due to the implementation of the CA practices. Compared to the impact of CA practices by Parajuli et al., (2013), this study only simulated a very small impact toward the crop yield. Despite the substitute crop in the crop rotation used by Parajuli et al., (2013) was different (soybean), it can still give an indication of an impact on crop yield on different location and substitute crop. In addition, higher crop yield output that the paper simulated could also because the study location was in US where the SWAT database provides more accurate values related to plants characteristics and breed.

5.3 PRACTICAL IMPLICATIONS OF THE STUDY

This study has certain practical significance especially for the farmers and water authority in the Hupsel catchment. Conservation agriculture practices impacts was modelled as an alternative to address the agricultural and hydrological droughts issues happened in the area. Based on the results, the implementation of mulching can increase the crop yield while the crop rotation between corn and triticale increased the streamflow. Despite the small impacts of CA practices on both hydrology and crop yield due to the limitations of this study, the results still show reasonable direction of relative change. Furthermore, this study also provides indication of residue management to be implemented in the area whereas if mulching is to be applied, the supply of the residue needs to be managed and secured properly in order to have all desired agricultural land in the catchment covered with mulch. In addition, the timing of the operations need to be adjusted to the earlier months (around February or March) in the future to provide better result and prevent undesired climate change impact. For instance, the plant and harvesting schedule along with the mulching implementation should be adjusted based on the temperature that is suitable with crops, which in future case the crop growing season is beginning earlier.

5.4 GENERALIZATION OF THE METHODS AND RESULTS

The research approach and methodology used in this study can be easily implemented to other locations to provide simulation of the possible agricultural practices impact in the catchment area. This research method could also be extended to be used for assessing different best management practices while also looking at other topics such as water quality, sediment transport, and soil erosion using SWAT model. Furthermore, the methodology of this study is not limited to be used for the SWAT model only but also for other crop-water models such as APEX provided that other models incorporate related components for the intended topic of research (e.g., water quality, etc.). In addition, the results can be generalized as reference for further study or assessment on different location provided that it also has similar soil properties and crops grown in the catchment area since CA practices depend on these variables.

6. CONCLUSION AND RECOMMENDATION

6.1 CONCLUSION

As mentioned in section 1.4, three research questions were created to further address the problem of this study. Each research topic is briefly addressed in this section, and based on the findings of this study, the research aim is addressed.

1. To what extent does the baseline scenario represents the farming practices used in the study area?

The SWAT+ model performed well enough in modeling the condition of conventional agriculture, which is the type of agriculture currently being practiced in the Hupsel catchment. The model was calibrated and validated with daily observed streamflow, whereas the model obtained good performance quantitatively (NSE>0.65) and qualitatively. Furthermore, the model also simulated a similar annual crop yield compared to the observed data in the Netherlands. Therefore, the model is able to represent both hydrology and crop yield in the study area.

2. How do the individual and combined practices under the CA farming system affect the hydrology and agricultural productivity compared to the baseline scenario under the historical climate conditions?

The results show that in general, the CA practices have a small impact toward the hydrological fluxes and crop yield. Crop rotation practices have the highest impacts on increasing the hydrological fluxes related to the water loss from the system while mulching provides the opposite impact by reducing the hydrological fluxes in favor for the increasing the crops' water uptake. All CA practices scenario observed to have the impacts in the middle between mulching and crop rotation scenario because the crop rotation impact compensated the effect provided by the mulching practice. On the other hand, no tillage practice observed to have quite significant reduction of surface runoff while barely showed any change for the other hydrological fluxes. Furthermore, both mulching and all CA practices scenario have highest impact during the wet period while the rest of the practices barely showed any difference in wet-dry conditions except the no-tillage scenario that observed to have the highest reduction of surface runoff in both wet and dry conditions. Additionally, mulching scenario was observed to have the most positive effect toward reducing the hydrological drought severity.

From the perspective of crop yield, mulching practice has the highest impact on increasing the corn yield while the other practices observed to have a small reduction. Furthermore, the mulching practice has the highest impact on increasing the corn yield during dry period while the other practices have barely any effect under different climate condition. As for the grass yield, no tillage was the only practice that has any impact on the yield. The absence of tillage practice reduced the grass yield by a small amount. Furthermore, crop rotation and all CA scenarios were observed to reduce the severity of agricultural drought.

3. How do the individual and combined practices under the CA farming system affect the hydrology and agricultural productivity compared to the baseline scenario in the future climate condition?

Several KNMI'14 scenarios of the future climate change conditions were observed to increase the hydrological fluxes in general except only a small decrease in soil water compared to the baseline scenario under the historical climate condition. Mulching practice has significant impact on increasing the plant transpiration which also the highest impact observed compared to the other scenario relative to the conventional agriculture under the WL future climate scenario. It also has the highest reduction in soil evaporation and small change in both surface runoff and percolation. On contrary, crop rotation practice has the opposite impacts compared to the mulching practice in terms of the evapotranspiration while also has the highest increase in both surface runoff and percolation compared to the other practices. From the perspective of crop yield, both mulching and all CA scenarios observed to increase the amount of corn yield under the future climate change condition while the other practices barely showed any change. On the other hand, CA practices both individually and combined as one scenario have almost no impact on the amount grass yield relative to the conventional agriculture. In addition, mulching observed to have the highest reduction in hydrological drought severity while both crop rotation and all CA scenario are in favor of lowering the agricultural drought severity.

6.2 RECOMMENDATIONS

Based on the results of this study, there are several recommendations to further improve the study in the future. Firstly, instead of using the SCS curve number for estimating the surface runoff in the SWAT+ model, the Green & Ampt method should be used since it is able to also estimate on the amount of water infiltrating into the soil profile. This method would be beneficial for further analysis on the CA practices especially the mulching practice to actually observe whether it has any impact on retaining the water from precipitation and helps more water to be infiltrated into the soil.

Secondly, the open-source SWAT+ toolbox software needs to have more updates and improvements to prevent missing SWAT+ parameters that could influence the sensitivity analysis and calibration of the model. Otherwise, SWAT-CUP is another option to help in sensitivity analysis and calibration of the SWAT+ model, whereas this software is commonly used by other studies that also perform analysis using SWAT model. This software was not used in this study since it is a licensed software compared to the SWAT+ toolbox which is free.

Thirdly, the databases provided in the SWAT model need to be adjusted according to the study location since they are specifically available only for US. The databases such as the manning value, plant, soil, operations, etc. are derived from the condition in US which will be less accurate if it is used for analysis in different area. For instance, the radiation-use efficiency (RUE) of corn provided in the SWAT+ model was derived from the USDA database while in reality it will be different from the corn that has been through a breeding process with higher value of RUE. Therefore, it is recommended to adjust the database according to the location as much as possible to get higher accuracy of the model. Fourthly, operation for mulching practice should be manually or later on be included in the newer version of the SWAT+ since it is currently unavailable to implement the mulching practice freely into the catchment area.

Fifth, study on other possible combinations of crop rotation practices should be done in-depth to get the best combination implemented especially in the Hupsel catchment. The interaction and possible impact of different crop rotations is a whole different topic compared to this study which include the agroecological complexity between the crops.

Lastly, despite considerably small impacts of CA practices, other researchers along with the water authority would be recommended to have some follow-up research to re-confirm the findings in this study. This is due to the results having the expected change direction in accordance with other studies but with considerably small effects. Another reason is because there is a possibility to further increase the amount of crop yield in the future climate change condition specifically for corn or arable crops in general and help to reduce the severity of hydrological and agricultural droughts. On the other hand, it is also recommended to analyze other best management practices in favor for the grasslands. For instance, implementing the contouring and strip cropping could reduce the surface runoff and increase the infiltration rate.

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APPENDICES

APPENDIX A MANAGEMENT OPERATIONS AND SCHEDULES OF THE CA SCENARIOS

Scenario No-tillage Corn

Operations

	OPERATION	YEAR	MONTH	DAY	HU	DATA			
	till	1	4	24	0	zerotill		0	✕
	fert	1	4	27	0	urea	aerial_liquid	100	✕
	fert	1	4	27	0	ceap_p_p	aerial_liquid	30	✕
	till	1	4	28	0	zerotill		0	✕
	plnt	1	5	1	0	corn		0	✕
	fert	1	5	21	0	urea	aerial_liquid	200	✕
	fert	1	7	25	0	urea	aerial_liquid	200	✕
	hvkl	1	9	25	0	corn	grain	0	✕
	till	1	9	28	0	zerotill		0	✕

Scenario No-tillage Grass

Operations

	OPERATION	YEAR	MONTH	DAY	HU	DATA			
	fert	1	3	17	0	urea	aerial_liquid	100	✕
	fert	1	3	17	0	ceap_p_p	aerial_liquid	50	✕
	till	1	4	24	0	zerotill		0	✕
	till	1	4	28	0	zerotill		0	✕
	plnt	1	5	1	0	rnge		0	✕
	graz	1	5	20	0	beef_high		120	✕
	harv	1	10	28	0	rnge	grass_bag	0	✕
	till	1	10	31	0	zerotill		0	✕

Scenario Mulching Corn

Operations

	OPERATION	YEAR	MONTH	DAY	HU	DATA			
	fert	1	1	25	0	ceap_p_p	aerial_liquid	20	
	fert	1	1	25	0	urea	aerial_liquid	200	
	hvkl	1	4	14	0	rye	grass_mulch	0	
	till	1	4	24	0	mldboard		0	
	fert	1	4	27	0	urea	aerial_liquid	100	
	fert	1	4	27	0	ceap_p_p	aerial_liquid	30	
	till	1	4	28	0	fldcult		0	
	plnt	1	5	1	0	corn		0	
	fert	1	5	21	0	urea	aerial_liquid	200	
	fert	1	7	25	0	urea	aerial_liquid	200	
	hvkl	1	9	25	0	corn	grain	0	
	till	1	9	28	0	chisplow		0	
	plnt	1	10	1	0	rye		0	

Scenario Mulching Grass

Operations

	OPERATION	YEAR	MONTH	DAY	HU	DATA			
	harv	1	2	17	0	rnge	grass_mulch	0	
	fert	1	3	17	0	urea	aerial_liquid	100	
	fert	1	3	17	0	ceap_p_p	aerial_liquid	50	
	till	1	4	24	0	mldboard		0	
	till	1	4	28	0	fldcult		0	
	plnt	1	5	1	0	rnge		0	
	graz	1	5	20	0	beef_high		120	
	harv	1	10	28	0	rnge	grass_bag	0	
	till	1	10	31	0	chisplow		0	

Scenario Crop Rotation

Operations

OPERATION	YEAR	MONTH	DAY	HU	DATA		
till	1	4	24	0	mldboard		0
fert	1	4	27	0	urea	aerial_liquid	100
fert	1	4	27	0	ceap_p_p	aerial_liquid	30
till	1	4	28	0	fldcult		0
plnt	1	5	1	0	corn		0
fert	1	5	21	0	urea	aerial_liquid	200
fert	1	7	25	0	urea	aerial_liquid	200
hvkl	1	9	25	0	corn	grain	0
till	1	9	28	0	chisplow		0
till	2	4	24	0	mldboard		0
fert	2	4	27	0	ceap_p_p	aerial_liquid	30
fert	2	4	27	0	urea	aerial_liquid	100
till	2	4	28	0	fldcult		0
plnt	2	5	1	0	trit		0
fert	2	5	21	0	urea	aerial_liquid	200
fert	2	7	25	0	urea	aerial_liquid	200
hvkl	2	9	25	0	trit	grain	0
till	2	9	28	0	chisplow		0

Scenario All CA Corn

	OPERATION	YEAR	MONTH	DAY	HU	DATA			
	fert	1	1	25	0	ceap_p_p	aerial_liquid	20	
	fert	1	1	25	0	urea	aerial_liquid	200	
	hvkl	1	4	14	0	rye	grass_mulch	0	
	till	1	4	24	0	zerotill		0	
	fert	1	4	27	0	urea	aerial_liquid	100	
	fert	1	4	27	0	ceap_p_p	aerial_liquid	30	
	till	1	4	28	0	zerotill		0	
	plnt	1	5	1	0	corn		0	
	fert	1	5	21	0	urea	aerial_liquid	200	
	fert	1	7	25	0	urea	aerial_liquid	200	
	hvkl	1	9	25	0	corn	grain	0	
	till	1	9	28	0	zerotill		0	
	plnt	1	10	1	0	rye		0	
	fert	2	1	25	0	ceap_p_p	aerial_liquid	20	
	fert	2	1	25	0	urea	aerial_liquid	200	
	hvkl	2	4	14	0	rye	grass_mulch	0	
	till	2	4	24	0	zerotill		0	
	fert	2	4	27	0	ceap_p_p	aerial_liquid	30	
	fert	2	4	27	0	urea	aerial_liquid	100	
	till	2	4	28	0	zerotill		0	
	plnt	2	5	1	0	trit		0	
	fert	2	5	21	0	urea	aerial_liquid	200	
	fert	2	7	25	0	urea	aerial_liquid	200	
	hvkl	2	9	25	0	trit	grain	0	
	till	2	9	28	0	zerotill		0	
	plnt	2	10	1	0	rye		0	

Scenario 4 All CA Grass

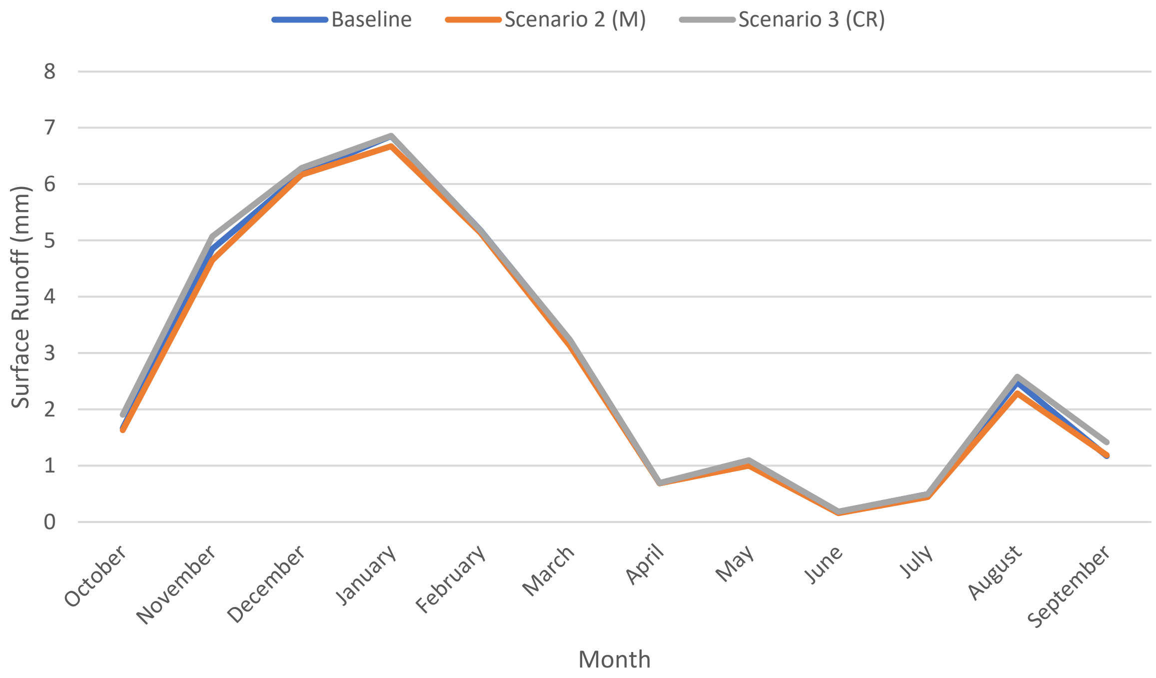
	OPERATION	YEAR	MONTH	DAY	HU	DATA			
	fert	1	3	17	0	urea	aerial_liquid	100	
	fert	1	3	17	0	ceap_p_p	aerial_liquid	50	
	harv	1	4	1	0	rnge	grass_mulch	0	
	till	1	4	24	0	zerotill		0	
	till	1	4	28	0	zerotill		0	
	plnt	1	5	1	0	rnge		0	
	graz	1	5	20	0	beef_high		120	
	harv	1	10	28	0	rnge	grass_bag	0	
	till	1	10	31	0	zerotill		0	

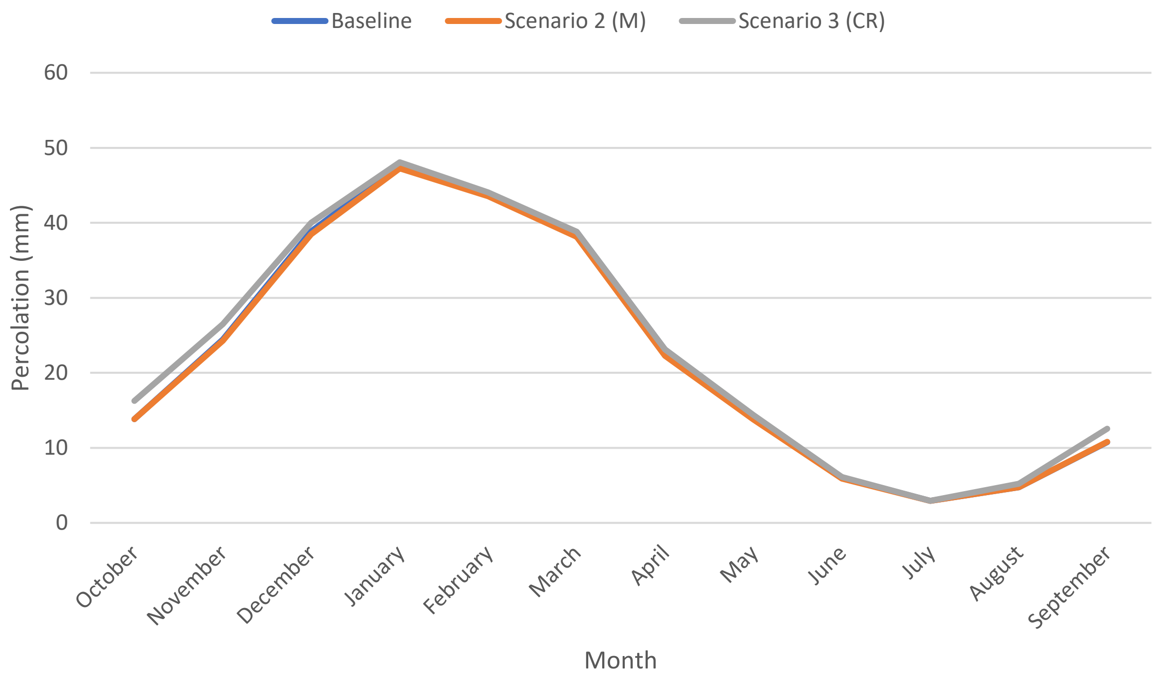
APPENDIX B LAND USE AND SOIL LOOKUP TABLE

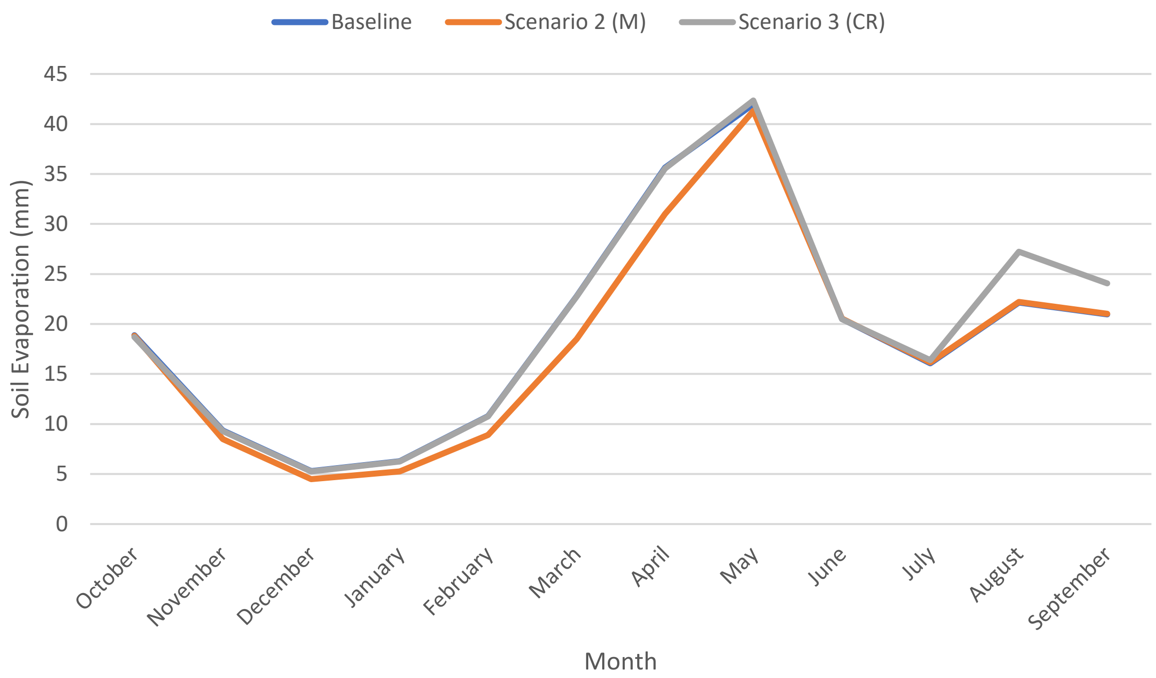
LANDUSE_ID	SWAT_CODE
1	RNGE
2	CORN
3	POTA
4	SGBT
5	BARL
6	AGRR
8	AGRC
9	ORCD
10	AGRL
11	FRSD
12	FRSE
16	WATR
18	URMD
19	URHD
20	FRST
22	FRST
23	RNGE
24	URLD
25	URBN
26	URBN
28	RNGE
35	URLD
36	RNGB
37	RNGB
38	RNGB
39	WETN
40	WETF
41	WETF
42	WETN
43	WETF
45	RNGE
61	AGRC
62	AGRR

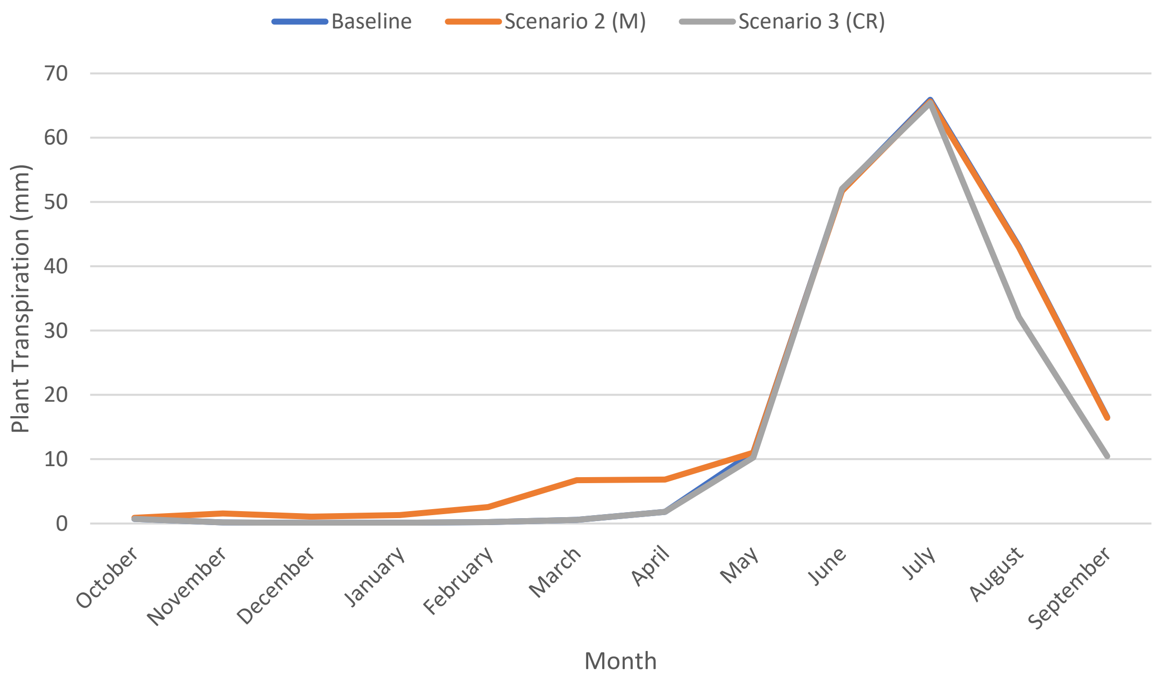
SOIL_ID	SNAM
2448	Qf22-1a-898
11492	Qc33-1a-880
11910	Qc33-1a-880
12004	Qc33-1a-880
12648	Qc33-1a-880
12882	Qf32-1-2b-910
13449	Qc33-1a-880
32287	Ws6-1a-1761
32288	Ws6-1a-1761
32340	Ws6-1a-1761
32342	Ws6-1a-1761
32343	Ws6-1a-1761
32361	Ws6-1a-1761
32529	Ws6-1a-1761
32584	Ws6-1a-1761
32606	Ws6-1a-1761
32607	Ws6-1a-1761
35387	Lf36-1a-1462
37990	Kl43-1a-4400
38357	Kl43-1a-4400

APPENDIX C MONTHLY AVERAGE HYDROLOGICAL FLUXES OF MULCHING AND CROP ROTATION UNDER HISTORICAL CLIMATE CONDITION

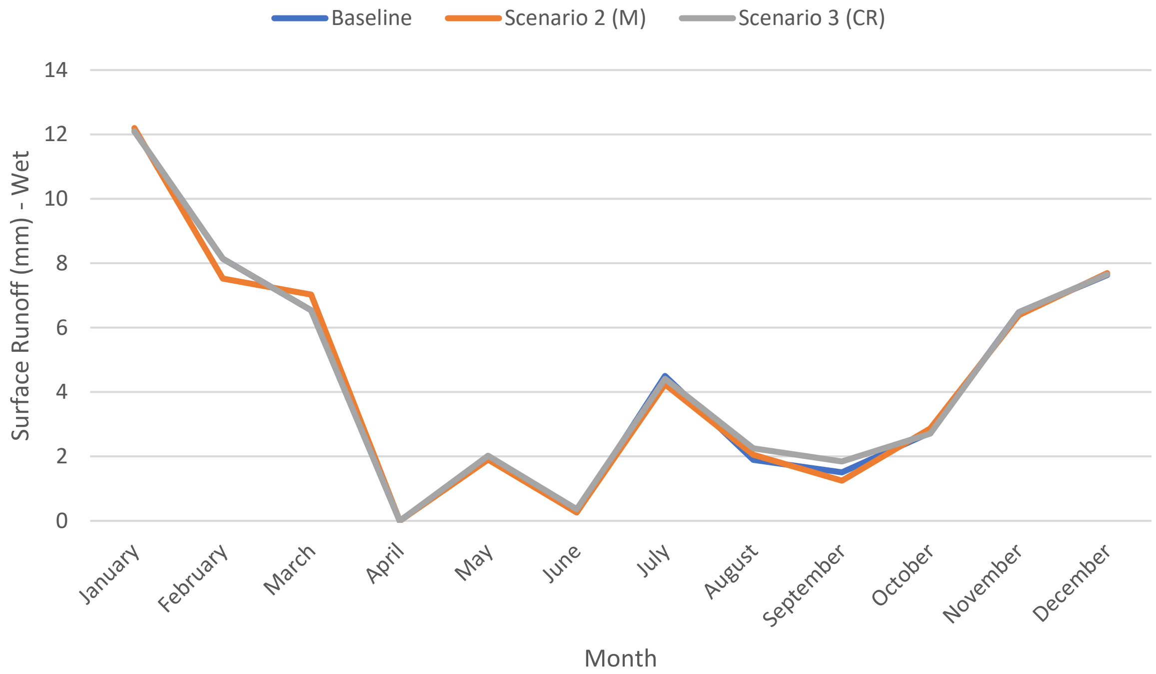


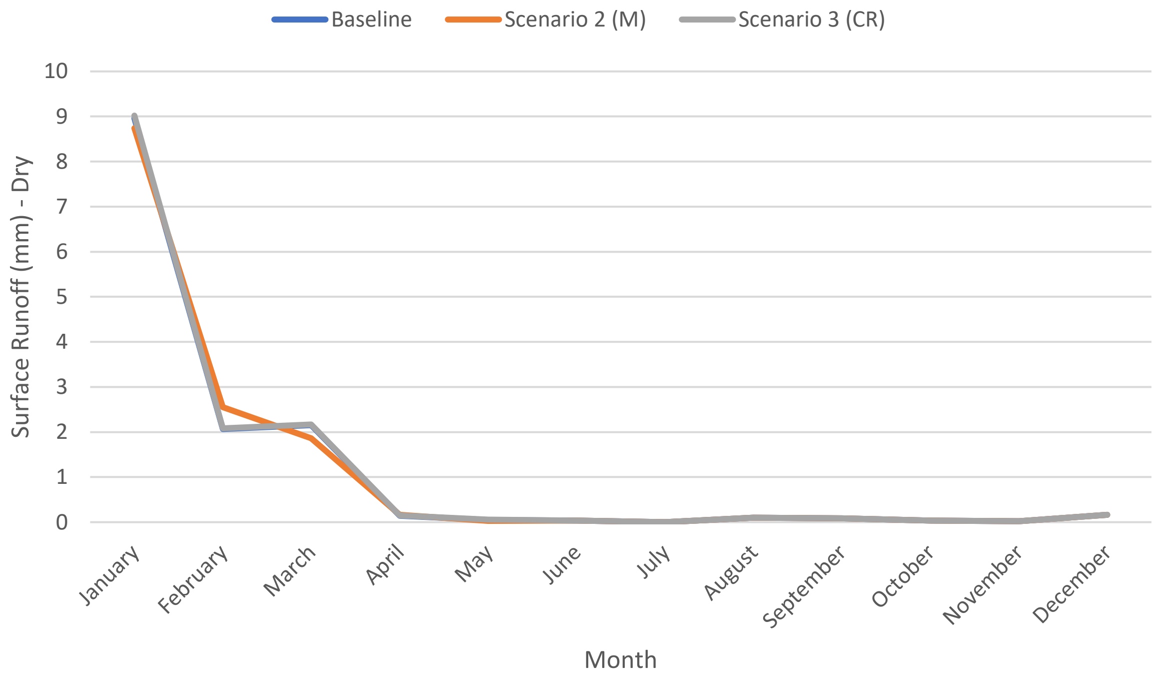


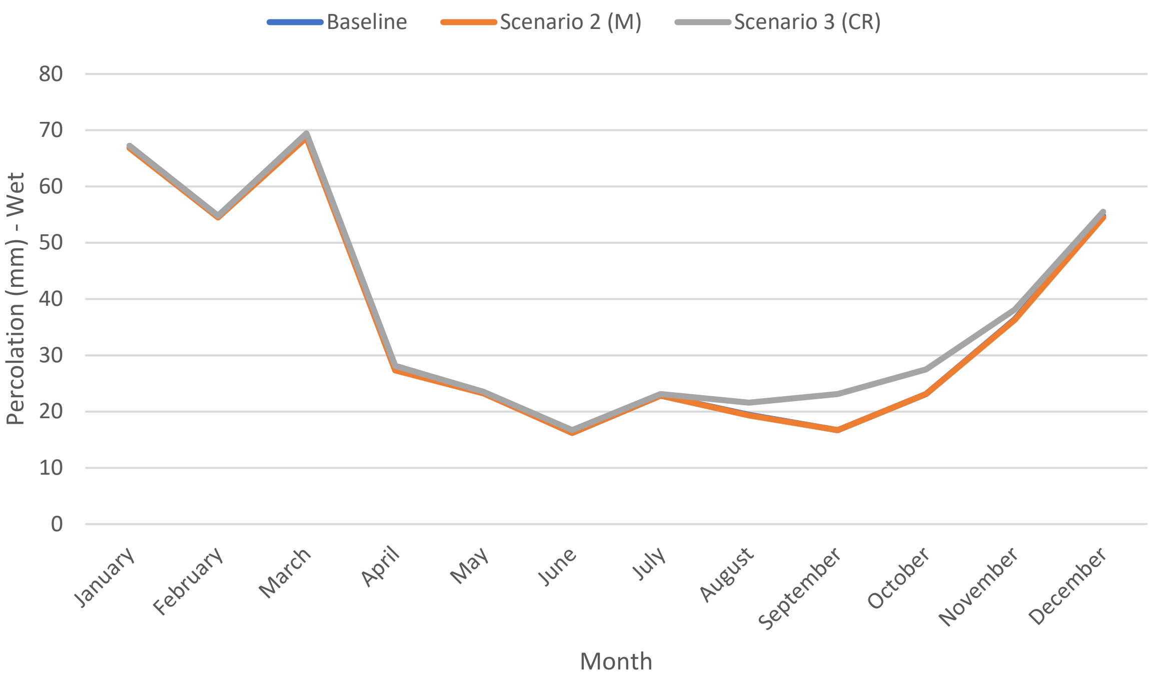

Baseline
Scenario 2 (M)
Scenario 3 (CR)
Soil Evaporation (mm)
45
40
35
30
25
20
15
10
5
0
October
November
December
January
February
March
April
May
June
July
August
September
Month

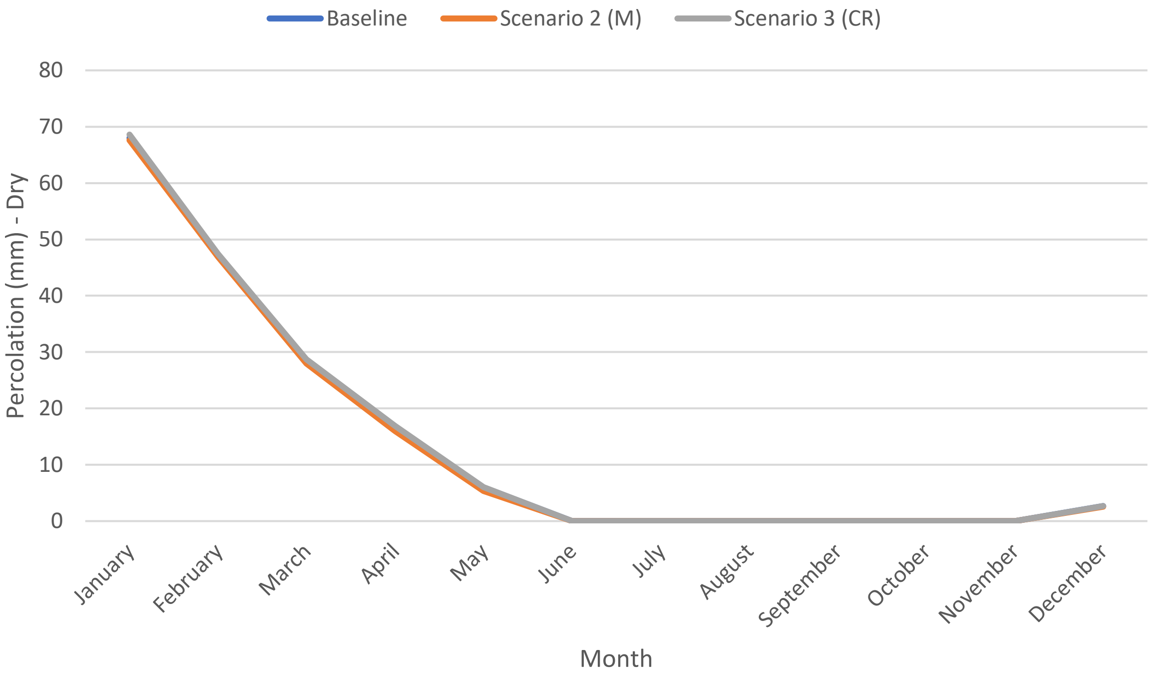

Baseline
Scenario 2 (M)
Scenario 3 (CR)
Plant Transpiration (mm)
70
60
50
40
30
20
10
0
October
November
December
January
February
March
April
May
June
July
August
September
Month

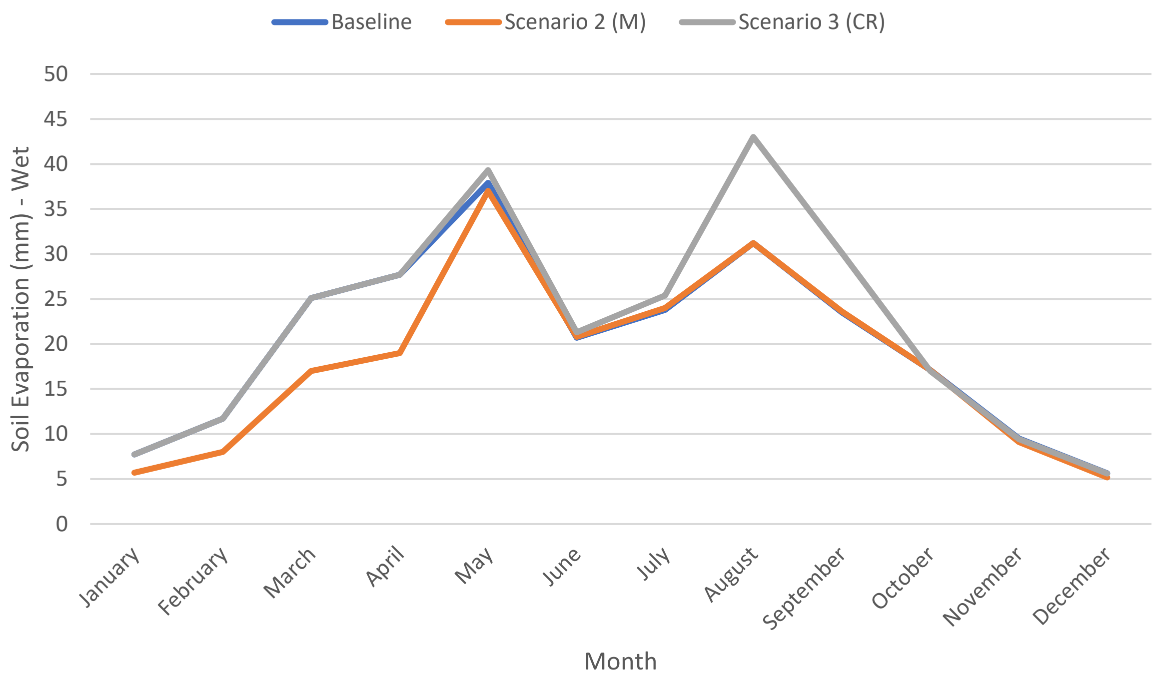
APPENDIX D MONTHLY HYDROLOGICAL FLUXES OF MULCHING AND CROP ROTATION UNDER HISTORICAL WET-DRY CLIMATE CONDITIONS

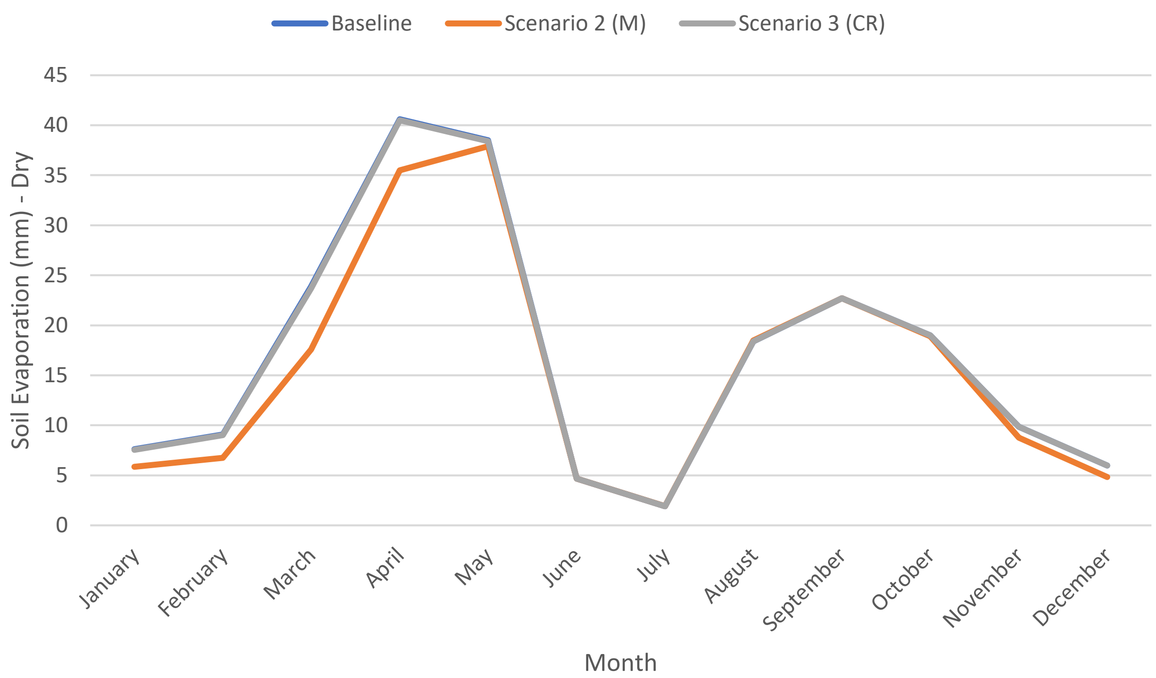


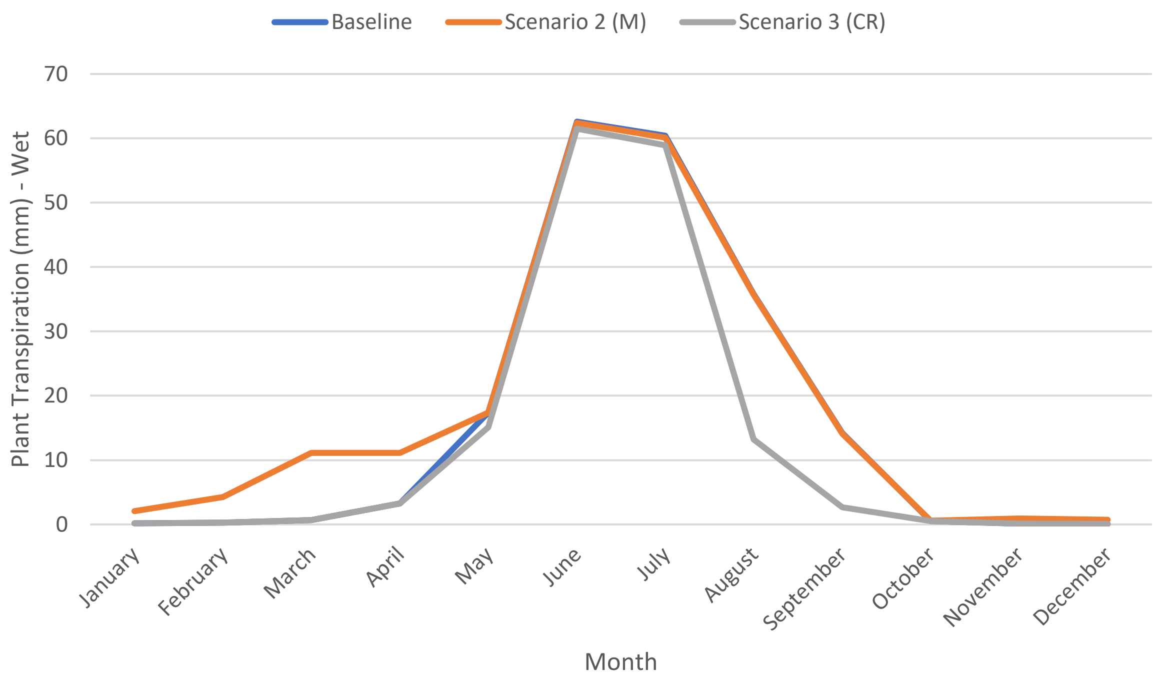


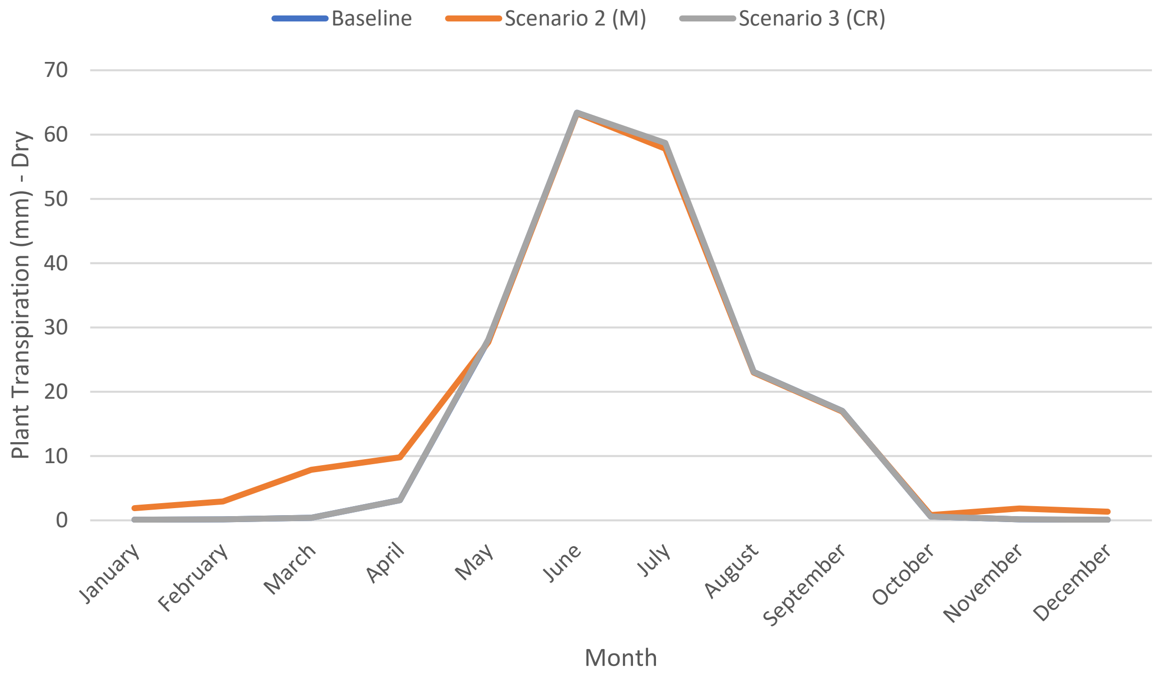

Baseline
Scenario 2 (M)
Scenario 3 (CR)
80
70
60
50
40
30
20
10
0
Percolation (mm) - Wet
January
February
March
April
May
June
July
August
September
October
November
December
Month


Baseline
Scenario 2 (M)
Scenario 3 (CR)
80
70
60
50
40
30
20
10
0
Percolation (mm) - Dry
January
February
March
April
May
June
July
August
September
October
November
December
Month

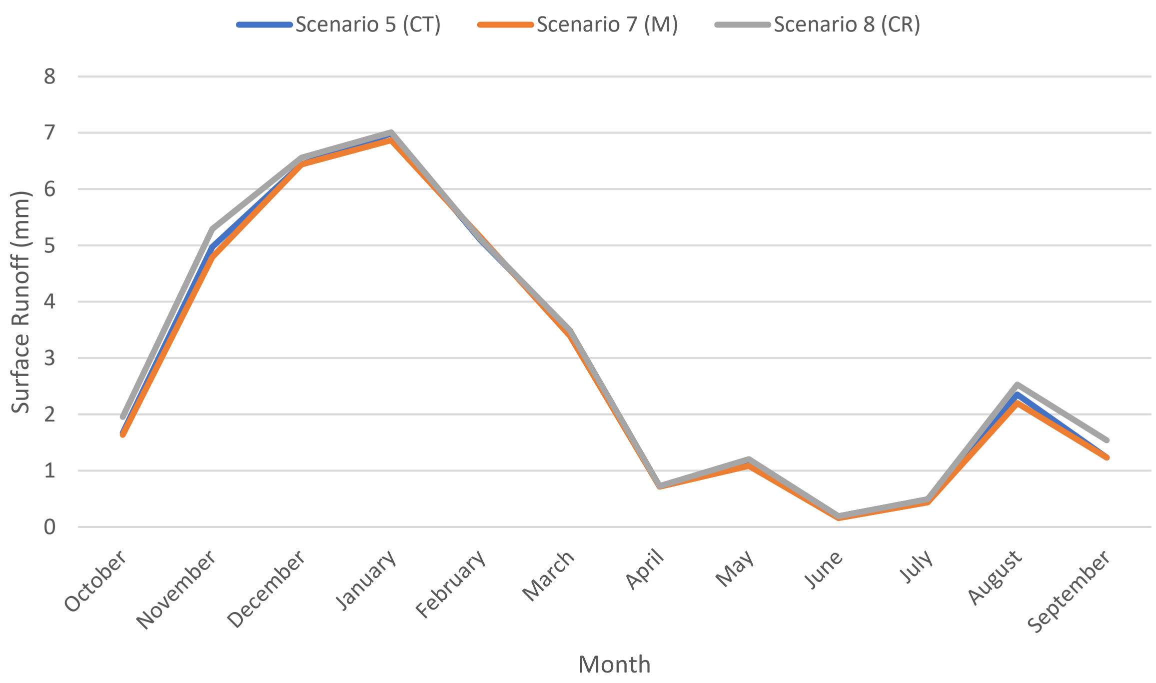

Baseline
Scenario 2 (M)
Scenario 3 (CR)
Soil Evaporation (mm) - Wet
50
45
40
35
30
25
20
15
10
5
0
January
February
March
April
May
June
July
August
September
October
November
December
Month

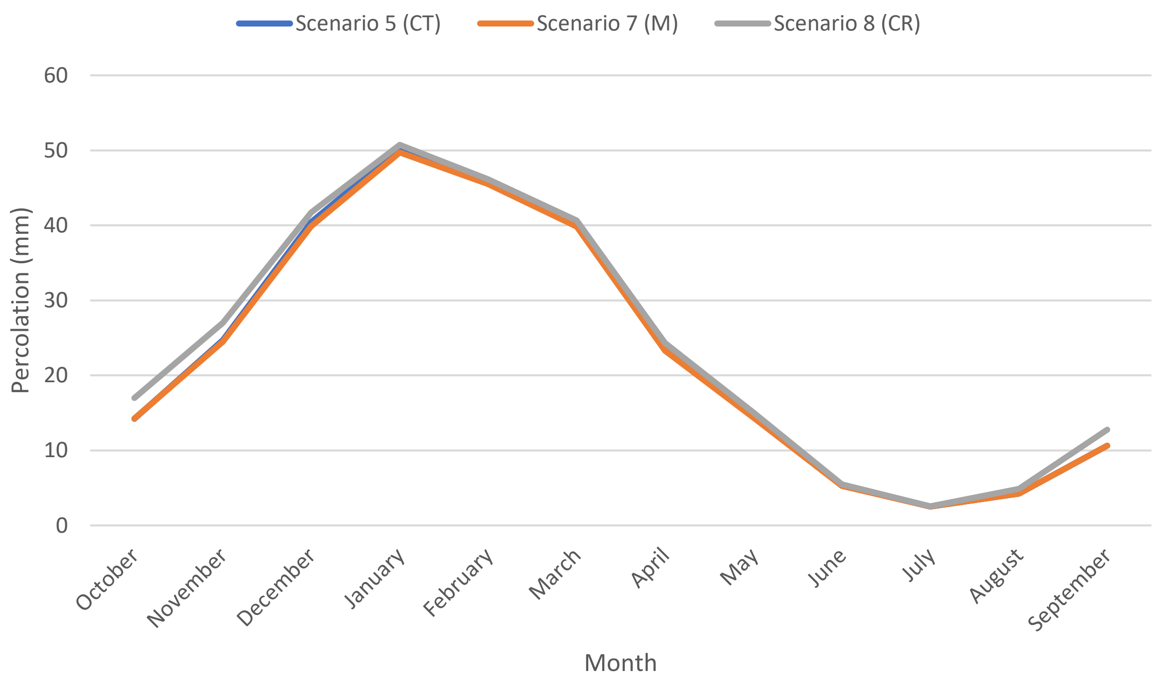

Baseline
Scenario 2 (M)
Scenario 3 (CR)
Soil Evaporation (mm) - Dry
45
40
35
30
25
20
15
10
5
0
January
February
March
April
May
June
July
August
September
October
November
December
Month

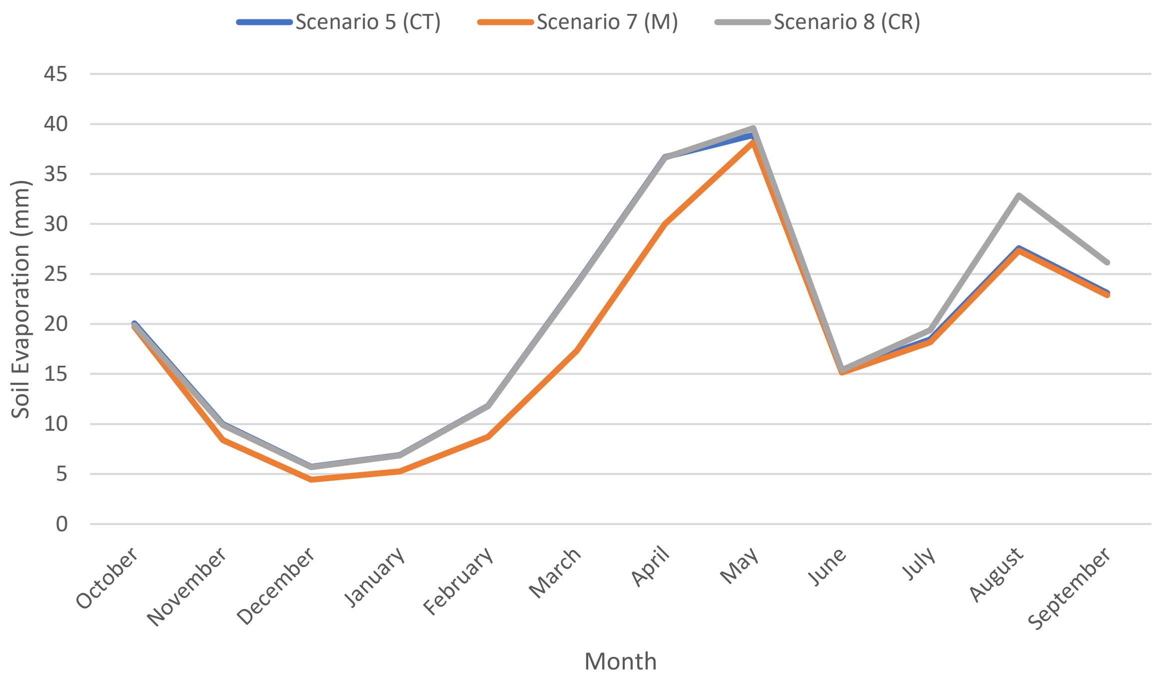

Baseline
Scenario 2 (M)
Scenario 3 (CR)
Plant Transpiration (mm) - Wet
70
60
50
40
30
20
10
0
January
February
March
April
May
June
July
August
September
October
November
December
Month

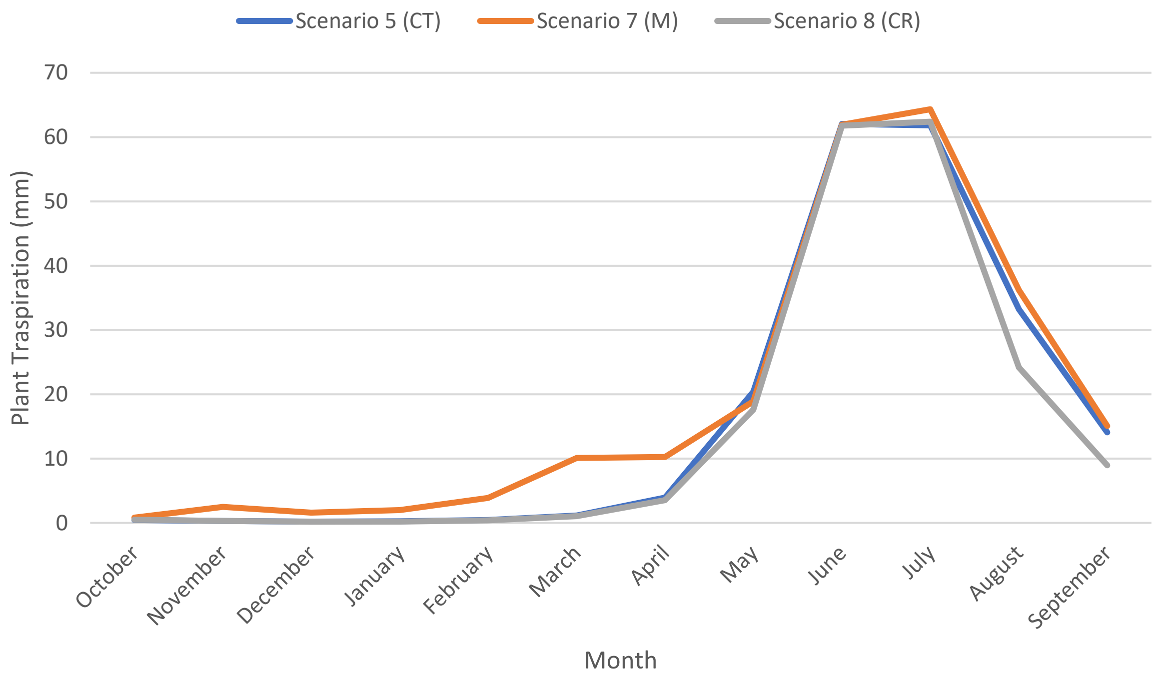

Baseline
Scenario 2 (M)
Scenario 3 (CR)
Plant Transpiration (mm) - Dry
70
60
50
40
30
20
10
0
January
February
March
April
May
June
July
August
September
October
November
December
Month

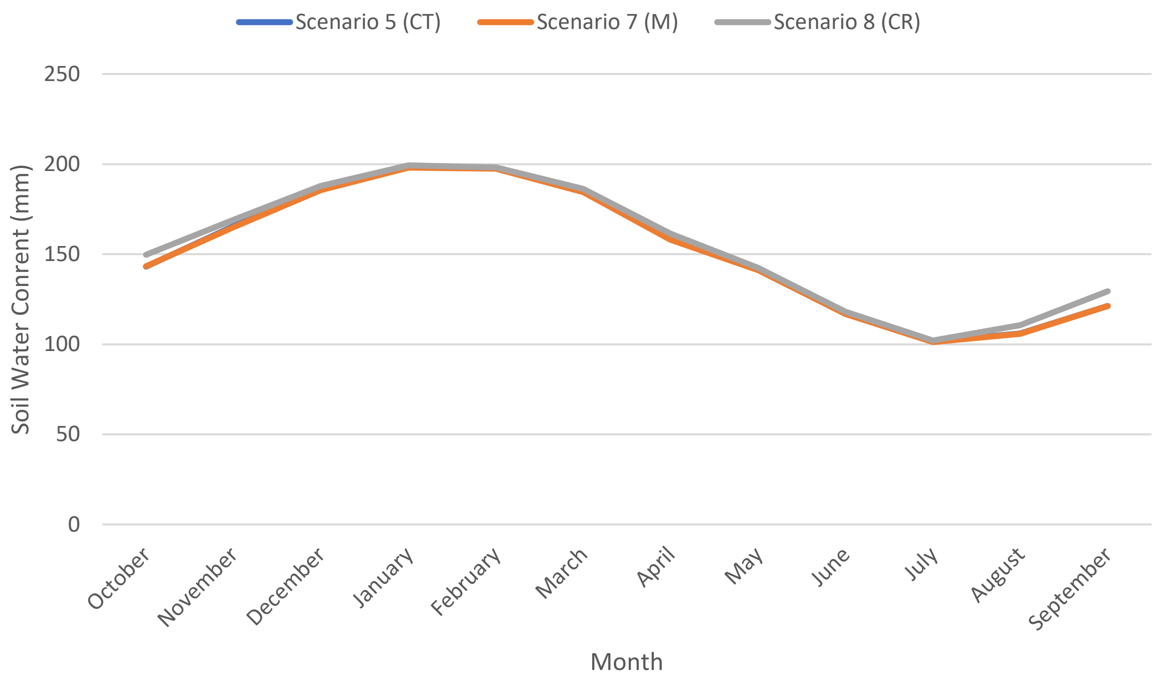
APPENDIX E MONTHLY AVERAGE HYDROLOGICAL FLUXES OF MULCHING AND CROP ROTATION UNDER FUTURE CLIMATE SCENARIO






Scenario 5 (CT)
Scenario 7 (M)
Scenario 8 (CR)
Soil Evaporation (mm)
45
40
35
30
25
20
15
10
5
0
October
November
December
January
February
March
April
May
June
July
August
September
Month


Scenario 5 (CT)
Scenario 7 (M)
Scenario 8 (CR)
Plant Traspiration (mm)
70
60
50
40
30
20
10
0
October
November
December
January
February
March
April
May
June
July
August
September
Month


Scenario 5 (CT)
Scenario 7 (M)
Scenario 8 (CR)
Soil Water Conrent (mm)
250
200
150
100
50
0
October
November
December
January
February
March
April
May
June
July
August
September
Month