THE INCREASING WATER DEMAND IN NORTH-WEST AFRICA: A LAND SYSTEMS APPROACH

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ABSTRACT

North-West Africa is a region with severe constraints on land and water resources. It is expected that the region will experience warming that exceeds global trends, leading to a decrease in precipitation and an increase in evapotranspiration. Simultaneously, the region can expect a population increase of 43% between 2010 and 2050. If the North-West African countries Morocco, Algeria, and Tunisia want to keep satisfying the growing demand of their population for resources, the agricultural, industrial, and domestic water use will see an increase. This research identifies the potential conflict over water demand between different sectors in North-West Africa until 2050, and the influences on its land systems change. These changes are projected with the use of the CLUMondo model and spatially analysed within a geographic information system environment. This study is hereby the first that considers land system changes by taking the domestic, industrial, and livestock drinking water use into account. The results show a drastic decrease of irrigated cropland, leading to an expansion and intensification of rain-fed cropland. Such a dependence on precipitation for food production might lead to an increase in food imports. Traditional mosaic land systems continue to play a large role in the production of food, and will simultaneously be able to provide ecosystem services and protect the biodiversity of the region. Moderate technological advancements in water use productivity and irrigation efficiency are analysed, however, the effect was negligible. This research shows the importance of taking all water uses into account when making land system change predictions. In addition, it provides policy recommendations for the protection of biodiversity, climate mitigation, and food security.

Key words Land systems – water resources – irrigation efficiency – climate change – land-use intensification – North-West Africa – agricultural mosaics

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1. INTRODUCTION

In 2010, the increase of global water stress and depletion of freshwater resources, in combination with maintaining high agricultural yields, were identified as two of the main challenges of the 21st century (UNEP/MAP-Plan Bleu, 2010). 10 years later, the challenges remain. In 2016, an estimated four billion people lived under conditions of severe physical water scarcity for at least one month a year (Mekonnen & Hoekstra, 2016). The Organisation for Economic Co-operation and Development estimates the global water demand to increase by 55% between 2000 and 2050, which is mostly fuelled by growing demands from manufacturing (+400%), thermal power generation (+140%), and domestic use (+130%) (OECD, 2012). Currently, the amount of water used for irrigation accounts for 69% of all freshwater withdrawals. However, the competition from the industrial and domestic sectors are slowing the growth of freshwater allocations to the agricultural sector (UNESCO, 2020). Proper water management is crucial to ensure Sustainable Development Goal 6, which relates to water availability and sustainable management of water resources for all (UN, 2015).

North-West Africa, consisting of Morocco, Algeria, and Tunisia, is a dynamic region with severe constraints on land and water and has been identified as one of the regions that will face the greatest economic threats from water scarcity due to climate change (Giorgi & Lionello, 2008; Giannakopoulos et al., 2009; Garcia-Ruiz et al., 2011; Fader et al., 2016). This is projected to cost up to 6% of its gross domestic product (GDP) (World Bank, 2016). It has been estimated that the region will experience warming that exceeds global trends, and can, by the end of this century and under a high-emissions scenario even increase to up to 4-5 degrees Celsius more than their preindustrial levels (UNESCWA et al., 2017). Fuelled by this changing climate, the region can expect an increase in potential evapotranspiration (PET), and a decrease in precipitation patterns (UNESCO, 2020), which will threaten the water availability of the region. Simultaneously, North Africa is amongst the regions with the highest population growth and dependency on food imports (Wright & Cafiero, 2011). If the countries want to keep feeding their population in the upcoming century they need to increase agricultural production (Mueller et al, 2012).

There are more factors to consider for the North-West African region concerning water stress and land-use change, including the potential of social unrest. The 2011 Arab Spring was preceded by a long drought that started in 2006 (Shatanawi, 2015). Although the protests and uprisings were caused by a multitude of social, economic, political, and religious factors, the role that water and climate played cannot be fully ignored. The rising food prices, due to a global food crisis that was fuelled by drought, were described as an aggravating factor by World Bank President Robert Zoellick (Johnstone & Mazo, 2011). In addition, land-use change could influence the biodiversity of the region. The Mediterranean ecoregion, which spreads over large parts of North-West Africa, has been identified as one of the Global Biodiversity Hotspots (Cuttelod et al., 2009). This is particularly due to its traditional agro-silvo-pastoral mosaic systems, which house a significant number of plant and animal species, a lot of them endemic (Malek & Verburg, 2017). The conservation of these landscapes is important for biodiversity and cultural heritage and could be influenced by water use and its resulting land-use change. For example, an increased need for domestic water, or a decrease in available water for irrigation might lead to an expansion of urban areas and rain-fed cropland, which could result in a decrease in mosaic systems.

Land can be seen as a limited resource, which provides goods and services such as shelter, food, and ecosystem services. Human activities and environmental developments continuously transform the natural landscape, able to change both land use and land cover (Van Asselen & Verburg, 2013). It is important to understand these changes within the context of the services that each land system provides, thus looking at the production of food, water, and ecosystem services. A drier climate can make it impossible for cropland to expand, and an increase in population can lead to more built-up areas. Simultaneously, land cover and land use influence climatic and socioeconomic processes. The use of fertilizers could impact biodiversity, and fertile land can attract labour and stimulate trade (van Asselen & Verburg, 2013). Land systems are a combination of land use, land cover, and land management. They are seen as integrated social-ecological systems (Malek & Verburg, 2017) and are therefore central components of climatic, social, and economic structures (van Asselen & Verburg, 2013). In other words, they allow us to not only look at the biophysical characteristics, or the socio-economic activities on land, but at both in an integrated manner.

Although research (Mualla, 2018; Wada et al., 2016) has shown that competing water demands will negatively impact water availability, there has been little research that illustrates the consequential land system changes in North-West Africa. In the recent decade, Mediterranean land-use changes have been assessed (Eitelberg et al., 2016; van Asselen & Verburg, 2012; Zomer et al., 2009, Souty et al 2012, Letourneau et al., 2012), although mostly within global or continental models. These models drew conclusions on the best methods to predict land system changes, however, did not take specific regional land system characteristics into account, such as the diversity of agro-silvo-pastoral mosaics or differences in land-use intensity (Malek & Verburg, 2017). Through the use of the CLUMondo model, Van Asselen & Verburg (2013) divided the world into 24 sub-regions, including North Africa, accounting for specific regional land system characteristics. They did, however, not account for potential technological developments and did not treat water as a limiting resource (Malek & Verburg, 2018). The assumption of unlimited water availability can lead to an overestimation of expanding irrigated areas, especially when considering the climatic changes the region will see in the upcoming years (Malek et al., 2018). In addition, it has been argued that the inclusion of changes in land management, such as irrigation efficiency and intensification, may be more important than the land cover changes when modelling future scenarios (Malek et al., 2018).

This research builds on the work done by Malek et al. (2018), and Malek & Verburg (2017, 2018). It will follow the land system classification as presented by Malek & Verburg (2017), thereby accounting for the specific land systems characteristics of the Mediterranean region. Malek & Verburg (2018) found that irrigation efficiency improvement plays a large role when projecting the intensity of rain-fed cropland and that these improvements are needed if the region wants to satisfy its food demand. However, this study only took water use for irrigation into account. In reality, the region has additional water demands, such as for domestic, industrial, and livestock purposes. In addition, the increase in potential evapotranspiration that is already present in the region (Hayashi et al., 2013) was not considered (Malek et al., 2018; Malek & Verburg, 2018). Moreover, it can be beneficial to take a smaller study area, as this will allow for more specific data and a more in-depth analysis.

This paper aims to identify the potential conflict over water demand between different sectors in North-West Africa in 2050, and its influence on land systems change. This will be done by projecting two land systems change scenarios based on not only irrigation water use, but also domestic, industrial and livestock drinking water use. Both scenarios will assume a decrease in water availability due to climate change. One of the scenarios will make a projection based on irrigation efficiency developments (Malek & Verburg, 2018), and domestic and industrial water use productivity (Ercin & Hoekstra, 2014). Based on the results, policy recommendations will be provided, which will assist in providing for the growing water needs to North-West Africa's increasing population, whilst protecting its biodiversity, climate mitigation and food security in the coming 30 years.

2. RESEARCH CONTEXT

2.1 Study Area

The countries of interest - Morocco, Algeria and Tunisia - cover 723,040 km^2 and house about 120 million people (Our World in Data, 2019). Their climate is arid to semi-arid and knows dry summers and mild winters (Zomer et al., 2008). Countries with similar climates are known to have harsh water and land resource constraints (Giannakopoulus et al, 2009; Fader et al., 2016). The three countries heavily depend on food imports, experience fluctuations in the food supply (Wright & Cafiero, 2011), and their prices could potentially become a threat for food security (Sowers et al., 2010). Some instances of water and land grabbing have already been identified (Houdret et al., 2012). The Mediterranean, which North-West Africa is a part of, is characterized by two processes of change. Rural mountainous and less developed areas see itself increasingly abandoned, whereas other areas see an intensification of land management and an increasing human influence (García-Llorente et al., 2012; Nieto- Romero et al., 2014). The consequences of climate change and population growth could lead to more regional instability, social and political vulnerability and conflicts (Evans, 2008; Sowers et al., 2010).

The area that is studied in this research, hereafter referred to as the North-West African region, covers the northern parts of Morocco, Algeria and Tunisia. It represents the area of these countries that is included in the Mediterranean forests, woodlands and scrub eco-region as presented by Olson et al., (2001). The land systems in 2010 are adopted from Malek & Verburg (2018) and can be observed in Figure 1. Morocco and Algeria are largely characterized by extensive and intensive arid grazing (Malek &Verburg, 2017). Some cropland and rangeland, which mostly exists of low-intensity cereal fields with livestock grazing, and parts of irrigated cropland can also be found, with forests covering the Atlas mountains (Malek & Verburg, 2017). Tunisia is largely covered by rain-fed intensive annual crops, and some irrigated cropland and extensive permanent crops. Small urban areas and wetlands can also be identified (Malek & Verburg, 2017). Historically, these wetlands are a source of water and fodder for livestock, with livestock numbers still increasing in the 1990s (Houerou, 1993; Medail & Quezel, 1999).

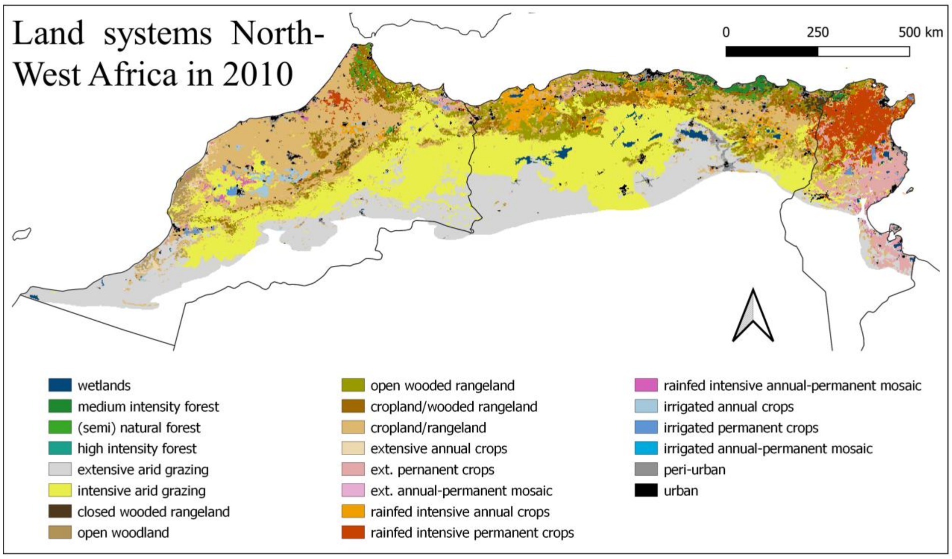

Figure 1. Land systems in North-West Africa in 2010

2.2 Water use and drivers in the region

Currently, irrigation is the largest consumer of freshwater resources in the North-West African region. In 2017, respectively 88%, 64%, and 77% of Morocco's, Algeria's and Tunisia's water withdrawal was used by the agricultural sector (FAO, 2017). Simultaneously, the Mediterranean South, including North-West Africa, imported 56% of its total crop consumption (Wright & Cafiero, 2011), and this is expected to increase to 73% in 2050 (World Bank, 2009). North-West Africa has a considerable amount of cropland with low yields and inefficient agricultural management (Mueller et al., 2012). Due to trade regulations, safety requirements and protection by the European market, it is difficult for the countries to export their fruits and vegetables (Larson et al., 2002; Cioffi & Dell'Aquilla, 2004; Garcia Martinez & Poole, 2004). This might be a reason for the fact that Morocco, Algeria and Tunisia respectively only used 36%, 69% and 77% of their internal renewable water resources for agricultural, industrial and domestic uses in 2014 (Ritchie, 2017). Because of this, the regions can still increase their water extraction. That being said, increasing the water extraction to its full potential might be a risky business. Due to inconsistent precipitation, the groundwater recharge varies. If groundwater extraction exceeds groundwater recharge for longer periods, persistent groundwater depletion can occur, which can have serious effects on the natural stream flow, groundwater fed wetlands and related ecosystems (Wada et al., 2010).

The underused water availability does not mean that the region will be able to provide for all its water demands in the future, especially considering the predicted climate change and socioeconomic developments. The North-West African region is expected to experience warming that will exceed global trends, leading to a decreasing precipitation and increasing temperature until the end of the 21st century (UNESCO, 2020). The consequential decrease in water availability (Chenoweth et al., 2011; Keenan et al., 2011; Guiot & Cramer, 2016) is already observed in West Africa (Batisha, 2012). Additionally, this will affect future trends in soil moisture and groundwater, which might influence the frequency and severity of soil moisture drought spells (Van Loon et al., 2016).

In comparison to the agricultural water use, the water uses for the industrial and domestic sector are, apart from the domestic water use in Algeria, relatively small. Morocco, Algeria and Tunisia used respectively 2%, 1.8% and 20% of the total water use for the industrial sector, and 10%, 34% and 3% for the domestic sector (FAO, 2017). However, it can be expected that these uses increase, following the projected socioeconomic development of the countries. Following the Shared Socioeconomic Pathway (SSP) 2 scenario, Morocco, Algeria and Tunisia are expected to have a respective population growth of 16%, 40% and 22% by 2050, compared to 2010 (KC & Lutz, 2017), with a substantial growth in urban population (Jiang & O'Neill, 2017). This is confirmed by UNESCO (2020), which projects that the fastest growing cities will be the ones with less than one million inhabitants, of which many are situated in Africa. The increase in population and urbanization will most likely lead to an increase in domestic water use (Wada et al., 2016). Socioeconomic developments will most likely also lead to an increase of industrial water use (Florke et al., 2013). Where the share of total water use in the whole African continent was 8% for industrial water use in 2010, it is projected to have grown to 18% in 2050, which is a change rate of 125% (UNESCO, 2020).

Although the non-agricultural water sectors are expected to grow most, the agricultural sector can be expected to see an increase in water use too. Due to the population increase and socioeconomic development, we will see a higher global food demand (van Asselen & Verburg, 2013). First of all, an intensification of livestock density is likely, which is often related to a high water footprint (Mekonnen & Hoekstra, 2012). Due to climate change, an increasing demand in feed substitutes such as soy and cereals can be expected, as the drought will most likely impact the sensitive grazing lands (UNESCO, 2020). In addition, an expansion and intensification of irrigated crop production can be expected, to maintain the high crop demand (van Asselen & Verburg, 2013). To satisfy the projected food demand with irrigated crops, substantial improvements to irrigation systems are necessary (Malek & Verburg, 2018). Due to climate change, however, it might be necessary to put restrictions on the water extractions, which might lead to an expansion of rain-fed cropland (Malek & Verburg, 2018).

3 METHODS

3.1 CLUMondo Model

CLUMondo (Conversion of Land Use on Mondial Scale) simulates future changes to land, combining information on land cover and land use, livestock, and management type and intensity (van Asselen & Verburg, 2012). The model assumes changes based on specific demands for goods and services that are provided by land systems, such as crops, livestock, industrial output and built-up areas (Malek et al., 2018; Malek & Verburg, 2017). The land systems classification allows for better representation of the composition and characteristics of the land systems and considers change driven by multiple demands simultaneously. CLUMondo is the only open access, spatially explicit land system model. By applying this model to the North-Western African region, it is possible to account for specific regional land system characteristics and driving factors (van Asselen & Verburg, 2013).

The changes to land systems are based on spatial restrictions, spatial preference and competition between land systems (Malek & Verburg, 2018). Figure 2 shows a visualization of the CLUMondo model. In summary, the model allocates land systems based on an iterative procedure whilst looking at the local suitability of different land systems, conversion rules, and future demand. Within the context of this research, the demand includes annual and permanent crops, built-up areas, livestock and water for the different sectors. For an overview of commodities produced per land system, refer to Table A in the appendix. Due to future climate change, a limit is put on the available water resources. On the supply side, the model takes crops, living space, livestock and water use into account. For this research, not only irrigation water use, but also domestic, industrial and livestock drinking water use are used as input. In addition, the water use efficiency is increased.

With this input, the model makes changes to land systems in individual pixels for each year. A land system is assigned to each cell if it is allowed in that location (conversion rules), and if it is has the highest transition potential (spatial preference) on that location. When that is done, the amount of commodities and services is calculated. If the demand and supply do not match, land systems that are producing undersupplied demands are given a higher transition potential (Debonne, Van Vliet & Verburg, 2019). Unlike other models, CLUMondo can address multiple demands at the same time and therefore does not assume a hierarchy in demand when allocating land systems (Ornetsmüller, Verburg & Heinimann, 2016). The model is described in more detail by van Asselen and Verburg (2013) and can be requested at www.environmentalgeography.nl/site/data-models/data/clumondo- model/.

3.2 Input data adopted from Malek & Verburg (2018)

The Mediterranean land systems map for the year 2010 (Malek & Verburg, 2018) (Figure 1) is used as a starting point to simulate future land system change until 2050. 2010 is used as a base year because the most recent data on sub-national crop production statistics were from 2010 and the reported national crop production for 2010 deviates the least from the average national crop production of the last 20 years (Malek et al., 2018). The map presents 22 different land systems on a 2x2 km resolution. The land system classification has been developed by Malek &Verburg (2017), and presents a multitude of land systems divided into wetlands, forest systems, arid grazing systems, agro-silvo-pastoral mosaics, croplands, and settlements.

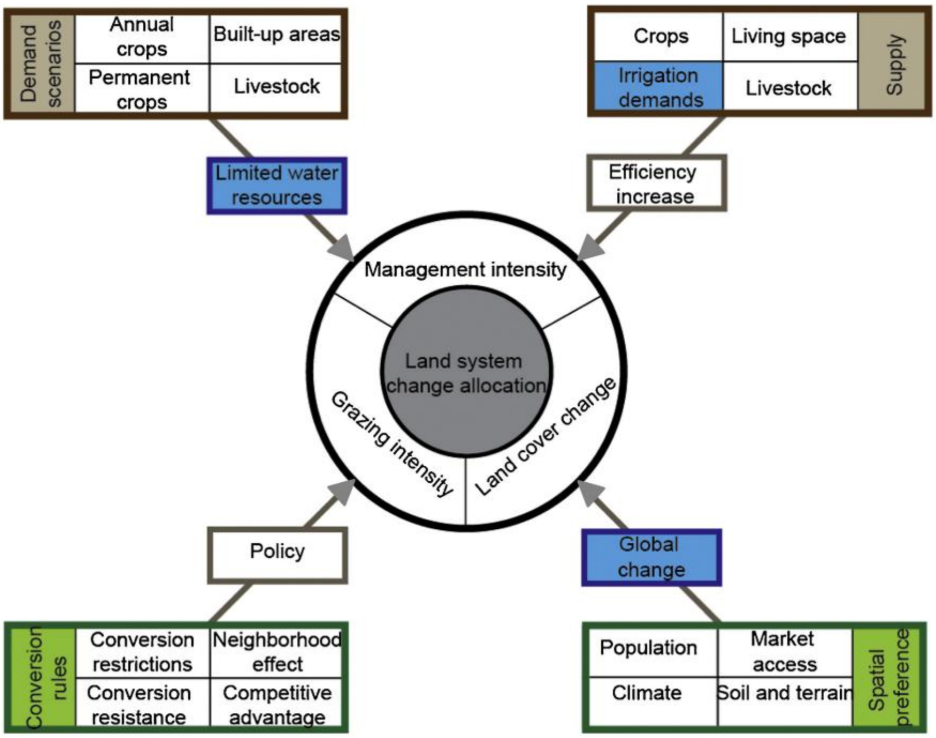

Figure 2. CLUMondo model structure (Malek et al., 2018).

To properly predict the future land system changes up to 2050, it is necessary to provide CLUMondo with input on the average supply of annual and permanent crops per land system unit, livestock production, and built-up area for each land system, which are adopted from Malek & Verburg (2018). The production of annual and permanent crops is based on food production projections following the SSP2 Marker scenario. The demand for built-up areas is linked to population change (Malek & Verburg, 2018). In addition, the water use for irrigation for each land system was provided by Malek & Verburg (2018).

Malek & Verburg (2018) calculated the mean of 19 CMIP5 (Coupled Model Intercomparison Project) simulations, forced by RCP4.5, for temperature and precipitation. With the use of 2050 values (mean of 2041 – 2060), they prepared annual temperature and precipitation maps. These were used to derive the Aridity Index (AI), which was used as a limiting factor for particular land system change processes (Malek & Verburg, 2018).

3.3 Current water use

To provide a more accurate representation of the land systems in 2010 and the years to come, this current research adds the average water uses for domestic, industrial and livestock drinking water purposes per pixel for each land system. See Tables B1-B3 in the appendix for the average water use per sector for each land system in 2010, the BAU, and the productivity scenario. The domestic and industrial water uses are calculated based on the national statistics of municipal and industrial water withdrawal in cubic metres per year (FAO, 2021). In addition, the livestock drinking water is calculated with the use of livestock units (LSUs). A LSU is a reference unit that combines the livestock of different species and age, by using specific coefficients that are based on the nutritional or feed requirement of each type of animal (EUROSTAT, 2020). The average water requirement is based on the LSU equation from EUROSTAT (2020), and uses data on the average drinking water in litres per year for milking and dry cows, and sheep on grassland (FAO, 2019). For goats, the same value as the drinking water for sheep on grassland is used, as there was no other data available.

3.4 Future water use and availability

The land system changes towards 2050 are projected based on the SSP2 Marker scenario. The SSPs illustrate five scenarios of socioeconomic developments. The SSP2 Marker scenario can be described as the 'Middle of the Road' scenario. It is characterized by medium challenges to mitigation and adaptation, and is therefore depicted as a 'central case' where the social, economic and technological trends follow a similar course as they have historically (Riahi et al., 2017). In this scenario, the population grows gradually, and income inequality only improves slightly at best (Riahi et al., 2017). Following the SSP2 scenario, North-West Africa is expected to have a population increase of 27% and an increase in GDP of 94% (KC & Lutz, 2017; Dellink et al., 2017). The relative change in domestic water use for the years 2011 – 2050 is calculated based on the relative population growth in the same timeframe from the SSP2 scenario, as it is expected that the domestic water use will follow a similar trend. The industrial water use is calculated based on the relative GDP growth between 2011 and 2050. The livestock drinking water is based on the projected livestock numbers as provided by Malek & Verburg (2018).

The water that is available to be used is projected by following the climatic changes projected by Representative Concentration Pathway (RCP) 4.5. The RCPs illustrate four pathways that describe the land use and emissions of air pollutants and greenhouse gases on a spatial scale for the period extending to 2100 (Van Vuuren et al., 2011). The RCP4.5 is one of the two medium stabilization scenarios, stabilizing at 4.5 W/m^2 in 2150. It is a cost minimizing scenario that equals a "medium" and probable scenario compared to other scenarios (Thomson et al., 2011). Considering land use, its projections are based on the assumption that carbon in natural vegetation will be valued as part of global climate policy, leading to reforestation and a decrease in cropland and grassland (van Vuuren et al., 2011).

For the current research, not only precipitation, but also potential evapotranspiration (PET) changes, derived from Malek & Verburg (2018), are used to predict the water availability between 2011 - 2050. Although climate studies often only focus on the changes in temperature and precipitation, it is important to include potential evapotranspiration too (Terink et al., 2013). With a higher rate of evapotranspiration, increasing temperatures and solar radiation lead to a lower rate of surface water. In combination with a decrease in precipitation, this can have a severe effect on water stress (Terink et al., 2013). A decrease of 13% in precipitation patterns, and an increase of 2% in PET levels is observed between the period of 2010 and 2050.

3.5 Scenarios, irrigation efficiency and water productivity

This study will make use of three scenarios: the reference scenario, the Business as Usual (BAU) scenario, and the productivity scenario. An overview of the three scenarios can be found in Table 1. Additional information on the scenarios is lined out below.

The reference scenario is adopted from Malek &Verburg (2018) and follows the SSP2 and RCP4.5 without improvements in irrigation efficiency and with limitations to water extractions. Malek & Verburg (2018) found that this scenario cannot contribute to future increases in food demand and will result in a decrease in irrigated cropland. This scenario takes the agricultural water demand into account. The results of this scenario will be compared with the BAU and productivity scenarios. The BAU scenario of this research also takes the domestic, industrial and livestock drinking water into consideration. Just like the reference scenario, it takes a water extraction limitation into account, following the RCP4.5 scenario as lined out above. Both the reference scenario as the BAU scenario assume an overall irrigation efficiency of 66% in North-West Africa (Malek & Verburg, 2018). The overall irrigation efficiency describes the amount of water used efficiently and the amount that is lost from the total water that is extracted from the supply on a national scale (FAO, 2016). This is calculated as a product of conveyance efficiency and field application efficiency, following Fader et al., (2016) (Malek & Verburg, 2018).

To account for technological improvements, a scenario with advanced irrigation efficiency and water productivity in domestic and industrial water use is projected. In the past years, significant improvements in irrigation efficiency have been made by implementing sprinkler or drip irrigation systems (Wriedt et al., 2009; Daccache et al., 2014). For this analysis, a Sprinkler scenario is used, as this has an average efficiency increase, and is more likely to be implemented on a large scale. Sprinkler irrigation is suitable for varying sizes of land, whereas drip irrigation is mostly suitable for row crops, expensive in infrastructure, and requires specific skills (Albaji et al., 2050)**.** An irrigation efficiency of 71% in 2050 is assumed following the implementation of sprinkler irrigation (Malek & Verburg, 2018). Compared to 66% irrigation efficiency in 2010, there is a decrease in water loss of 15% up until 2050. Technological improvements in the domestic and industrial sector can also be expected, mainly due to improvements in wastewater treatment levels and blue water use efficiencies. To reflect this progress, a 20% reduction in water use for these sectors is applied, following Ercin & Hoekstra (2014). This relates to a moderate improvement in water productivity.

Table 1. Overview of the three scenarios

	Water uses taken into account	Irrigation efficiency (compared to 2010)	Water productivity (compared to 2010)
Reference scenario*	Agricultural water use	No improvement (66%)	N/A
BAU scenario	Agricultural, domestic, industrial & livestock drinking water use	No improvement (66%)	No improvement
Productivity scenario	Agricultural, domestic, industrial & livestock drinking water use	Moderate improvement (71%)	Moderate improvement (20%)

**Adopted from Malek & Verburg (2018)*

To summarize, the productivity scenario follows the same trajectories as the BAU scenario, however, with 15% less irrigation water use, and 20% less domestic and industrial water loss. The land use change projections of the reference, BAU and productivity scenarios are compared, and the resulting changes in land system patterns are spatially analyzed in a geographic information system environment.

3.6 Studied adaptations

To understand the land system changes that take place between 2010 and 2050, several adaptations categories are compared. These adaptations consists of the expansion, renunciation or change in intensity in the different land system groups. They relate to an increasing demand of built-up areas (urbanisation), crops (intensification and expansion of cropland), and livestock (intensification of forest and arid systems). In addition, changes to irrigation were studied, to further analyze the effect of the growth of domestic and industrial water use. Furthermore, certain adaptation options, such as the intensification instead of expansion of forest systems, cropland systems and arid systems, relate to land scarcity. As the agro-silvo-pastoral mosaics play a large role in the cultural heritage of the region (Malek & Verburg, 2018), there is also a specific focus on the expansion of these multi-functional mosaic systems, called diversification. All studied adaptations, and their descriptions can be found in Table 2.

Table 2. Studied adaptations

Adaptation	Description	Land system conversions
Changes to irrigation use	Increase: increase in irrigated cropland	Rain-fed to irrigated cropland
	Decrease: decrease in irrigated cropland	Irrigated to rain-fed cropland
Changes to cropland intensity	Increase in intensity of cropland activities	Extensive cropland to intensive rain-fed cropland
	Decrease in intensity of cropland activities	Intensive rain-fed cropland to extensive cropland
Changes to cropland cover	Expansion: introducing cropland activities	Non-cropland to cropland land system
	Abandonment: abandonment of cropland activities	All cropland types to non-cropland land system
Diversification	Introducing new activities on cropland or woodlands, e.g. livestock grazing	Mono-functional systems to multifunctional mosaic systems
Changes to arid systems	Increase in intensity of arid systems	Extensive arid to intensive arid system
	Decrease in intensity of arid systems	Intensive to extensive arid system
Changes to forest systems	Increase in intensity of forest systems	Extensive to intensive forest system
	Decrease in intensity of forest systems	Intensive to extensive forest system
Urbanisation	Introducing urban settlements	All non-urban land system types to urban land system
No change	Activities stay the same	No change in land system

4 RESULTS

The spatial distributions of land systems in 2050 for Malek & Verburg's (2018) reference scenario, the Business as Usual (BAU) scenario, and the productivity scenario can be seen in Table 4, Figure 3, and Appendix C. Figure 4 shows the adaptations for each of the three scenarios between the years of 2010 and 2050, which are also displayed in Appendix D and Figure 5. All three scenarios seem to show similar major trends. There is a decrease in area covered by forest systems, irrigated cropland, and extensive cropland. These are converted into arid systems, agro-silvo-pastoral mosaics, settlements and rain-fed intensive cropland. Next to the major trends, some smaller, but substantial differences between the scenarios can be observed. There is a higher decrease in irrigated cropland, and a higher increase in rain-fed intensive cropland in the BAU and productivity scenarios compared to the reference scenario. In addition, there is a higher rate of forest loss, and a lower rate of diversification. A higher rate of urban expansion can also be observed in the BAU and productivity scenarios.

These differences can be better understood when taking the projected differences in water use per sector between 2010 and 2050 into account. Where the agricultural sector used 70% of all water in 2010, this share decreases to respectively 27% and 31% in 2050 in the BAU and productivity scenario (Table 3). Within these scenarios, the domestic and industrial water uses are expected to grow with such extremity, that little water seems to be available for irrigation. When not taking the other water uses into account, the agricultural sector is still projected to use about 70% of the available water in 2050.This is what fuels the differences between the reference scenario and the BAU and productivity scenarios.

Table 3. The share of water use of each sector in 2010, the reference (2050), BAU (2050), and productivity (2050) scenarios

	Share irrigation water use	Share domestic water use	Share industrial water use	Share livestock water use
2010	70.42%	24.03%	4.66%	0.89%
Reference (2050)	70.23%	N/A	N/A	N/A
BAU (2050)	26.56%	48.00%	23.80%	1.63%
Productivity (2050)	31.18%	44.74%	22.19%	1.90%

4.1 Croplands

There is a decrease in irrigated cropland in all three scenarios, however, this is considerably larger in the BAU and productivity scenario than in the reference scenario (Table 4). Where irrigated cropland takes up almost half of all cropland in 2050 in the reference scenario, this is reduced to 10-15% in the BAU & productivity scenario. This can be explained by the added water use of the industrial and domestic sector, leaving less water for irrigation. Irrigated cropland has a higher yield than rain-fed cropland, meaning that a decrease in irrigated cropland leads to less crop production per area.

This is made up for by a shift from extensive to intensive rain-fed cropland, and a general expansion of cropland area. The cropland expansion almost exclusively happens on previous agro-silvo-pastoral mosaics (Appendix E2). In the reference scenario, almost all of these mosaic systems are turned into rain-fed intensive cropland, although a considerable part converts to irrigated cropland. In the BAU and productivity scenario, the added cropland is turned into both extensive and intensive rain-fed cropland, with no addition in irrigated cropland.

Although a small part of the cropland area sees a change from intensive to extensive rain-fed cropland, this is considerably smaller than the shift from extensive to intensive rain-fed cropland, leading to a general intensification of rain-fed cropland (D). This makes up for the yield lost by the decrease in irrigated cropland. The cropland expansion can mostly be observed in central Tunisia and North-West Algeria. Cropland intensification plays the biggest role in North-West Algeria (Figure 4).

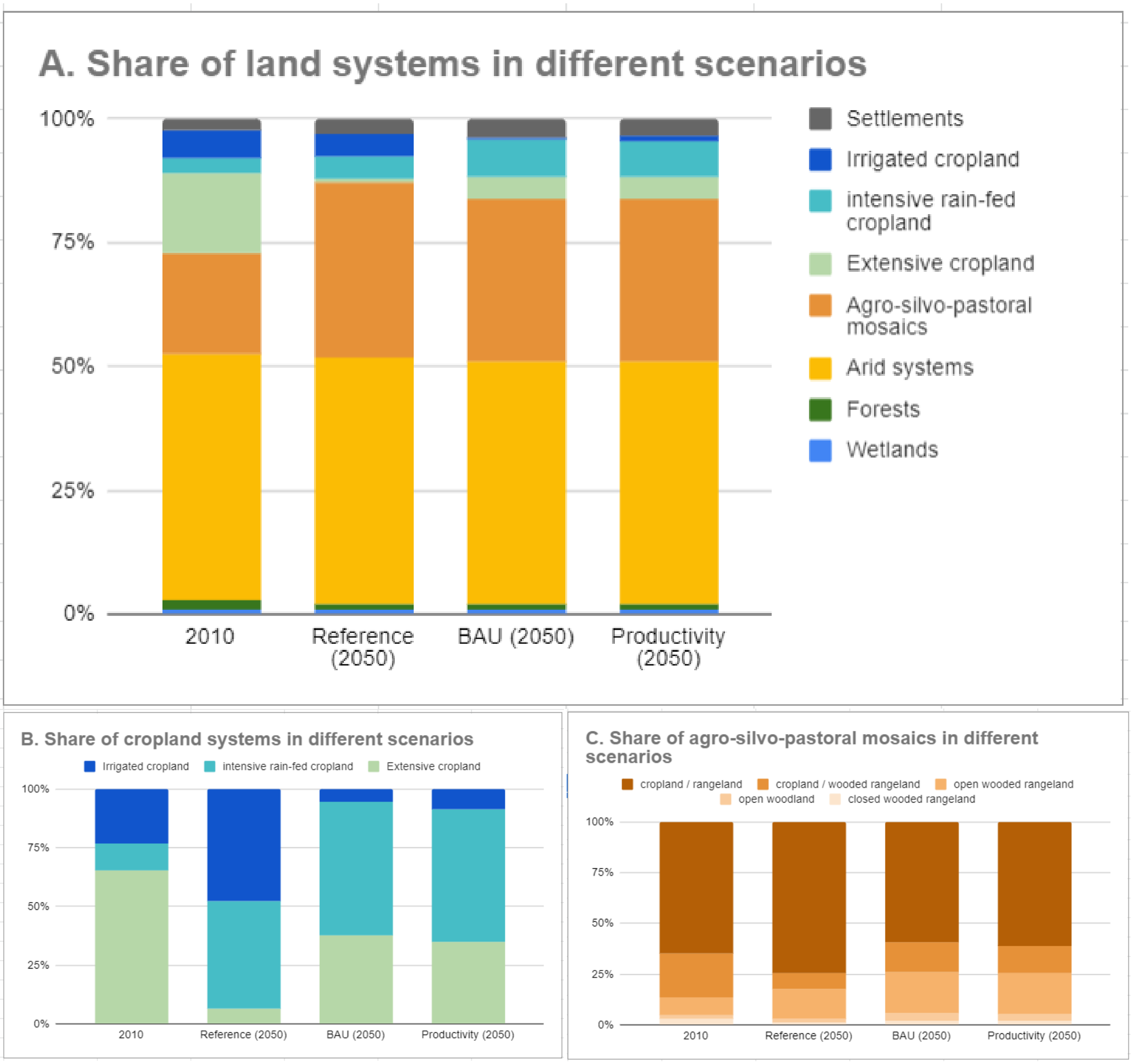

Figure 3. The share of all land systems (A), cropland systems (B), and agro-silvo-pastoral mosaics (C), in 2010 and the reference (2050), BAU (2050) and productivity (2050) scenarios.

Table 4. Distribution of land systems in North-West Africa in 2010 and the reference (2050), BAU (2050) and productivity (2050) scenarios.

	2010		2050 Reference			2050 BAU			2050 Productivity		
	km^2	Share of total area	km^2	Share of total area	Change compared to 2010	km^2	Share of total area	Change compared to 2010	km^2	Share of total area	Change compared to 2010
Wetlands	6464	0.78%	6464	0.89%	14.28%	6464	0.89%	14.28%	6464	0.89%	14.28%
Forest systems	12904	1.56%	8688	1.20%	-23.05%	8156	1.13%	-27.77%	7872	1.09%	-30.28%
Arid systems	360976	43.68%	358252	49.55%	13.42%	355220	49.13%	12.46%	355836	49.21%	12.66%
Agro-silvo-pastoral mosaics	147552	17.86%	257888	35.67%	99.74%	234772	32.47%	81.84%	236884	32.76%	83.48%
Extensive cropland	116700	14.12%	4432	0.61%	-95.66%	34760	4.81%	-65.96%	31640	4.38%	-69.01%
Rainfed inten. cropland	19988	2.42%	31656	4.38%	81.00%	52508	7.26%	200.22%	51104	7.07%	192.20%
Irrigated cropland	144932	17.54%	32916	4.55%	-74.04%	5032	0.70%	-96.03%	7572	1.05%	-94.03%
Settlements	16808	2.03%	22744	3.15%	54.65%s	26128	3.61%	77.66%	25668	3.55%	74.53%

In 2010, the North-West African food production was mostly taken care of by its irrigated cropland, although rain-fed cropland and the agro-silvo-pastoral mosaics also played a part. In 2050, the reference scenario projects that intensive rain-fed cropland and irrigated cropland each play a similar role, being responsible for roughly one third of the food production each (Appendix F). However, when taking into account the other water use sectors, the little amount of water that is left for irrigation purposes causes irrigation to almost disappear, leaving rain-fed cropland responsible for half of the region's food production, the rest divided over mosaics and settlements.

Whereas both the BAU and productivity scenario experience a bigger decrease in irrigated cropland, and a bigger increase in rain-fed intensive cropland than the reference scenario, these differences are larger in the BAU scenario (Figure 5). The increases in irrigation efficiency and water use productivity in the domestic and industrial sector leave a bit more water for irrigated cropland, leading to a slightly lower rate of cropland expansion and rain-fed cropland intensification.

4.2 Natural systems

The arid systems, which already take up a big part of the land in 2010, experience an increase, taking up almost half of the land area in 2050 in all three scenarios (Figure 3). Within arid systems, a high rate of intensification can be observed, it being the second biggest adaptation in all three scenarios (Figure 5). This means that the arid systems will be able to host more cropland and livestock. The differences between the three scenarios are shown in Appendix D. The intensification can mostly be observed in the inland parts of Morocco and Algeria (Figure 4).

On the other hand, the size of forest systems decreases, with a higher rate in the BAU and productivity scenario (Table 4). Both in 2010, and in all three 2050 scenarios, forests take up only a small portion of the North-West African eco-region (Figure 3). Of all forest loss, almost all can be attributed to an increase of agro-silvo-pastoral mosaics, with intensive rain-fed cropland playing a small role in the BAU and productivity scenario (Appendix E6). In the BAU and productivity scenario there is almost no forest intensification or extensification, however, in the reference scenario forest extensification can be observed (Figure 5). As the higher intensity forests can accommodate for more cropland than the low intensity forest, this leads to slightly more cropland in the BAU and productivity scenario than in the reference scenario. All together, the change from forest systems to mosaics, which is larger in the BAU and productivity scenario, is projected to lead to a higher proportion of cropland and livestock and less trees.

4.3 Diversification

Of all adaptations, diversification is most present by far (Figure 5). Diversification takes place when mono-functional land systems such as cropland or forest systems develop into multi-functional land systems (Malek & Verburg, 2018). These multi-functional systems, specifically agro-silvo-pastoral mosaics, are landscapes where forest activities coincide with grazing and agriculture. They are characterized by medium- to high-intensity cropland, combined with a relatively high rate of tree cover, and a medium amount of livestock. The systems include closed wooded rangeland, open woodland, open wooded rangeland, cropland/wooded rangeland, and cropland / rangeland, in order of a high tree rate with a low cropland and livestock rate to a low tree rate with a high cropland and livestock rate.

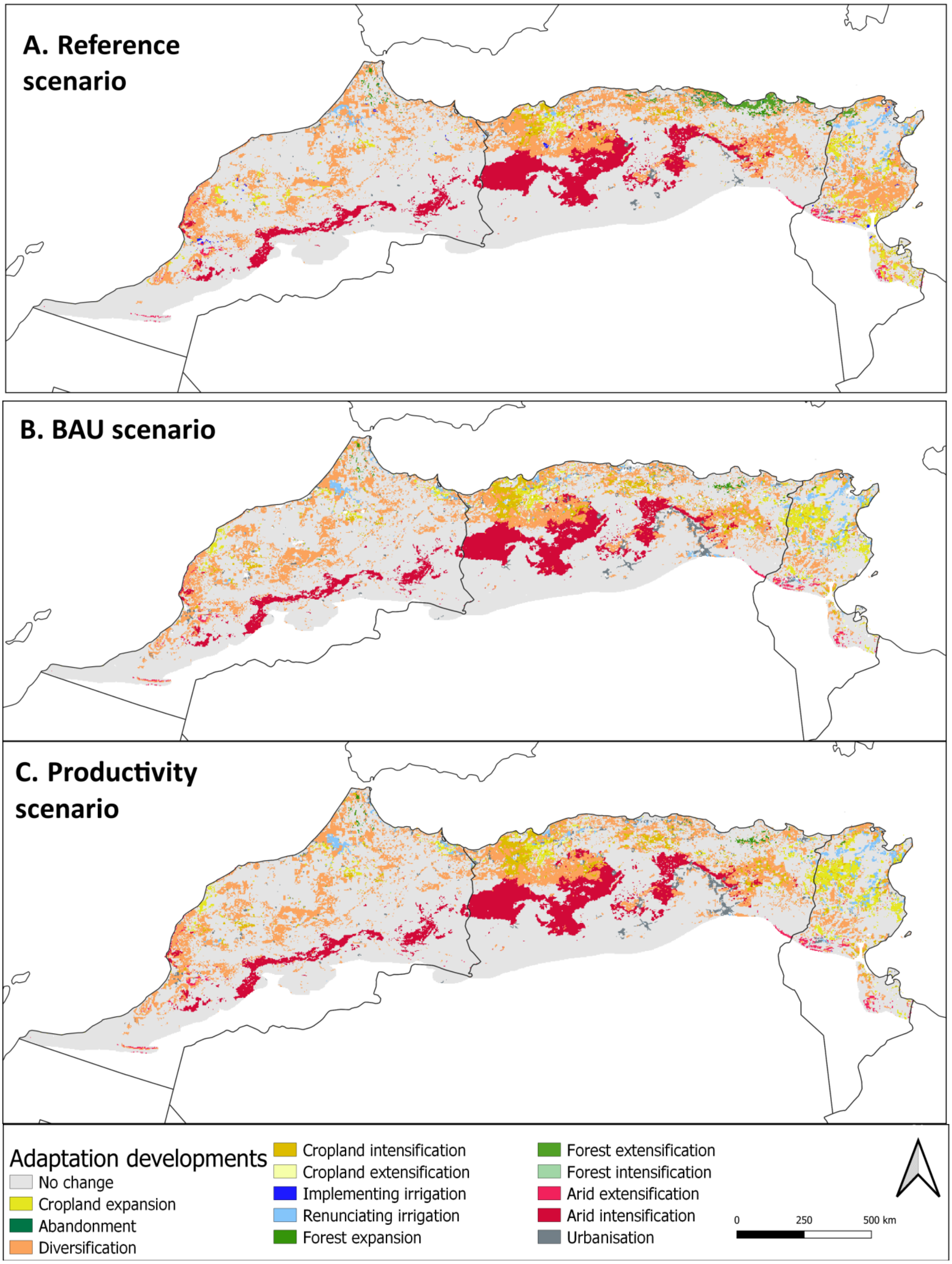

Figure 4. Adaptations 2010-2050 for the reference (A), BAU (B), and productivity (C) scenarios.

The area covered by agro-silvo-pastoral mosaics is projected to experience a big increase, almost doubling by 2050 following the reference scenario, and seeing an increase of just over 80% in the BAU and productivity scenario (Table 4). In 2010, the agro-silvo-pastoral mosaics in the region were mostly characterized by cropland / rangeland, and cropland / wooded rangeland. The increase mainly occurs as an encroachment in area covered by open wooded rangeland and cropland / rangeland (Appendix E5). This results into open wooded rangeland and cropland/rangeland as the largest agro-silvo-pastoral mosaics in 2050 in all three scenarios (Figure 3). Most of the diversification happens on previously extensive cropland in the reference scenario (Appendix E4). In the BAU and productivity scenario this is similar, although a considerable amount of mosaics are converted from irrigated cropland. Open wooded rangelands host a substantial amount of trees, croplands and livestock, thus being able to cater to a growing food demand while keeping some of the tree cover. Cropland / rangeland accommodates most crops out of all mosaic systems and a considerable amount of livestock, and thus provides more food for a growing population (Malek & Verburg, 2017).

The projected diversification takes place in all three countries, at both coastal and more inland areas (Figure 4). Little differences can be observed between the BAU and productivity scenario, indicating that an increased irrigation efficiency and water use productivity do not play a large role in the preservation or expansion of these traditional Mediterranean landscapes.

4.4 Settlements

The size of settlements increases too. This is projected in all three scenarios, although with 25% more in the BAU and productivity scenario compared to the reference scenario (Table 4). The highest rates of urbanisation can be found in the inland part of Algeria (Figure 4). The urban expansion mostly takes place on arid systems and croplands (Appendix E1). In the reference scenario, it is mostly the extensive croplands that are converted into peri-urban or urban lands, in the BAU and reference scenario, this happens on irrigated cropland. Where a relative amount of urbanisation takes place on mosaics in the reference scenario, this development is halved in the BAU and productivity scenario. The increase in urbanisation in the BAU and productivity scenario compared to the reference scenario is mostly likely an artificial by-product of the CLU-Mondo model and the provided data by Malek & Verburg (2018). Generally, irrigated cropland hosts a relatively high amount of people and built-up areas, higher than extensive or intensive rain-fed croplands. To make up for the lost living space due to a decrease in irrigated cropland, the model expands the urban areas. In reality, however, it is uncertain if this urbanization rate is that much higher when taking into account domestic and industrial water use.

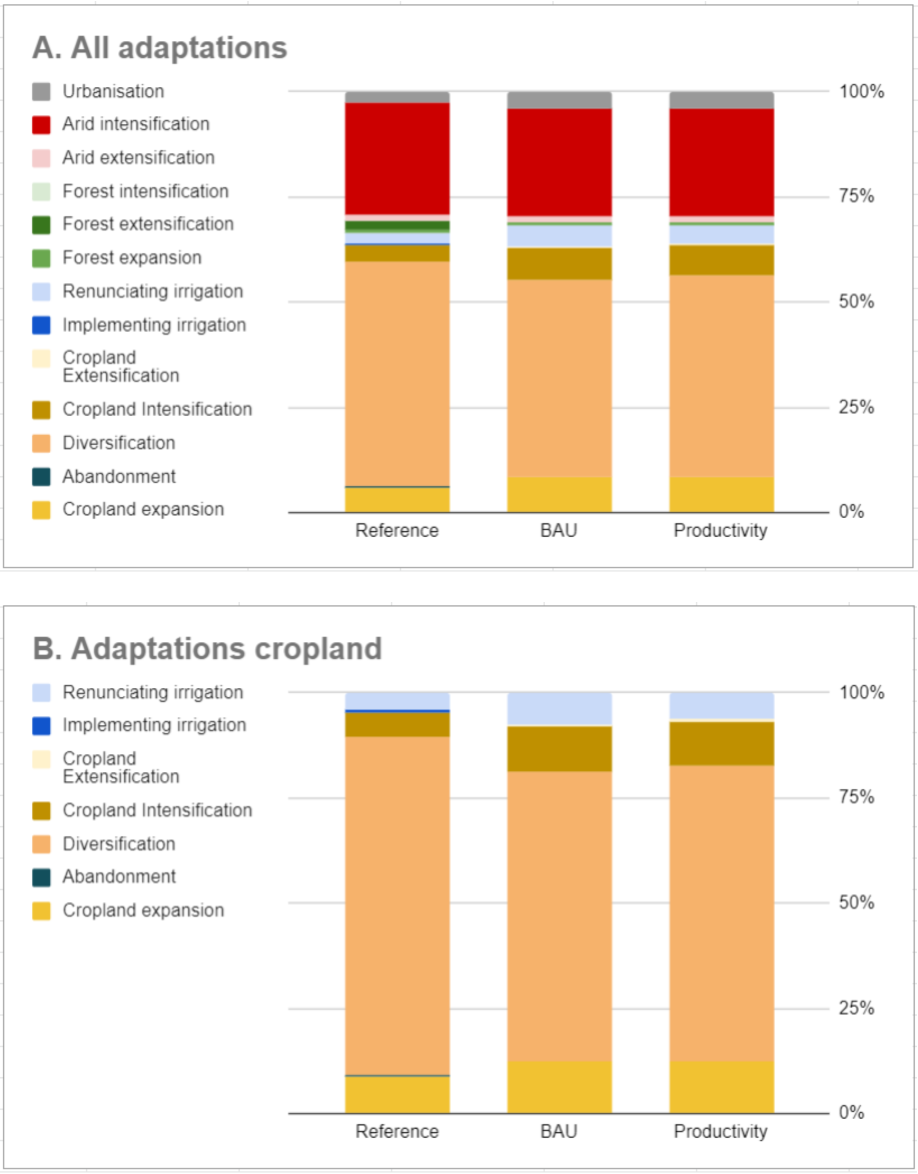

Figure 5. All adaptations (A) and cropland adaptations (B) between the period of 2010 – 2050 in the reference, BAU and productivity scenarios.

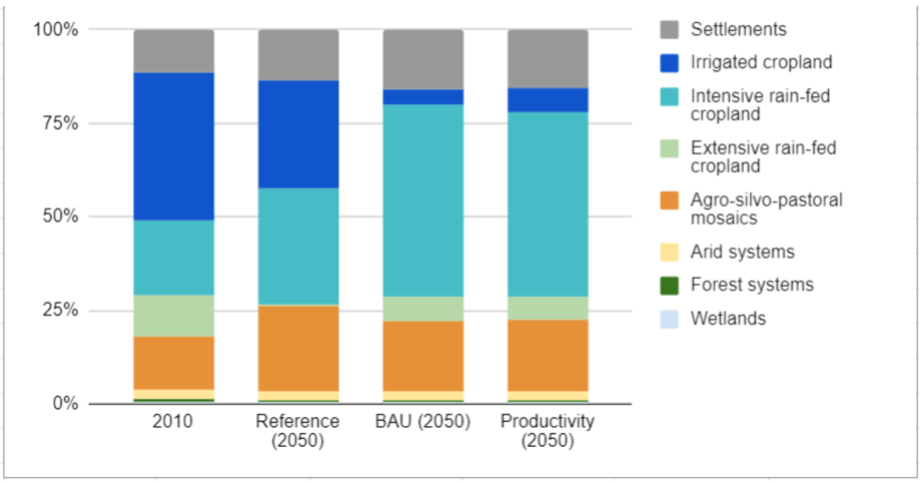

Figure 6. Crop production of each land system in 2010 and in reference (2050), BAU (2050), and productivity (2050) scenarios.

5 DISCUSSION

Malek & Verburg (2018) conclude that the limited amount of freshwater constraints the extent of irrigated cropland in the Mediterranean, especially with low irrigation efficiency improvements and limited water availability. Although the current research would not draw any different conclusions, differences in land system change outcomes are present when taking domestic, industrial and livestock drinking water use into account. Projections on population and GDP growth incite an increase in domestic and industrial water use that limit the use for irrigation. Following the models as presented in the current research, the share of water use for irrigation is projected to drop from 70% in 2010, to respectively 27% and 31% in 2050 in the BAU and productivity scenario. This has several implications to food production and biodiversity in the North-West African region, as outlined below.

5.1 Food production

CLUMondo projects that the region will still be able to feed its growing population in 2050, due to an intensification and expansion of its rain-fed cropland. However, such a big reliance on rain-fed cropland can be risky. Extreme weather events, such as long periods of drought will likely increase in both frequency and intensity, in addition to simply more variability in precipitation. This means that there could be an increased reliance on food imports (Rudel et al., 2009), which can mean higher global food prices, and more fluctuations on the market (Johnstone & Mazo, 2011). This can add to tension and social unrest within the region's population, like we have seen in the lead-up to the Arab Spring (Shatanawi, 2015).

The intensification of rain-fed agriculture will also mean that it will get harder for small-scale farmers to make a livelihood. High-intensive cropland needs high inputs of labour, capital and pesticides, and is often owned by big corporations taking part in industrial farming activities. The agro-silvo-pastoral mosaics, where cropland, trees and livestock co-exist and which are usually occupied by small-scale farmers, do increase in area size. It is good to note that this increase is lower in the BAU and productivity scenario than it is in the reference scenario, showing that if additional water uses are not taken into account, the size of these mosaic systems might be overestimated. Woertz (2017) claims that the high level of unemployment in the wake of the Arab Spring could be partially solved by a higher demand for farmers. In addition, it is likely that young people who grow up in the country side and feel like there is no work for them on the fields anymore, will move to the cities, leaving the countryside empty. To prevent this from happening, it is crucial to direct energy to preserving these mosaics, especially since most extensive rain-fed cropland will disappear. Shown by Malek et al. (2018), this is possible with the help of rural development policies that focus on improving the socio-economic conditions of rural areas, and by increasing yields within traditional mosaic systems.

The differences between the BAU and productivity scenario are small, suggesting that improved water productivity and the widespread implementation of sprinkler irrigation will not lead to enough water saved to stop the disappearance of irrigated cropland. Although it has been shown that more drastic irrigation efficiency, such as the implementation of drip irrigation, would lead to much different higher rates of irrigated cropland (Malek & Verburg, 2018), it is unlikely that this will be implemented on a large scale, as it is more expensive, harder to use and not suitable for all sizes of land.

The increase in livestock is mostly taken care of by a high rate of intensification of arid systems, and a small expansion of arid systems in all three scenarios. There is little difference between the three scenarios, indicating that the increasing domestic and industrial water uses do not have an influence on the area size or intensification of arid systems. This would suggest that grazing areas are largely in locations that are unsuitable for rain-fed cropland, which is not surprising, as these areas are known for being subject to little precipitation. Although the share of livestock drinking water almost doubles, it still only makes up a few percent of the total water use.

As elaborated on by Malek & Verburg (2018), the intensification of grazing systems can, amongst others, be done by fertilising, implementing controlled fires, or increasing the use of feed complements (Godde et al., 2018). There is a risk of overgrazing, however, which can lead to land degradation, the reduction of the land's capacity to provide ecosystem goods and services and assure its ecosystem functions (FAO, 2016). This can decrease land productivity, damage ecosystems, and cause food insecurity, migration and limited development (FAO, 2016). The impact of the intensification of grazing systems on the degradation of the land is varied and depends on the agro-ecological context and the farming practices involved (Godde et al., 2018). Simultaneously, however, less arid grazing system intensification will most likely lead to an expansion of grazing systems, most likely on previous forest systems. This can have an impact on the biodiversity and its accompanying ecosystem services. If the arid intensification is taken care of by traditional communities, there is a higher chance that they will also take up the responsibility of land recover through tree planting and conservation (Reid et al., 2014).

5.2 Biodiversity

Agro-silvo-pastoral mosaics can not only play a part in the region's future crop production, they also play a large role in the preservation of the North-West African biodiversity (Fagúndez et al., 2016). Although studies show that these landscapes are experiencing an increasing abandonment due to intensification (Bajocco et al., 2012; Schaich et al., 2015), the projections of this research expect a considerable increase in area size covered by agro-silvo-pastoral mosaics. That said, the BAU and productivity scenario project a smaller increase in agro-silvo-pastoral mosaics than the reference scenario, indicating that it is important to take all water use into account when making these predictions.

Due to their value for livestock production, crop production, biodiversity, and job protection of small-scale farmers, the agro-silvo-pastoral mosaics must be preserved and expanded on. These traditional Mediterranean landscapes are linked to the preservation of the 20% of the world's floristic richness (Médail & Quezel, 1999). In addition, they can play a role in preventing the soil erosion that is caused by more intensive cropland (Almagro et al., 2016). They are suitable in hilly areas with changing environmental conditions (Malek & Verburg, 2018), and might thus be more resilient to future climate change than mono-functional cropland systems. That said, extreme weather events might reduce the crop and livestock production (Latorre et al., 2001; Freier et al., 2014).

As opposed to the mosaics, the North-West African forest systems are projected to decrease. Although they only cover 1.5% of the whole ecosystem in 2010, this decreases even more in 2050 in all scenarios. The projected forest loss is a continuation of a trend that already started earlier. Mace (2005) found that forest cover in the Mediterranean area has been lost at a rate of 30% since the 1950s, which is not much different than the findings of this research. Forest systems play an important role in the lives of humans and fauna, providing food and fibre, and protecting watersheds and their vegetation, water flows and several types of ecological services (Mohajane et al., 2017).

The North-West African forests contain, amongst others, high rates of holm oak, cedar forest, bare soil, cork oak, zeen oak, and maritime pine (Achour et al., 2018; Mohanaje et al., 2017). A study done in Saïda, Algeria, identified as one of the world's biodiversity hotspots, found that about 13% of the flora studied in the area was rare, with a great biological and heritage interest (Djebbouri & Terras, 2019). If the region wants to protect its biodiversity, and the accompanying services it provided, it is of high importance that further forest loss is contained and that habitat protection projects are set up.

5.3 Climate Change

Climate change does not only influence the development of land systems, land system change also affects climate change. The deforestation that is projected to take place will lead to a reduction in tree cover. Forests and trees store large amounts of carbon in their vegetation and soils, and are therefore a crucial component in climate change mitigation (Zomer et al., 2008). The projected reduction in irrigated cropland and the consequential expansion of rain-fed cropland thus affects the carbon sequestration in the countries studied. A solution for this problem could be the implementation of agroforestry with the help of small-holder farmers and rural communities, as elaborated on by Zomer et al. (2008). This would not only increase carbon stocks, but would simultaneously tackle problems related to food security.

Another issue related to climate change and land systems is the use of fertilizers on the expanded intensive rain-fed cropland. Due to the limited water available for irrigation, the food production largely needs to be taken care of by an intensification of rain-fed cropland, thereby increasing the use of fertilizers. Synthetic nitrogen, one of the most widely used fertilizers, affects atmospheric concentrations of carbon dioxide, methane and nitrous oxide: the three most important greenhouse gases (Suddick et al., 2013). In addition, nitrogen emissions will affect air quality and aquatic ecosystems (Suddick et al., 2013). To decrease the amount of nitrogen use, it is important to initiate this within the context of food security policies and livelihood income policies (Bockel & Smit, 2009). In addition, reducing the dependence on chemical inputs will increase the resilience of food production (Bockel & Smit, 2009).

5.4 Research limitations

Although a plausible and detailed set of projections was developed, it is important to be aware of the missing information and generalization that this research poses. The presented scenarios only cover a fragment of potential future realities. First of all, the SSP and RCP projections are subject to a certain uncertainty range, which translates to similar uncertainties in this analysis. For both the RCP and SSP scenarios, a medium pathway was chosen. In reality, climate change could be subject to a lot higher temperatures, or the SSP scenario to higher or lower population and economic growth. Furthermore, the use of GDP as an estimating factor for industrial water use is most likely a simplification of the reality. Although a correlation between the two has been reported (Ercin & Hoekstra, 2014), Duarte et al. (2013) show a negative income elasticity for GDP and water withdrawal per capita for all three countries studied, implying that in the long run, an increase in GDP will result in a slight decline of water use per capita. The correlation between GDP and industrial water use as followed in the current research is thus a simplification and could be assumed to be different in reality.

In addition, there is an uncertainty range concerning technological advancements. All scenarios include improvements to yield densities, and the productivity scenario applies a moderate improvement in water productivity for domestic and industrial water use, and a moderate irrigation efficiency improvement. It is, however, possible that the yield losses will be higher, due to climate change, and that technological advancements will be different. Improvements in irrigation efficiency and water productivity is costly, and political instability may limit investments in technological improvements to water productivity, irrigation efficiency, and other measures that might otherwise improve agricultural efficiency. Simultaneously, however, the economic development of the countries can lead to a higher awareness of water scarcity, and therefore more priority might be given to the development of water saving technologies.

Apart from differences in possible scenarios, CLUMondo does not have the ability to take all socioeconomic decisions into account. First of all, Jensen (2007) poses that improved irrigation efficiency will not actually lead to a reduction in water extraction, but rather to increases in irrigated areas. Due to the productivity of their land, they are stimulated to increase their production, and thus expand their irrigated cropland. In addition, political instability may not only play a role in water use productivity and efficiency improvements, but also on the development of other land systems. For example, Hanson et al. (2009) noted that 80% of the armed conflicts have taken place in biodiversity hotspots, and Achour et al. (2018) found that forest losses have almost tripled in the four years after the Arab Spring started, compared to the four years before. Although no definite conclusions can be drawn from this, it is a good reminder that many more factors play a role when determining future land system change.

Furthermore, the water use for tourism has not been included in this analysis. Tourism is a major competitor for water use (Ortuño, Hernández & Civera, 2015), but is an understudied and often overlooked area (Gössling, 2005; Gössling, 2006; Gössling et al., 2012). The Mediterranean is one of the world's main holiday destinations, having received 30% of the international arrivals in 2011 (De Stefano, 2004). In 2010, respectively 7.2% and 6% of the GDP could be attributed to tourism in Morocco and Tunisia (Bouzahzah & El Menyari, 2013). The two countries have ranked in the top three of largest sources of foreign exchange (Bouzahzah & El Menyari, 2013). There has, however, been very limited research done on tourism-related water demand, especially when comparing this to other water uses (Deyà Tortella & Tirado, 2011), which makes for a lack of available data. If more data on tourism water use becomes available, however, it is highly recommended to run a similar analysis whilst taking tourism water use into account.

Finally, combining data on land use, management intensity, and irrigation with crop production and water withdrawal values, leads to a certain level of generalization. This is especially the case on a larger scale (Malek & Verburg, 2018). Adding data on domestic, livestock and industrial water use will only increase this generalization and can lead to an aggregation of uncertainties. As the size of the region is relatively high, the spatial resolution leads to higher spatial inaccuracies. Altogether, the scenarios presented should be seen as potential opportunities for being able to meeting such water demands, within the context of possible climate change. The model shows the possible land system changes and adaptations that the region might (need to) go through to ensure enough water for all sectors.

6. CONCLUSION

Building on the research carried out by Malek & Verburg (2017, 2018) and Malek et al. (2018), land system changes were projected based on future water use in the North-West African region with the use of the CLUMondo model. The assumption that the water use for irrigation is the most essential when making such predictions is understandable, especially considering that the sector is responsible for about 70% of the global water use. However, as implementing irrigation has often been presented as a climate adaptation option in semi-dry areas, it is important to realize its competition with other water uses. The projected population and GDP growth in the region predicts a large increase in the share of domestic and industrial water use, even when taking into account potential improvements in water use productivity due to technological advancements. It is recommended to take the domestic, industrial and livestock drinking water uses into account when making future land system projections. To make predictions even more accurate, accessible tourism water use data on this region is needed.

Although the added water uses do not fully change the land system adaptations compared to the research of Malek & Verburg (2018), they do enlarge the projected developments. The results highlight the need to support small scale farmers to maintain their work on agro-silvo-pastoral mosaics, as they will be able to play a large role in the conservation and expansion of these traditional landscapes. The mosaics will not only play a role in the future food production, but also in the conservation of one of the world's main biodiversity hotspots. If the countries would like to protect their forest biodiversity and carbon sequestration, it can be recommended to put more forest protection regulations in place, and put a focus on the implementation of agroforestry.

With the projected loss of almost all irrigated cropland and with increased changes in precipitation and extreme weather events, it is unlikely that the region will provide for all of its food demand. To avoid high food prices, which have led to uprisings before, the countries need to develop good trade regulations in collaboration with the global community.

Putting all bets on improving the irrigation efficiency and water use productivity does not seem to be paying off, at least not with moderate improvements. The differences between the BAU and productivity scenario are too small to make a big difference. It could be possible that bigger technological advancements might have a much higher impact. It is, however, debatable if this will be realistic. Drip irrigation, the higher irrigation efficiency option, is not suitable to be widely implemented in the region, and technological improvements might be hindered for as long as there will be political instability.

Altogether, up until 2050, the region will be able to provide enough food and water for its population This would, however, be accompanied by certain tradeoffs, such as the loss of forests, and the widespread intensification of rain-fed cropland and arid grazing zones, potentially adding to the global warming. This paper has offered several policy recommendations with regards to these tradeoffs. In the end, however, it is up to the socio-economic developments and climate change projections what land system changes will really play out in the upcoming years.

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Appendix

A. North-West African land system characteristics table per 4km^2 land system unit

Table A. North-West African land system characteristics table per 4km^2 land system unit

Land System	Annual crops (t)	Permanent crops (t)	Livestock (nr)	Built up (ha)	Demand for water (m^3)
wetlands	119.57	48.579	1154.387	0.48	26886
medium inten. forest	56.445	56.905	64.333	1.32	14719
(semi)natural forest	54.651	5.573	56.559	0.28	3939
high inten. forest	86.685	57.82	75.308	1.906	20918
ext. arid system	4.479	2.091	6.273	0.365	3851
int. arid system	11.603	10.288	33.938	0.4	4735
closed wooded rangel.	63.996	50.368	109.508	1.6	18441
open woodland	38.385	33.686	37.205	2.265	23863
open wooded rangel.	49.336	26.78	60.273	0.554	6811
cropl./wooded rangel.	112.313	23.362	62.895	1.12	12647
cropland/rangel.	130.498	64.191	73.877	1.254	14226
exten. annual	125.334	17.146	29.514	1.32	14056
exten. permanent	58.637	352.788	55.206	1.92	20679
exten. mosaic	102.902	119.275	52.885	1.48	16137
rainfed inten. annual	2344.575	49.252	51.722	2.88	30426
rainfed inten. perm.	1186.197	450.186	89.801	0.92	11115
rainfed inten. mosaic	1788.211	161.314	73.842	1.68	18580
irrigated annual	1553.235	75.64	49.717	3.04	1081131
irrigated permanent	822.48	1097.105	68.454	3.72	1400258
irrigated mosaic	1106.78	459.708	59.332	3.76	1145441
peri-urban	1097.654	267.022	90.255	46.16	802484
urban	719.29	210.618	40.195	159.2	1796003

B. Water use per sector for each land system in 2010, BAU (2050), and productivity (2050) scenarios

Water use per sector for each land system in 2010

Table B1. Water use per sector for each land system in 2010

	Irrigation water use per land system (m3)	Domestic water use per land system (m3)	Industrial water use per land system (m3)	Livestock water use per land system (m3)
wetlands	0	6641760	1287952	35519680
medium inten. forest	0	24355810	4723760	2639875
(semi)natural forest	0	1162545	225525	522345
high inten. forest	0	9562934	1854690	840324
ext. arid system	0	168193750	32616132	6404818
int. arid system	0	124745350	24184208	23528612
closed wooded rangel.	0	15274385	2962555	2324775
open woodland	0	12818773	2486021	467988
open wooded rangel.	0	15519096	3010240	3756256
cropl./wooded rangel.	0	75550020	14653080	9437844
cropland/rangel.	0	257279994	49888884	33714534
exten. annual	0	265653510	51522960	13209810
exten. permanent	0	22685820	4399440	1450380
exten. mosaic	0	54362880	10544820	4320030
rainfed inten. annual	0	18346296	3558552	732840
rainfed inten. perm.	0	27569500	5348000	5985000
rainfed inten. mosaic	0	10831152	2100870	1058718
irrigated annual	5670423335	140686745	27284440	5118535
irrigated permanent	2909659788	68097438	13208564	2785814
irrigated mosaic	3172752506	92364586	17914036	3241970
peri-urban	928436709	1115725821	216399888	4849914
urban	231360346	1879698352	364574504	1054935

Water use per sector for each land system in 2050 in the BAU scenario

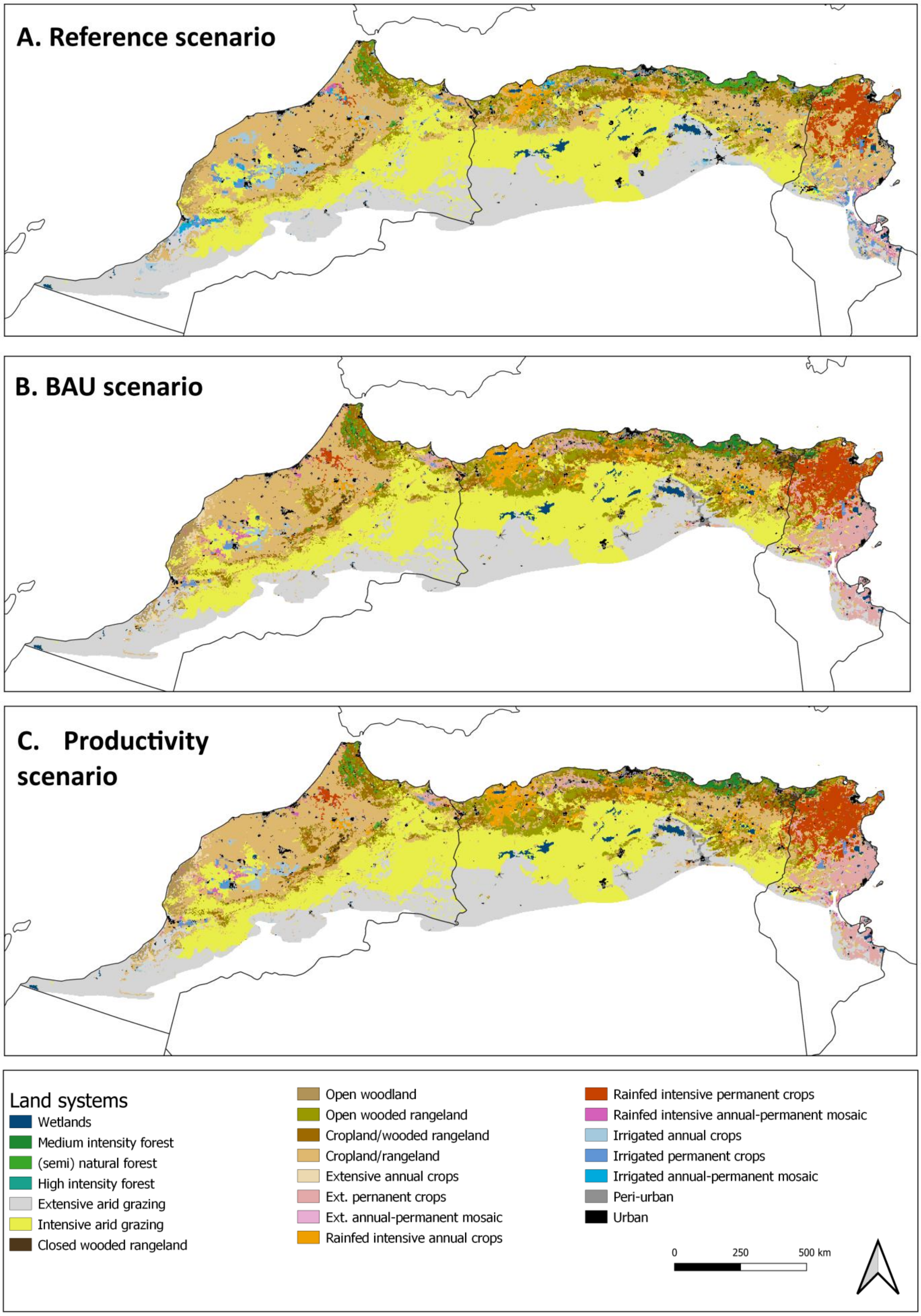
Table B2. Water use per sector for each land system in 2010				
	Irrigation water use per land system (m3)	Domestic water use per land system (m3)	Industrial water use per land system (m3)	Livestock water use per land system (m3)
wetlands	0	6187103	3068162	35518918
medium inten. forest	0	12108114	6004370	1408635
(semi)natural forest	0	1925174	954687	928273
high inten. forest	0	410479	203555	38714
ext. arid system	0	113214496	56142659	4644582
int. arid system	0	159265570	78979220	34385922
closed wooded rangel.	0	14638215	7259038	2549449
open woodland	0	37831156	18760334	1581275
open wooded rangel.	0	53345000	26453593	14768609
cropl./wooded rangel.	0	75559737	37469800	10797431
cropland/rangel.	0	349302244	173217721	52366036
exten. annual	0	10402449	5158537	591867
exten. permanent	0	117539637	58287481	8600160
exten. mosaic	0	318735	158060	28983
rainfed inten. annual	0	110747607	54919338	5061218
rainfed inten. perm.	0	54288380	26921412	13484470
rainfed inten. mosaic	0	12167458	6033799	1360902
irrigated annual	729129365	16852453	8357070	701338
irrigated permanent	766201338	16705369	8284132	782257
irrigated mosaic	0	0	0	0
peri-urban	1316189766	1473491435	730699078	7331398
urban	424468220	3212686259	1593159506	2064136

Water use per sector for each land system in 2050 in the productivity scenario

Table B3. Water use per sector for each land system in 2010

	Irrigation water use per land system (m3)	Domestic water use per land system (m3)	Industrial water use per land system (m3)	Livestock water use per land system (m3)
wetlands	0	4949682	2454529	35518918
medium inten. forest	0	9096879	4511109	1322892
(semi)natural forest	0	1522272	754889	917505
high inten. forest	0	437845	217126	51619
ext. arid system	0	90788202	45021542	4655690
int. arid system	0	127568154	63260587	34427942
closed wooded rangel.	0	12394625	6146450	2698371
open woodland	0	27258667	13517474	1424204
open wooded rangel.	0	42029073	20842065	14544731
cropl./wooded rangel.	0	57546181	28536943	10279134
cropland/rangel.	0	289508165	143566053	54252425
exten. annual	0	5584473	2769320	397174
exten. permanent	0	88469443	43871677	8091434
exten. mosaic	0	245544	121765	27909
rainfed inten. annual	0	80897899	40116976	4621341
rainfed inten. perm.	0	44105823	21871918	13694082
rainfed inten. mosaic	0	9230116	4577181	1290459
irrigated annual	1125834490	24519713	12159237	1275528
irrigated permanent	687478574	14123900	7003991	826719
irrigated mosaic	31922159	815758	404532	40946
peri-urban	1062159221	1120472048	555638039	6968675
urban	372196049	2654466149	1316340171	2131853

C. Spatial distribution of land systems in North-West Africa in 2050 for the reference (A), BAU (B), and productivity (C) scenarios.



D. Adaptations between 2010 – 2050 for the reference, Business as Usual (BAU), and productivity scenarios.

Table D. Adaptations between 2010 – 2050 for the reference, Business As Usual (BAU), and productivity scenario

	Reference		BAU		Productivity	
	Area (km²)	% of whole area	Area (km²)	% of whole area	Area (km²)	% of whole area
No Change	499424	69.07%	486564	67.81%	493296	68.23%
Cropland Expansion	13364	1.85%	19552	2.72%	19248	2.66%
Abandonment	356	0.05%	52	0.01%	64	0.01%
Diversification	119736	16.56%	108436	15.11%	110300	15.26%
Cropland Intensification	8444	1.17%	17520	2.44%	16832	2.33%
Cropland Extensification	84	0.01%	668	0.09%	644	0.09%
Implementation Irrigation	1096	0.15%	4	0.00%	12	0.00%
Renunciation Irrigation	5764	0.80%	11724	1.63%	9868	1.36%
Forest Expansion	1496	0.21%	1480	0.21%	1456	0.20%
Forest Extensification	4732	0.65%	60	0.01%	40	0.01%
Forest Intensification	164	0.02%	60	0.01%	108	0.01%
Arid Extensification	3308	0.46%	3288	0.46%	3296	0.46%
Arid Intensification	59136	8.18%	58796	8.19%	59016	8.16%
Urbanisation	5936	0.82%	9320	1.30%	8860	1.23%

E. Land conversions between 2010 and 2050 in the reference, BAU, and productivity scenario

The land systems in 2010 that will become urban or peri-urban in 2050

Table E1. Land systems experiencing urbanization

	Reference	BAU	Productivity
Forests	0.54%	0.17%	0.23%
Mosaics	13.68%	6.05%	6.59%
Arid	45.89%	61.76%	58.01%
Extensive crop	21.02%	5.54%	6.68%
Intensive crop	3.50%	0.86%	0.86%
Irrigated crop	15.36%	25.62%	27.63%

The land systems in 2010 that will become cropland systems in 2050

Table E2. Land systems experiencing cropland expansion

	Reference	`BAU	Productivity
Forests	1.22%	1.96%	1.66%
Mosaics	98.78%	98.04%	98.34%

The share of each cropland system that is expanded on between 2010 - 2050

Table E3. Cropland system that is expanded on

	Reference	BAU	Productivity
Rain-fed extensive	3.23%	42.25%	38.22%
Rain-fed intensive	80.41%	57.75%	61.78%
Irrigated	16.36%	0.00%	0.00%

The land systems in 2010 that will become agro-silvo-pastoral mosaics in 2050

Table E4. Land systems experiencing diversification

	Reference	BAU	Productivity
Forests	4.97%	5.42%	5.63%
Rain-fed extensive	79.88%	68.65%	69.48%
Rain-fed intensive	6.52%	5.19%	5.16%
Irrigated	8.63%	20.75%	19.73%
All cropland	*95.03%*	*94.58%*	*94.37%*

The share of each mosaic system that is expanded on between 2010-2050

Table E5. Mosaic system that is expanded on

	Reference	BAU	Productivity
Close wooded rangeland	0.75%	0.82%	1.04%
Cropland / rangeland	79.70%	57.49%	60.00%
Cropland / wooded rangeland	4.13%	11.67%	10.50%
Open wooded rangeland	12.66%	24.66%	23.67%
Open woodland	2.76%	5.35%	4.78%

The forest loss between 2010 - 2050

Table E6. Land system that is responsible for forest loss

	Reference	BAU	Productivity
Mosaics	98.02%	91.45%	94.81%
Urban	0.53%	0.34%	0.31%
Extensive cropland	0.13%	0.26%	0.00%
Intensive cropland	1.25%	7.95%	4.88%
Irrigated cropland	0.07%	0.00%	0.00%

F. Crop production per land system in 2010, the reference (2050), BAU (2050), and the productivity (2050) scenarios

Table F. Crop production per land system in 2010, the reference (2050), BAU (2050), and productivity (2050) scenarios

	2010		Reference (2050)		BAU (2050)		Productivity (2050)	
	Crop production (t)	Share of total crop production	Crop production (t)	Share of total crop production	Crop production (t)	Share of total crop production	Crop production (t)	Share of total crop production
Wetlands	271729	0.61%	271729	0.56%	271729	0.55%	271729	0.55%
Forest systems	358158	0.81%	135781	0.28%	186167	0.37%	178931	0.36%
Arid systems	1150925	2.60%	1354601	2.79%	1348243	2.71%	1350189	2.72%
Agro-silvo-pastoral mosaics	6158192	13.89%	10932444	22.50%	9147433	18.40%	9316010	18.79%
Extensive rain-fed cropland	4869898	10.99%	333907	0.69%	3304456	6.65%	3071141	6.20%
Intensive rain-fed cropland	8976340	20.25%	14880037	30.63%	25416770	51.14%	24510313	49.44%
Irrigated cropland	17402396	39.26%	14128635	29.08%	2212794	4.45%	3254312	6.56%
Settlements	5134823	11.59%	6543936	13.47%	7814101	15.72%	7621077	15.37%