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Ciclo XXVI

CLIMATE CHANGE EFFECTS ON DURUM WHEAT (TRITICUM DURUM L.) IN MEDITERANEAN AREA

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Sommario

ABSTRACT

This study work is carried out within the Agroscenari Project - Scenarios of adaptation to climate change in Italian agriculture, funded by the Ministry of Agriculture and Forestry with DM 8608/7303/08 of 7 August 2008. Within the different agricultural systems, this is the only work that considered rainfed agricultural systems with cereals as main crop, and specifically durum wheat.

In the EU, too, cereals are the most widely produced crop. Cereals in fact account for over 50 % of some regions' UAA (Utilized Agricultural Area). Agricultural systems worldwide over the last 40-50 years have responded to the effects of the interacting driving forces of population, income growth, urbanization and globalization on food production, markets and consumption (Von Braun, 2007). To these forces can be added the twin elements of climate variability and climate change which have direct effects and serious consequences for food production and food security (Parry et al., 2004). Climate change is considered as one of the main environmental problems of the 21st century (Reidsma et al., 2010). It is definitively accepted that our climate is changing due to increased “greenhouse gases” atmospheric concentrations and this change is expected to have important impact on different economic sectors (eg. Agriculture, forestry, energy consumptions, tourism, etc) (Hanson et al., 2006). In particular, for agriculture, such a change in climate may have significant impacts on crop growth and yield, since these are largely determined by the weather conditions during the growing season. Even in temperate regions, there are some early warning signs of climate change impacts on the yields of some major crops like wheat. A slower increase in grain yields compared to past decades has been reported in a range of countries, including Europe. Specifically climate change is projected to have a significant impact on temperature and precipitation profiles in the Mediterranean basin. The incidence and severity of drought will become commonplace and this will reduce the productivity of rain-fed crops such as durum wheat. The semi-arid regions, like Mediterranean area, are particularly sensitive to climate change for their characteristic climate conditions and increases in temperatures and in rainfall variability could generate negative impacts because high summer temperatures and water stresses already now limit crop production, according to the latest Assessment Report of the IPCC, Climate-Change 2007 (IPCC, 2007). Durum wheat is a rain-fed crop that is widely cultivated over the Mediterranean Basin. The major climatic constraints to durum wheat yield in Mediterranean environments are high temperatures and drought, frequently occurring during the crop’s growth cycle (Porter and Semenov, 2005; Garcìa del Moral et al., 2003). As a consequence, projected climate changes in this region, in particular rising temperatures and decreasing rainfall (Gibelin and D´equ´e, 2003), may

seriously compromise durum wheat yields, representing a serious threat to the cultivation of this typical Mediterranean crop.

Different aspects of climate change, such as higher atmospheric CO_2 concentration [CO_2], increased temperature and changed rainfall all have different effects on plant production and crop yields. In combination, these effects can either increase or decrease plant production and the net effect of climate change on crop yield depends on the interactions between these different factors (F. Ludwig, S. Asseng,2006). Higher CO_2 almost always increases plant production (Amthor, 2001; Poorter and Perez-Soba, 2001), but higher temperatures can, potentially, both increase or decrease grain yields (Van Ittersum et al., 2003; Peng et al., 2004). Assessments of climate change impacts on European agriculture (potential crop yield and biomass production) are examined using the Crop Growth Monitoring System (Supit et al., 2010) and suggest that in northern Europe, crop yields increase and possibilities for new crops and varieties emerge (Ewert et al., 2005; IPCC, 2007a; Olesen and Bindi, 2002).

This study was carried out to assess the effects of climate change on Durum wheat yields at field scale using a crop growth simulation model, EPIC and a climatic scenarios in order to simulate the crop response in future weather conditions. The climate scenarios were generated by General Circulation Models (GCM) and adapted to the field scale through downscaling processes. Specifically ECHAM 5.4 and RAMS were used. Understanding the consequences of long-term climate change is important for the agricultural policies and the choice of mitigation strategies.

If consider wheat yields as main parameter influenced by climate change, drought conditions were the main factors limiting grain yields on clay soil in a Mediterranean-type environment, in particular this condition was observed for the Oristano site. The simulation experiments with long - term historical weather records suggest that environments characterized by low rainfall have negative impacts on crop growth: future climate change including higher temperatures and less rainfall will reduce grain yields despite elevated atmospheric CO_2. In fact the CO_2 positive effects fail when we consider temperature and precipitations patterns in association with increased CO_2 concentrations. Probably yields reduction, for Oristano site in the first set of results, was connected both to the falling of rain. The same simulation experiments carried out in the other two sites, Benevento and Ancona, showed a different situation: higher yields were observed in the future, maybe caused by higher future rainfall respect to the future condition. The results suggest priorization of adaptation strategies in the regions condisidered, including development of local cultivars of drought – and het resistant crop varieties, earlier planting to avoid heat stress, development and adoption of slower-maturing varieties to increase the grain filling period.

Chapter 1

1. Introduction

1.1. Background

European cereals production

In terms of the area that they occupy and their importance in human and animal food supply, cereals constitute the largest crop group in the world.

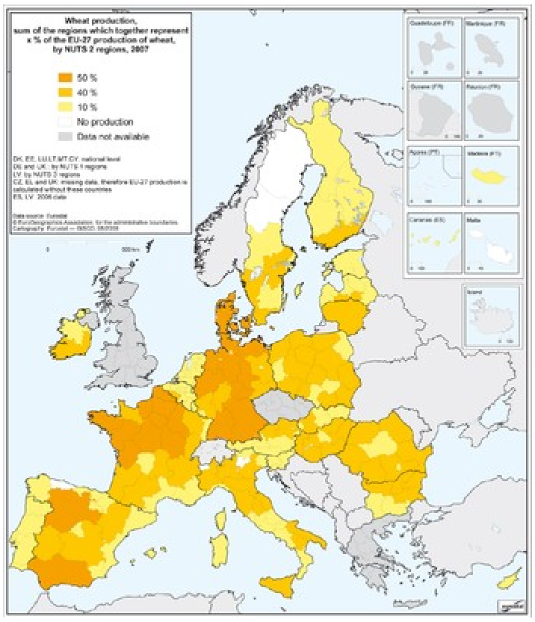
In the EU, too, cereals are the most widely produced crop. European statistics on cereals encompass wheat, barley,maize, rye, meslin, oats, rice and other cereals, such as triticale, buckwheat, millet and canary seed. Cereals in fact account for over 50 % of some regions' UAA (Utilized Agricultural Area). These regions include the Balkan regions such as in Romania and eastern European regions, in particular in Hungary and Slovakia.

Cereal crops cover a relatively small proportion of the UAA in southern regions (except Basilicata) in certain Alpine regions, on the Atlantic coast of the Iberian peninsula and in the regions of northern Sweden, where this type of crop accounts for less than 10 % of the UAA.

Specifically, these regions include almost all regions of Portugal (except Lisboa region), and certain coastal areas of Spain (Galicia, Principado de Asturias, Cantabria, Comunidad Valenciana and Canarias) and Italy (Liguria).

The Alpine regions of Austria and Italy have areas under cereals of less than 10 % of their UAA.

In certain regions in which the preference is for grassland and, in some cases, green fodder, a small proportion of the area is devoted to cereals. Those regions are in Belgium, France (Corsica, Limousin and the overseas department of Réunion), the Netherlands (Friesland, Overijssel, Gelderland, Utrecht and Noord-Holland), the whole of Ireland and the region of Mellersta Norrland in Sweden.



Europe wheat production

Wheat (common and durum wheat) is by far the crop with the highest production in European agriculture. In 2007, wheat accounted for 46 % of cereal production in the EU. Wheat is primarily used in human and animal food products, but also for making processed products, such as bioethanol and starch. It is also one of the most widely distributed crops in the EU. According to the statistics, only five regions do not produce wheat, namely Principado de Asturias in Spain, Valle d'Aosta/Vallée d'Aoste, Provincia Autonoma Bolzano/Bozen in Italy and Mellersta Norrland and Övre Norrland in Sweden.

In 2007, the EU produced 120 million tonnes of wheat (including 8.2 million tonnes of durum wheat), on a total area of 24 million hectares. Some 21 regions account for over half the wheat production in the EU (calculated without the figures for production in the Czech Republic, Greece and the United Kingdom, for which regional data are not available).

Of those 21 regions, 10 are in France, as follows (ranging from the highest production to the lowest): Centre (which accounts for 4.5 % of EU wheat production), Picardie, Champagne-Ardenne, Poitou-Charentes, Pays de la Loire, Nord Pas-de-Calais, Bourgogne, Haute-Normandie, Île-de-France and Bretagne. This makes France the biggest wheat producer in the EU. France harvested almost 33 million tonnes of cereal in 2007.

Germany, with 20.9 million tonnes, is the second biggest producer. It has eight of the 21 most productive regions, and they are as follows (from the largest producers to the lowest): Bayern (which accounts for 3.6 % of wheat production in the EU), Niedersachsen, Sachsen-Anhalt, Nordrhein-Westfalen, Mecklenburg-Vorpommern, Baden-Württemberg, Thüringen and Schleswig-Holstein.

It can, therefore, be said that the EU's wheat 'granary' is located in the northern half of France and Germany. The next 63 regions contribute 40 % of the EU's total production. These include all but three regions of Poland, which is the fourth biggest producer of wheat, after the United Kingdom (8.3 million tonnes) (Crop production statistics at regional level; Data from March 2009, most recent data: Further Eurostat information, Main tables and Database. http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Crop_production_statistics_at_regional_level).

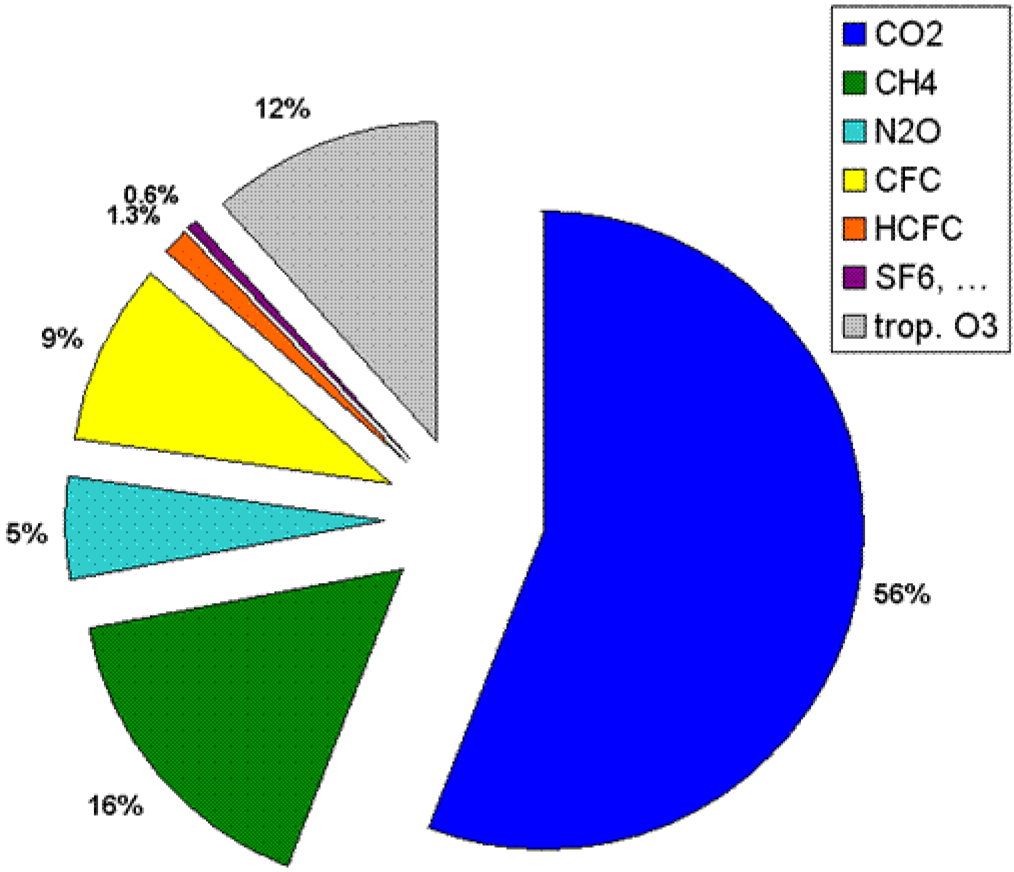
Even in temperate regions, there are some early warning signs of climate change impacts on the yields of some major crops like wheat. A slower increase in grain yields compared to past decades has been reported in a range of countries, including Europe and India. For example, since 1990, winter wheat yields have been increasing at a significantly slower rate in France than over previous decades (Gate, 2009) and this change has foremost been attributed to an increased variability in climate (Gate 2007, 2009). By contrast, circumstantial evidence for climate-induced increasing grain yield of winter wheat (Triticum aestivum L.) from 1981 to 2005 at two locations in China has been challenged by a recent re-analysis (White, 2009).

1.1.1. Climate change impacts on wheat production

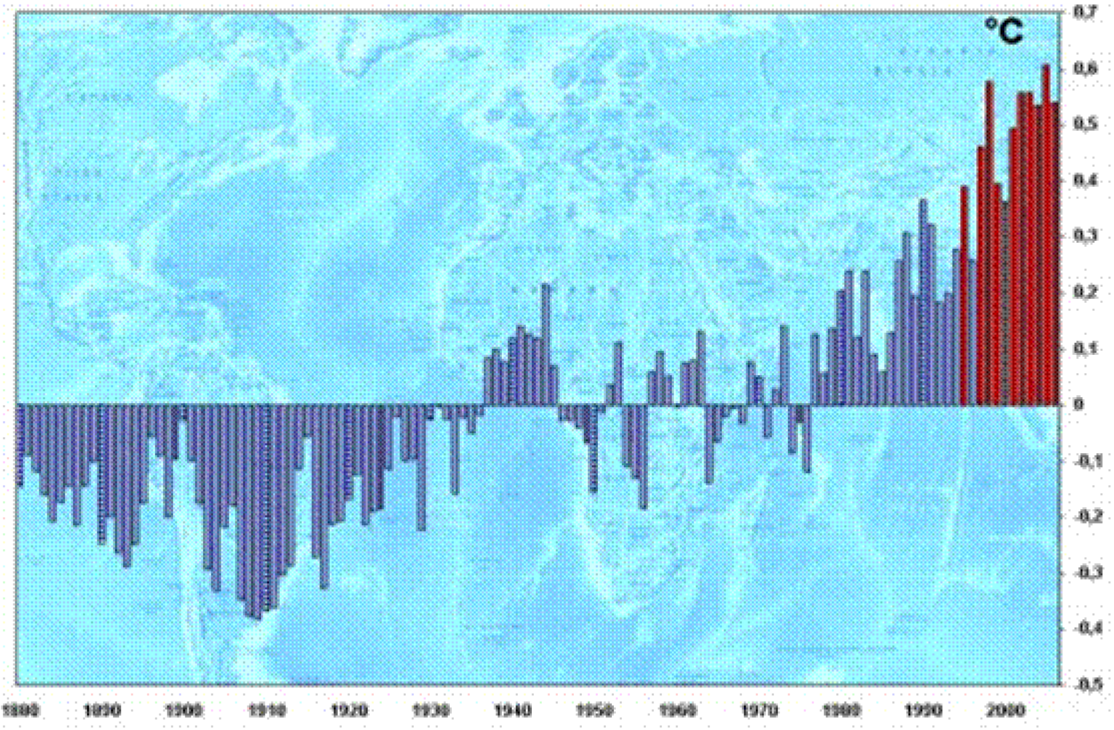
Climate change impacts on crop yield

Agricultural systems worldwide over the last 40-50 years have responded to the effects of the interacting driving forces of population, income growth, urbanization and globalization on food production, markets and consumption (Von Braun, 2007). To these forces can be added the twin elements of climate variability and climate change which have direct effects and serious consequences for food production and food security (Parry et al., 2004). There is evidence for the effects of recent accelerated warming on many biological systems (IPCC, 2007).

Climate change is considered as one of the main environmental problems of the 21st century (Reidsma et al., 2010). It is definitively accepted that our climate is changing due to increased "greenhouse gases" atmospheric concentrations and this change is expected to have important impact on different economic sectors (eg. Agriculture, forestry, energy consumptions, tourism, etc) (Hanson et al., 2006).



Graphic – Radioactive forcing between 1750 and the present (Elmar Uherek. IPCC Ar4 2007).



According to these premises, the assessment of cropping systems response to a warmer climate plays an important role for the evaluation of near future economic assets and the study of crop phenology response was indicated as a key stage for a better formulation of adaptation policies and options (Duchene and Schneider, 2005; Wolfe et al., 2005; Sadras and Monzon, 2006). 35

In particular, for agriculture, such a change in climate may have significant impacts on crop growth and yield, since these are largely determined by the weather conditions during the growing season.

The changing weather patterns also affect crop production and the climate change impact on food security is widely debated and investigated (Miraglia et al., 2009). For example, Ludwig et al. (2009) investigated the impacts of the climate change on the wheat production in western Australia. Pathak et al. (2003) researched the decline/stagnation of the rice and wheat yields in the Indo-Gangetic Plains. Peltonen-Sainio et al. (2009) investigated cereal yield trends in Finland. Richards (2002) discussed the environmental challenges in Australian agriculture. Olesen and Bindi (2002) and Tubiello et al. (2000) elaborate on the consequences of climate change for European agricultural productivity 42.

Althought climate change may benefit crop production in northern latitudes above about 55°, where warmer temperatures may extend the growing season, in the developing world (especially sub – Saharan Africa) the projected changes are likely to have negative impact and will further complicate the achievement of food security (Fisher et al., 2001; Parry et al., 2004; Stern 2007).

Fischer et al. (2001) modelled the spatial variation in effects of climate change anticipated in 2050 on potential yields of rain-fed cereal crops worldwide and demonstrated that cereal producing regions of Canada, and northern Europe and Russia might be expected to increase production, while many other parts of the world would suffer losses, including the western edge of the USA prairies, eastern Brazil, Western Australia and many, though not all, parts of Africa.

Overall, the results of this and subsequent work demonstrated that climate change would benefit the cereal production of developed countries more than the developing countries even if cropping practices evolved to allow more than one rain-fed crop per year (Fischer et al. 2002; 2005). 30

Winter wheat production and Mediterrean climate

The Mediterranean region, especially the Middle est and North Africa, ran out of renewable fresh decades ago. The region in one of the driest agricultural regions on earth, containing only 1% of the world's freshwater resources. The Mediterranean region in characterized by an extremely variable climate (Ceccarelli et al., 2007), with hot, dry summer and cool, wet winters, being the transition between dry tropical and temperate climates. This climate occurs on the west coasts of all continents between latitudes 30 and 45° due to global air circulation patterns. Mediterranean climate is associated with an area of about 2.76 million km^2, corresponding to 2.3% of the Earth's land surface. The largest part is the Mediterranean region with 1.68 million km^2 (60% of the total area of Mediterranean climate), followed by 0.61, 0.28, 0.13 and 0.06 million km^2 for Western Australia, California, Chile and South Africa, respectively (Joffre and Rambal, 2002).48

The semi-arid regions, like Mediterranean area, are particularly sensitive to climate change for their characteristic climate conditions and increases in temperatures and in rainfall variability could generate negative impacts because high summer temperatures and water stresses already now limit crop production, according to the latest Assessment Report of the IPCC, Climate-Change 2007 (IPCC, 2007). Durum wheat is a rain-fed crop that is widely cultivated over the Mediterranean Basin. The major climatic constraints to durum wheat yield in Mediterranean environments are high temperatures and drought, frequently occurring during the crop's growth cycle (Porter and Semenov, 2005; Garcìa del Moral et al., 2003). As a consequence, projected climate changes in this region, in particular rising temperatures and decreasing rainfall (Gibelin and D´equ´e, 2003), may seriously compromise durum wheat yields, representing a serious threat to the cultivation of this typical Mediterranean crop.

The main aspects of climate change on wheat production

Different aspects of climate change, such as higher atmospheric CO_2 concentration [CO_2], increased temperature and changed rainfall all have different effects on plant production and crop yields. In combination, these effects can either increase or decrease plant production and the net effect of climate change on crop yield depends on the interactions between these different factors (F. Ludwig, S. Asseng,2006). Higher CO_2 almost always increases plant production (Amthor, 2001; Poorter and Perez-Soba, 2001), but higher temperatures can, potentially, both increase or decrease grain yields (Van Ittersum et al., 2003; Peng et al., 2004)

Assessments of climate change impacts on European agriculture (potential crop yield and biomass production) are examined using the Crop Growth Monitoring System (Supit et al., 2010) and suggest that in northern Europe, crop yields increase and possibilities for new crops and varieties emerge (Ewert et al., 2005; IPCC, 2007a; Olesen and Bindi, 2002).

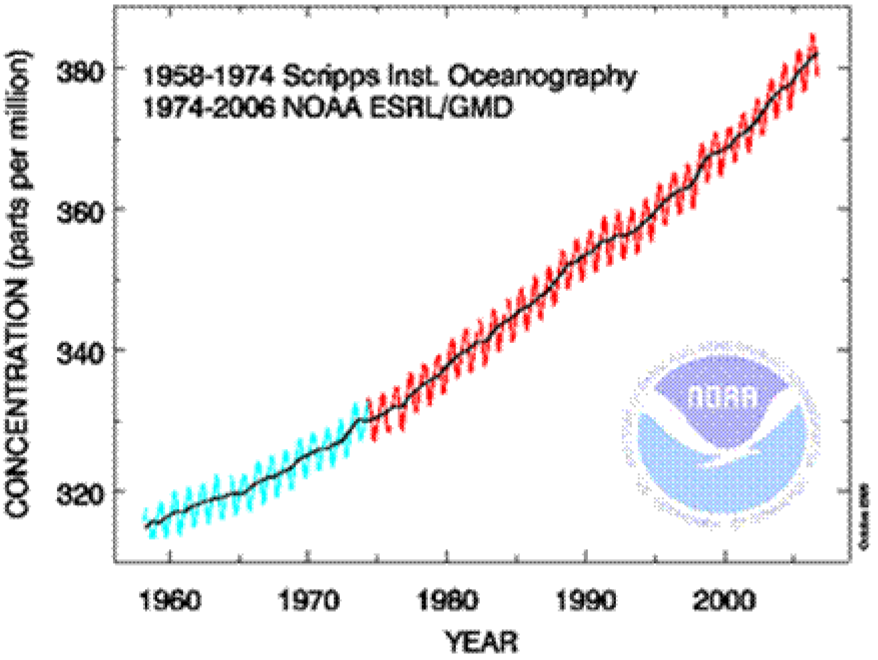
The main investigated crops are winter wheat, spring barley, maize, winter rapeseed, potato, sugar beet, pulses and sunflower.The changes appear in a geographical pattern. In Italy and southern central Europe, temperature and radiation change effects are more severe than elsewhere, in these areas potential crop yields of more than three crops significantly decreased. In the UK and some regions in northern Europe the yield potential of various crops increased (Supit et al., 2010).

In southern Europe, adverse effects are expected. Here, projected increases in temperatures and in water shortage reduce crop yields and the area for cropping. This will affect the livelihood of Mediterranean farmers (Metzger et al., 2006; Schröter et al., 2005). According to the IPCC definition, the extent to which systems are vulnerable to climate change depends on the actual exposure to climate change, their sensitivity and adaptive capacity (IPCC, 2001)

Specifically climate change is projected to have a significant impact on temperature and precipitation profiles in the Mediterranean basin. The incidence and severity of drought will become commonplace and this will reduce the productivity of rain-fed crops such as durum wheat (D. Z. Habash, Z. Kehel and M. Nachil, 2009). Respect durum wheat (Triticum turgidum L.) production in the Mediterranean basin, this cereal was originated in the Eastern Mediterranean and has been farmed in this region for the last 12 thousand years (Key, 2005). Whilst farming has spread globally, a premium is set on durum wheat quality cultivated in the Mediterranean basin and this can account for up to 75% of the world total production (Nachit, 1998a). The largest durum producers in this region are Syria, Turkey, and Italy followed by Morocco, Algeria, Spain, France, and Tunisia. The major environmental constraints limiting the production of durum wheat in this region are drought and temperature extremes with productivity ranging from 0–6 t ha_1 (Nachit and Elouafi, 2004). Changes in total seasonal precipitation and its pattern of variability are both important, and the occurrence of moisture stress during flowering, pollination, and grain-filling is harmful to wheat.

Increasing of CO_2

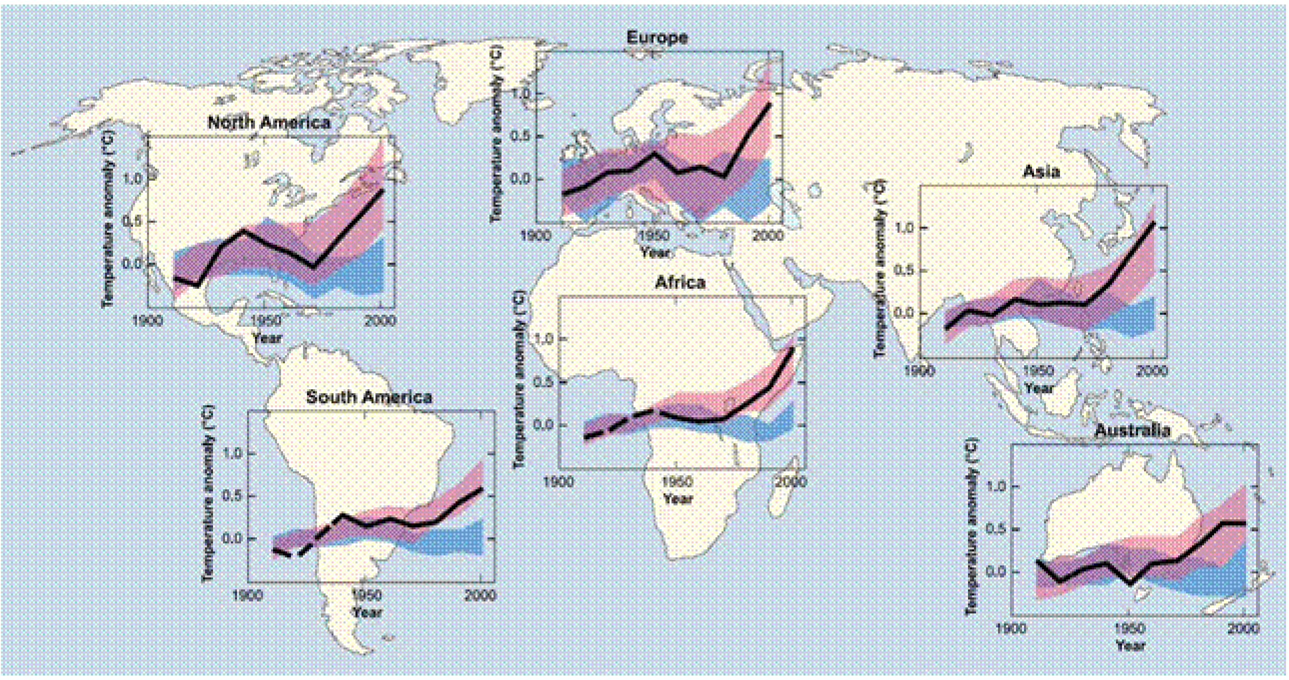
Over the past 800,000 years, atmospheric [CO_2] changed between 180 ppm (glacial periods) and 280 ppm (interglacial periods) as Earth moved between ice ages. From pre-industrial levels of 280 ppm, [CO_2] has increased steadily to 384 ppm in 2009, and mean temperature has increased by 0.76 C over the same time period. Projections to the end of this century suggest that atmospheric [CO_2] will top 700 ppm or more, whereas global temperature will increase by 1.8–4.0 _C, depending on the greenhouse emission scenario (IPCC, 2007).



Graphic – Tendency of CO_2 concentration from 1960 to 2000

Increasing of main temperature

The most significant factors for heat stress-related yield loss in crops include shortening of developmental phases induced by high temperature, reduced light perception over the shortened life cycle and perturbation of the processes associated with plant carbon balance (Barnabás, Järgen, & Fehér, 2008). It has been suggested that higher temperatures reduce net carbon gain by increasing plant respiration more than photosynthesis. In fact, the light-saturated photosynthesis rate of C3 crops such as wheat and rice is at a maximum for temperatures from about 20–32 _C, whereas total crop respiration shows a steep nonlinear increase for temperatures from 15 to 40 _C, followed by a rapid and nearly linear decline (Porter & Semenov, 2005)


Europe
Temperature anomaly (°C)
1.0
0.5
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1900
1950
2000
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North America
Temperature anomaly (°C)
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Asia
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Temperature anomaly (°C)
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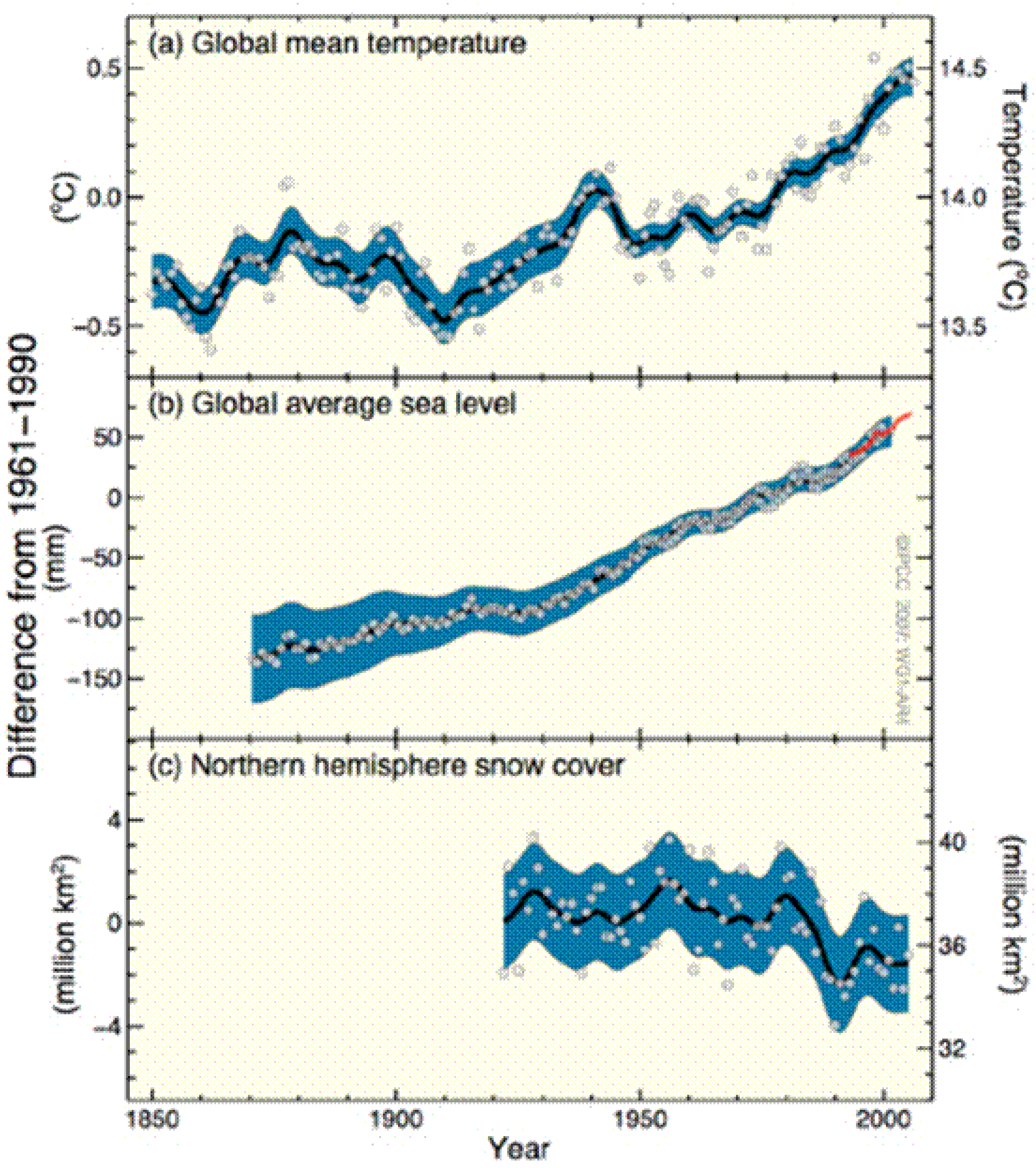
Grafic - Increasing of temperature registered in different world zones (IPCC, 2007, Fig. WGI-SPM-



4)

Grafic x – Differences in the period 1961-1990 for Global mean temperature, Globe average sea level and Northern hemisphere snow cover (IPCC Assessmente report).

Changing in variability of precipitation

Winters have become over twice as wet in western regions, but in the east the increase in precipitation has been smaller and restricted to the autumn. Summers have become drier in some regions, particularly the main arable areas, but there has been no change or an increase in rainfall in others. Air frost and days with snow cover also show spatial and temporal variation, with changes ranging from no reduction to around 40 days less.

In practice, this means longer growing seasons that can affect development of some crops. The consequences is the decrease in yield and quality as the whole crop is harvested by machine on one date. High summer temperatures can cause sterility in wheat ears (Porter and Gawith, 1999). Wetter autumn or winters in some regions can affect access to the land for both harvest and sowing (Cooper et al., 1997), consequently it may not be possible to take advantage of the longer growing season. Summer drought can also severely limit yield in sensitive crops and cause premature senescence. The date of first or last frost also does not necessarily correlate with total frost days. The spatial variation in change may affect cropping patterns in different ways in different regions, Furthermore, year to year variability is very large so it is difficult to capitalize on changes over shorter periods. However, the requirements for breeding varieties suitable for resilience to such conditions are clear.

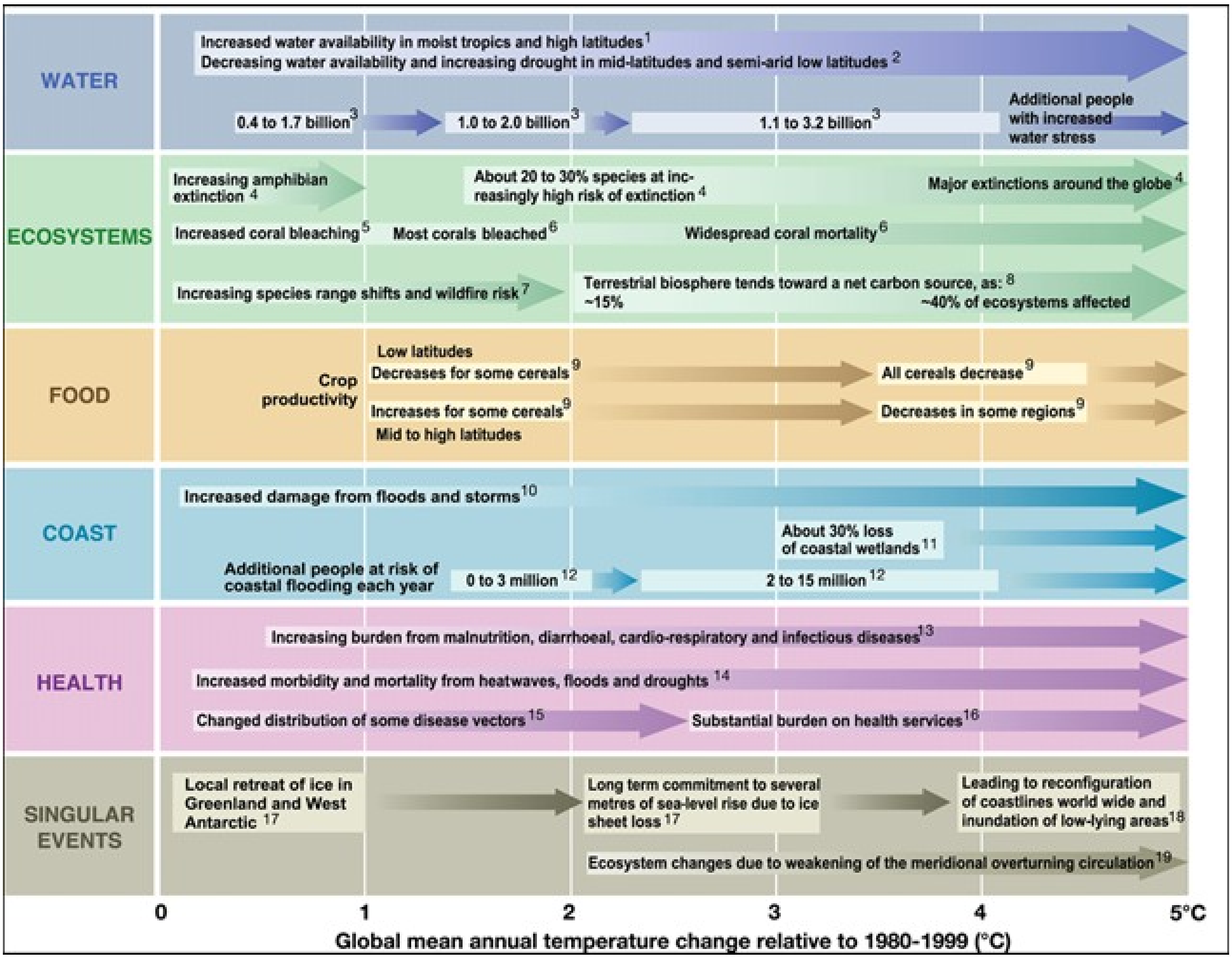
Combination of the three factors

These three different aspects of climate change, higher atmospheric CO_2 concentration [CO_2], increased temperature and changed rainfall regimes all have different effects on plant production and crop yields. In combination, these effects can either increase or decrease plant production and the net effect of climate change on crop yield depends on the interactions between these different factor (F.Ludwig and S.Asseng, 2006).

In general, higher [CO_2] increases plant production due to higher rates of photosynthesis and increased water use efficiency (Morison, 1985; Drake et al., 1997; Garcia et al., 1998), especially at low water and/or high nutrient availability (Kimball et al., 1995; Rogers et al., 1996; Amthor, 2001; Long et al., 2004). The negative effect of higher [CO_2], however, is reduced plant nutrient concentrations which result in lower grain quality (Rogers et al., 1996; Kimball et al., 2001).
Temperatures will increase in the near future in most of parts of the world due to higher concentrations of CO_2 and other greenhouse gasses (IPCC, 2001). Higher temperatures can negatively impact plant production directly through heat stress (Van Herwaarden et al., 1998). A major indirect effect of global warming is higher plant water demand due to increased transpiration at higher temperatures, which can potentially reduce plant production (Lawlor and Mitchell, 2000; Peng et al., 2004). However, higher [CO_2] can counteract these negative effects of higher temperatures through a lower stomatal conductance which reduces transpiration (Kimball et al., 1995; Garcia et al., 1998; Wall, 2001). Plants grown at higher [CO_2] tend to have a higher leaf water potential which results in reduced drought stress (Wall, 2001). Higher temperatures can also increase plant production (Van Ittersum et al., 2003). Especially, in Mediterranean environments where crops are grown in winter, plant growth is often limited by low temperatures and global

warming could potentially have positive effects on crop yields. Changes in rainfall patterns can have both negative and positive effects on agricultural production. In general, in (semi)-arid environments higher rainfall will increase production where less rain will further limit plant production. However, in high rainfall zones, more rain can also increase soil waterlogging and nutrient leaching which can reduce crop growth. These different impacts of climate change do not act independently but all interact with each other. To develop climate change adaptation strategies so yields can remain stable in a changing climate it is important to understand the interactions. between different aspects of climate change. While individual effects of higher temperatures, elevated [CO_2] and changed rainfall patterns are relatively well known, very few studies have looked at the interactions between different effects of climate change. It is important to know these interactions before developing adaptation strategies because adaptations to e.g. higher temperatures may be different from adapting to changed rainfall patterns. In south-west Western Australia more than 4 million ha is sown with wheat each year. Soil types in the area are dominated by sandy and duplex (sand over clay) soils with some clay soils in the eastern part of the region (Del Cima et al., 2004). The area has a Mediterranean-type climate with wet, cool winters and dry, hot summers. Rainfall is strongly seasonal and more than 75% of the rain falls between May and October. Wheat is mostly grown in areas with less than 550 mm annual rain and about half the farms in the region receive on average less than 325 mm rain per year. Future climate scenarios for the region vary widely. Predicted changes in winter rainfall, for 2070, range from a 60% reduction up to an increase by 10% (Pittock, 2003). However, one of the more likely scenarios is a reduction in winter rainfall of about 15% by 2030 and 30% by 2070 (IOCI, 2002). Already during the last 30 years the region has seen a significant drop in winter rain (Smith et al., 2000). This reduction in rainfall could be a significant threat for the grain industry in South-West Australia. Several previous studies have used crop models to study the impact or sensitivity of climate change on agricultural production (e.g.Mearns et al., 1996, 1997; Wolf et al., 1996; Howden et al., 1999; Richter and Semenov, 2005). Most previous studies focussed on simulating the individual effects of higher temperatures and [CO_2] (Wang et al., 1992; Van Ittersum et al., 2003; Howden et al., 1999). For example Van Ittersum et al. (2003) showed a linear increase of production with higher [CO_2]. Production also increased with up to 3 C higher temperatures on clay soils but on sandy soils higher temperatures always reduced production. In our study, we are not only simulating individual effects of changed T, [CO_2] and rainfall but we especially focus on how different aspects of climate change interact with each other. We concentrated on the effects of reduced rainfall and whether higher T and [CO_2] can compensate for negative effects of lower rainfall. Using a simulation model we studied the effects of higher [CO_2], increased temperature and changed rainfall on wheat yield and grain protein concentration. We focussed on three different sites within the Western Australian wheatbelt, with relatively large differences in temperature and rainfall. At each site, we studied whether different soil types respond differently to the effect of climate change on crop yield and grain protein concentration. 15

Impacts on biophysical, qualitative and socio economic aspects



Grafic x -

Biophisical impacts on crops

Crops exhibit known observed responses to weather and climate that can have a large impact on crop yield. Phenology is in fact the most important attribute involved in the final yield assessment and consequently in the adaptation of crops to the changing environment. Both the timing of phenological stages and the relative duration of the pre and post-flowering phases (vegetative and reproductive phases, respectively) are in fact critical determinant of yield (Sadras and Connor, 1991). The activity that is most demanding for a crop (i.e. reproductive phase) should take place at the time of optimal conditions (i.e. temperature and rainfall) (Visser and Both, 2005), whereas its duration should be as long as possible for optimal biomass partitioning to the fruit (Bindi et al., 1996). Since crop development rate is highly temperature dependent, a warmer climate is expected to affect both these terms, by advancing phenological stages (shifting crop-growing period into a new climatic window) and by reducing the time for biomass accumulation (Peiris et al., 1996; Harrison and Butterfield, 1996; Bindi and Moriondo, 2005). Additionally, a changing climate may exhibit increased climatic variability and this can produce relatively large changes in the frequency of extreme climatic events. Accordingly, the increase of extreme events centred at the time of sensitive growth stages are expected to have a great impact on final yield. Warmer and wetter future winters, as prospected in some areas, may cause advanced bud-burst leaving plants vulnerable to spring frosts. On the other hand, increased dry spell may lead to a greater frequency of dry summers requiring irrigation for summer crops. Heat waves at anthesis should be also taken into account due to their effect on yield quality and quantity (Porter and Gawit, 1999).

The generally weak relations between yield and climatic variables indicate a few of the difficulties inherent in ascribing variation in yield to climate change or other factors. In winter wheat, one might expect warmer winter temperatures to increase yield through reduced winterkill and a longer effective growing period, whereas warmer temperatures during grain filling might reduce yields. Higher rainfall, while often beneficial, can bring greater cloudiness and lower solar irradiance. Such complex interactions imply that effective analyses must consider the physiology of crop growth and yield formation. Process based eco-physiological models are widely used in climate change research (e.g. IPCC, 2007), although controversies arise (e.g., Long et al., 2006). Vedi (Comments on a report of regression-based evidence for impact of recent climate change on winter wheat yields Jeffrey W. White *, 2009).

Accordingly, strategies for adapting to climate change should concentrate on the use of drought-tolerant cultivars, increasing water-use efficiency, and better matching phenology to new environmental conditions. The shortening of the growth cycle is a noticeable yield-reducing factor and the selection or use of cultivars with a longer cycle may be suggested as a way of compensating for the reduced time they have for biomass accumulation under warmer conditions (Tubiello et al., 2000). In the Mediterranean region, cultivars with an earlier anthesis may be selected, as this will allow the grain-filling period to occur in cooler and wetter periods, avoiding summer drought and heat stress. Management practices promoting advanced phenological stages, such as earlier sowing, may be adopted as well (Moriondo et al., 2010). Enhanced drought tolerance should be the characteristic most desired in a typical rain-fed crop of the Mediterranean basin, but other strategies should be considered, such as the application of irrigation in the crop-growth stages that are more sensitive to water stress (Zhang and Oweis, 1999), or deep ploughing to increase the available water content of the soil. 47

Biophisical impacts on environment

Pests, pathogenes and disease.

Climates continually change and there is evidence for the effect of recent accelerated warming on biological systems (IPCC, 2007). Not least of these are the effects on the geographic distributions of pest and pathogens (e.g. Woods et al., 2005; Admassu et al., 2008; Elphinstone and Toth 2008), with potentially serious implications for food security. However, cropping systems will also change in response to climate, with consequent impacts on their interactions with pest and pathogens.

In fact, although the focus of many assessment of climate change effects on crops has been the direct effects on potential yields driven largely by changes in temperature, CO_2 and water (Gregory et al., 2008), pests and pathogens have major effects in determining actual yields in practice.

The effects of climate change on pests and pathogens have been evaluated in some experimental and modeling studies (Garrett et al., 2006), but their consequences for yield were rarely assessed (e.g. Evans et al., 2008).

Socio-economic aspects

Socioeconomic scenarios (SRES) projecting green house gas emissions in CO_2 equivalents are the backbones of impact studies, providing the basis for assessing the impact of climate change on human activities, including agriculture (Parry et al., 2005).

Modelled future climate scenarios were incorporated into crop and pasture production models to examine the economic impact on the whole farming system. Uncertainties associated with climate and production projections were captured throught the development of scenarios and sensitivity analyses were performed to encompass a range of potential outcomes for the impact of climate change on the farming systems of the northern wheat – belt.

Testing of this process showed that the current farming ystems of the region may decline in profitability under climate change to a point where some become financially unviable in the long term. This decline in profitably is driven not only by the decline in crop yields from climate change but also from a continuation in the trend of declining terms of trade. (Abrahams M. et al., 2012)

1.1.2 Modelling climate change

Crops model

Crop growth models have been widely used to evaluate crop responses (development, growth and yield) to climate change impact assessments by combining future climate conditions, obtained from General or Regional Circulation Models, with simulations of CO_2 physiological effects, derived from crop experiments (see Downing et al., 2000; Ainsworth and Long, 2005) – (Ferrise et al., 2011 – Probabilistic assessments of climate change impacts on durum wheat in the Mediterranean region). The likely future increase in atmospheric CO_2 and associated changes in climate will affect global patterns of plant production. Quantifying and explaining the current global distribution of plant production and predicting its future responses to climate change and increasing atmospheric CO_2 are therefore major scientific objectives(A.D.Friend, 2010).

Decision making and planning in agriculture increasingly makes use of various model-based decision support tools, particularly in relation to changing climate issues. The crop growth simulation models applied are mostly mechanistic, i.e. they attempt to explain not only the relationship between parameters and simulated variables, but also the mechanism of the described processes (Challinor et al., 2009; Nix, 1985; Porter and Semenov, 2005). (simulation of winter wheat..Palosuo, 2011). In 1965 F.L. Milthorpe proposed that there was a need to develop a dynamic, quantitative approach to the analysis of crop responses to climate (Milthorpe, 1965). The need today for quantitative, predictive tools to inform public policy is even greater than 40 years ago (Pearson C.J. et al., 2008). Impacts of climate change on crop productivity are generally assessed with crop models (Easterling et al., 2007). Pubblicazione di Reidsma 2010.

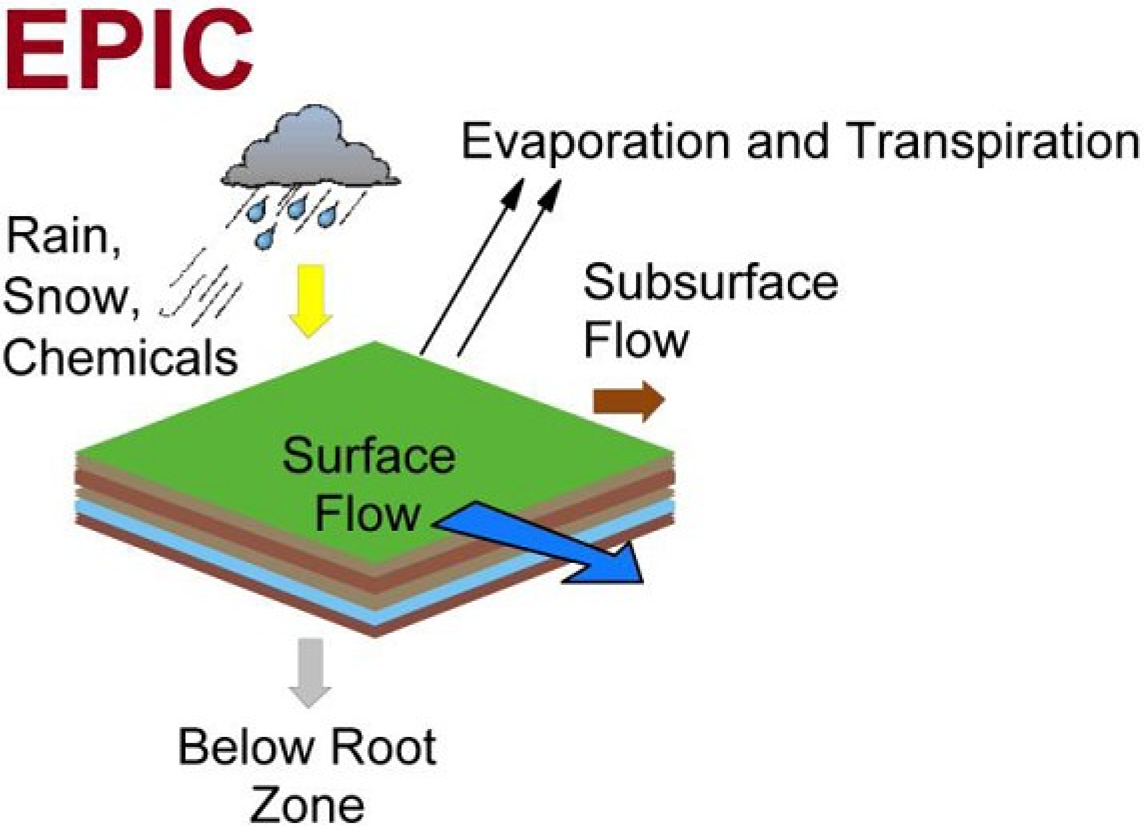
Models integrate understanding of the influence of the environment on plant physiologically processes and so enable estimate of future changes to be made. They allow to assess the consequences of different assumptions for predictions and so stimulate further research (A.D.Friend, 2010). The results of these predictive tools are scenarios: scenarios are neither predictions nor forecasts in a traditional sense; rather they are images of the future, or alternative futures that are meant to assist in climate change analyses (Nakicenovic, 2000).

Althought the consistency of these models with experimental data and their ability to simulate the effects of elevated CO_2 and of increased climate variability has been debated (Soussana et al., 2010), they are the best tool for predicting climate change

Recent changes in the simulated potential crop yield and biomass production caused by changes in the temperature and global radiation patterns are examined, using the Crop Growth Monitoring System (Supit, 2010).

Epic model

Introduction



The EPIC model was developed in the USA in the ’80s to investigate the relationships between erosion and soil productivity (William et al., 1984) and for this reason its first acronym was Erosion-Productivity Impact Calculator. Subsequently, the model was enhanced by the further addition of modules to improve the simulation of plant growth and others routine as that for implementation of CO_2 enrichment (William et al., 1989; Sharpley and Williams, 1990; Stockle et al., 1992).

Nowadays EPIC is a complete tool for the study of agro-ecosystem processes. EPIC is programmed to simulate, on a daily scale, the dynamics and the interactions between the components of a soil-plant-atmosphere system. EPIC is able to simulate processes as weather, soil erosion, hydrological and nutrient cycling, tillage, crop management and growth/yield. Crop growth is calculated on a daily base and requires, as weather inputs, precipitation, maximum and minimum daily temperature, solar radiation and wind speed as well as numerous crop parameters (morphology, phenology, physiology, etc.). The crop growth routine calculates the potential daily photosynthetic production of biomass and this is decreased by stresses caused by shortages of radiation, water and nutrients, by temperature extremes, and by inadequate soil aeration. The value of the most severe stress is used to reduce biomass accumulation, root growth, harvest index and crop yield. 54

The Agricultural Policy/Environmental eXtender (APEX) model was developed for use in whole farm/small watershed management. The model was constructed to evaluate various land management strategies considering sustainability, erosion (wind, sheet, and channel), economics, water supply and quality, soil quality, plant competition, weather and pests. Management capabilities include irrigation, drainage, furrow diking, buffer strips, terraces, waterways, fertilization, manure management, lagoons, reservoirs, crop rotation and selection, pesticide application, grazing, and tillage. Besides these farm management functions, APEX can be used in evaluating the effects of global climate/CO2 changes; designing environmentally safe, economic landfill sites; designing biomass production systems for energy; and other spin off applications. The model operates on a daily time step (some processes are simulated with hourly or less time steps) and is capable of simulating hundreds of years if necessary. Farms may be subdivided into fields, soil types, land scape positions, or any other desirable configuration.

The individual field simulation component of APEX is taken from the Environmental Policy Integrated Climate (EPIC) model, which was developed in the early 1980's to assess the effect of erosion on productivity (Williams, et al., 1984).

EPIC (Erosion-Productivity Impact Calculator) is a comprehensive model developed to determine the relationship between soil erosion and soil productivity throughout the USA. It continuously simulates the processes involved, using a daily time step and readily available inputs. Since erosion can be a relatively slow process, the model is capable of simulating hundreds of years if necessary. EPIC is generally applicable, computationally efficient, and capable of computing the effects of management changes on outputs. EPIC is composed of (a) physically based components for simulating erosion, plant growth, and related processes and (b) economic components for assessing the cost of erosion, determining optimal management strategies, etc. The EPIC physical components include hydrology, weather simulation, erosion-sedimentation, nutrient cycling, plant growth, tillage, and soil temperature.(The EPIC Model and Its Application, J.R. Williams, C.A. Jones, and P.T. Dyke*)

Various components from CREAMS (Knisel, 1980) and SWRRB (Williams, et al., 1985) were used in developing EPIC and the GLEAMS (Leonard, et al., 1987) pesticide component was added later. Since the 1985 National RCA application (Putman,et al., 1988), the model has been expanded and refined to allow simulation of many processes important in agricultural management (Sharpley and Williams, 1990; Williams, 1995). The drainage area considered by EPIC is generally a field-size area, up to about 100 ha, where weather, soils, and management systems are assumed to be homogeneous. The major components in EPIC are weather simulation, hydrology, erosion-sedimentation, nutrient cycling, pesticide fate, crop growth, soil temperature, tillage, economics, and plant environment control. Although EPIC operates on a daily time step, the optional Green and Ampt infiltration equation simulates rainfall excess rates at shorter time intervals (0.1 h). The model offers options for simulating several other processes—five PET equations, six erosion/sediment yield equations, two peak runoff rate equations, etc. EPIC can be used to compare management systems and their effects on nitrogen, phosphorus, carbon, pesticides and sediment. The management components that can be changed are crop rotations, tillage operations, irrigation scheduling, drainage, furrow diking, liming, grazing, tree pruning, thinning, and harvest, manure handling, and nutrient and pesticide application rates and timing.

The APEX model was developed to extend the EPIC model capabilities to whole farms and small watersheds. In addition to the EPIC functions, APEX has components for routing water, sediment, nutrients, and pesticides across complex landscapes and channel systems to the watershed outlet. APEX also has groundwater and reservoir components. A watershed can be subdivided as much as necessary to assure that each subarea is relatively homogeneous in terms of soil, land use, management, and weather. The routing mechanisms provide for evaluation of interactions between subareas involving surface runoff, return flow, sediment deposition and degradation, nutrient transport, and groundwater flow. Water quality in terms of nitrogen (ammonium, nitrate, and organic), phosphorus (soluble and adsorbed/mineral and organic), and pesticides concentrations may be estimated for each subarea and at the watershed outlet. Commercial fertilizer or manure may be applied at any rate and depth on specified dates or automatically. The GLEAMS pesticide model is used to estimate pesticide fate considering runoff, leaching, sediment transport, and decay. Because of routing and subdividing there is no limit on watershed size. The major uses of APEX have been dairy manure management to maintain water quality in Erath and Hopkins Counties, TX, (Flowers, et al., 1996) and a national study to assess the effectiveness of filter strips in controlling sediment and other pollutants (Arnold, et al.,1998). APEX has its own databases for weather simulation, soils, crops, tillage, fertilizer, and pesticides. Convenient interfaces are supplied for assembling inputs and interpreting outputs.

Model description

Although EPIC is a fairly comprehensive model, it was developed specifically for application to the erosion-productivity problem. Thus, user convenience was an important consideration in designing the model. The computer program contains 53 subroutines, although there are only 2700 FORTRAN statements. Since EPIC operates on a daily time step, computer cost for overnight turn around is only about $0.15 per year of simulation on an AMDAHL 470 computer. The model can be run on a variety of computers since storage requirements are only 210 K. The drainage area considered by EPIC is generally small (~ 1 ha) because soils and management are assumed to be spatially homogeneous. In the vertical direction, however, the model is capable of working with any variation in soil properties—the soil profile is divided into a maximum of ten layers (the top layer thickness is set at 10 mm and all other layers may have variable thickness). When erosion occurs, the second layer thickness is reduced by the amount of the eroded thickness, and the top layer properties are adjusted by interpolation (according to how far it moves into the second layer).

When the second layer thickness becomes zero, the top layer starts moving into the third layer, etc.

Hydrology Surface Runoff Surface runoff of daily rainfall is predicted using a procedure similar to the CREAMS runoff model, option one (Knisel 1980; Williams and Nicks 1982). Like the CREAMS model, runoff volume is estimated with a modification of the SCS curve number method (USDA Soil Conservation Service 1972). There are two differences between the CREAMS and EPIC daily runoff hydrology components:

(1) EPIC accommodates variable soil layer thickness; and (2) EPIC includes a provision for estimating runoff from frozen soil.

Peak runoff rate predictions are based on a modification of the Rational Formula. The runoff coefficient is calculated as the ratio of runoff volume to rainfall. The rainfall intensity during the watershed time of concentration is estimated for each storm as a function of total rainfall using a stochastic technique. The watershed time of concentration is estimated using Manning's Formula considering both overland and channel flow.

Percolation

The percolation component of EPIC uses a storage routing technique combined with a crackflow model to predict flow through each soil layer in the root zone. Once water percolates below the root zone, it is lost from the watershed (becomes groundwater or appears as return flow in downstream basins). The storage routing technique is based on travel time (a function of hydraulic conductivity) through a soil layer. Flow through a soil layer may be reduced by a saturated lower soil layer. The crack-flow model allows percolation of infiltrated rainfall even though the soil water content is less than field capacity. When the soil is dry and cracked, infiltrated rainfall can flow through the cracks of a layer without becoming part of the layer's soil water. However, the portion that does become part of a layer's stored water cannot percolate until the storage exceeds field capacity. Percolation is also affected by soil temperature. If the temperature in a particular layer is 0°C or below, no percolation is allowed from that layer. Water can, however, percolate into the layer if storage is available. Since the 1-day time interval is relatively long for routing flow through soils, EPIC divides the water into 4 mm slugs for routing. This is necessary because the flow rates are dependent upon soil water content which is continuously changing. Also, by dividing the inflow into 4 mm slugs and routing each slug individually through all layers, the lower layer water content relationship is allowed to function. Lateral Subsurface Flow Lateral subsurface flow is calculated simultaneously-with percolation. Each 4 mm slug is given the opportunity to percolate first and then the remainder is subjected to the lateral flow function. Thus, lateral flow can occur when the storage in any layer exceeds field capacity after percolation. Like percolation, lateral flow is simulated with a travel time routing function. Drainage Underground drainage systems are treated as a modification to the natural lateral subsurface flow of the area. Simulation of a drainage system is accomplished by shortening the lateral flow travel time of the soil layer that contains the drainage system. The travel time for a drainage system depends upon the soil properties and the drain spacing.

Evapotranspiration

The evapotranspiration component of EPIC is Ritchie's ET model (Ritchie 1972). The model computes potential evaporation as a function of solar radiation, air temperature, and albedo. The albedo is evaluated by considering the soil, crop, and snow cover. The model computes soil and plant evaporation separately. Potential soil evaporation is estimated as a function of potential evaporation and leaf area index (area of plant leaves relative to the soil surface area). The first-stage soil evaporation is equal to the potential soil evaporation. Stage 2 soil evaporation is predicted with a square root function of time. Plant evaporation is estimated as a linear function of potential evaporation and leaf area index. Irrigation The EPIC user has the option to simulate dryland or irrigated agricultural areas. If irrigation is indicated, he must also specify the irrigation efficiency, a plant water stress level to start irrigation, and whether water is applied by sprinkler or down the furrows. When the user-specified stress level is reached, enough water is applied to bring the root zone up to field capacity plus enough to satisfy the amount lost if the application efficiency is less than one. The excess water applied to satisfy the specified efficiency becomes runoff and provides energy for erosion. Snow Melt The EPIC snow melt component is similar to that to that of the CREAMS model (Knisel 1980). If snow is present, it is melted on days when the maximum temperature exceeds 0°C, using a linear function of temperature. Melted snow is treated the same as rainfall for estimating runoff, percolation, etc. Weather The weather variables necessary for driving the EPIC model are precipitation, air temperature, solar radiation, and wind. If daily precipitation, air temperature, and solar radiation data are available, they can be input directly to EPIC. Rainfall and temperature data are available for many areas of the USA, but solar radiation and wind data are scarce. Even rainfall and temperature data are generally not adequate for the long-term EPIC simulations (50 years +). Thus, EPIC provides options for simulating temperature and radiation given daily rainfall or for simulating rainfall as well as temperature and radiation. If wind erosion is to be estimated, daily wind velocity and direction are simulated. Precipitation The EPIC precipitation model developed by Nicks (1974) is a first-order Markov chain model. Thus the model must be provided as input monthly probabilities of receiving precipitation if the previous day was dry and monthly probabilities of receiving precipitation if the previous day was wet. Given the wet-dry state, the model determines stochastically if precipitation occurs or not. When a precipitation event occurs, the amount is determined by generating from a skewed normal daily precipitation distribution. Inputs necessary to describe the skewed normal distribution for each month are the mean, standard deviation, and skew coefficient for daily precipitation. The amount of daily precipitation is partitioned between rainfall and snowfall using average daily air temperature.

Air Temperature and Solar Radiation The temperature-radiation model developed by Richardson (1981) was selected for use in EPIC because it simulates temperature and radiation that exhibit proper correlation between one another and rainfall. The residuals of daily maximum and minimum temperature and solar radiation are generated from a multivariate normal distribution. Details of the multivariate generation model were described by Richardson (1981). The dependence structure of daily maximum temperature, minimum temperature, and solar radiation was described by Richardson (1982a).

Wind

The wind simulation model was developed by Richardson (1982b) for use in simulating wind erosion with EPIC. The two wind variables considered are average daily velocity and daily direction. Average daily wind velocity is generated from a two-parameter Gamma distribution. Wind direction expressed as radians from north in a clockwise direction is generated from an empirical distribution specific for each location Erosion Water The water erosion component of EPIC uses a modification of the USLE (Wischmeier and Smith 1978) developed by Onstad and Foster (1975). The Onstad-Foster equation's energy factor is composed of both rainfall and runoff variables. In contrast, the USLE energy factor contains only rainfall variables. The hydrology model supplies estimates of runoff volume and peak runoff rate. To estimate the daily rainfall energy in the absence of time distributed rainfall, it is assumed that the rainfall rate is exponentially distributed. This allows for simple substitution of rainfall rates into the USLE equation for estimating rainfall energy. The fraction of rainfall that occurs during 0.5 h is simulated stochastically. The crop management factor is evaluated with a function of above-ground biomass, crop residue on the surface, and the minimum factor for the crop. Other factors of the erosion equation are evaluated as described by Wischmeier and Smith (1978).

The Manhattan, Kansas, wind erosion equation (Woodruff and Siddoway 1965), was modified by Cole et al. (1982) for use in the EPIC model. The original equation computes average annual wind erosion as a function of soil erodibility, a climatic factor, soil ridge roughness, field length along the prevailing wind direction, and vegetative cover. The main modification to the model was converting from annual to daily predictions to interface with EPIC. Two of the variables, the soil erodibility factor for wind erosion and the climatic factor, remain constant for each day of a year. The other variables, however, are subject to change from day to day. The ridge roughness is a function of a ridge height and ridge interval. Field length along the prevailing wind direction is calculated by considering the field dimensions and orientation and the wind direction. The vegetative cover equivalent factor is simulated daily as a function of standing live biomass, standing dead residue, and flat crop residue. Daily wind energy is estimated as a nonlinear function of daily wind velocity.

Nutrients

Nitrogen

The amount of N03-N in runoff is estimated by considering the top soil layer (10 mm thickness) only. The decrease in NO3-N concentration caused by water flowing through a soil layer can be simulated satisfactorily using an exponential function. The average concentration for a day can be obtained by integrating the exponential function to give NO3-N yield and dividing by volume of water leaving the layer (runoff, lateral flow, and percolation). Amounts of NO3-N contained in runoff, lateral flow, and percolation are estimated as the products of the volume of water and the average concentration. Leaching and lateral subsurface flow in lower layers are treated with the same approach used in the upper layer, except that surface runoff is not considered. When water is evaporated from the soil, NO3-N is moved upward into the top soil layer by mass flow. Thus, the total NO3-N moved upward into the top layer by evaporation is the product of soil evaporation and NO3-N concentration of each layer to a maximum depth of 300 mm. A loading function developed by McElroy et al. (1976) and modified by Williams and Hann (1978) for application to individual runoff events is used to estimate organic N loss. The loading function estimates the daily organic N runoff loss based on the concentration of organic N in the top soil layer, the sediment yield, and the enrichment ratio. The enrichment ratio is the concentration of organic N in the sediment divided by that of the soil. A two-parameter logarithmic function of sediment concentration is used to estimate enrichment ratios for each event.

Denitrification, one of the microbial processes, is a function of temperature and water content. Denitrification is only allowed to occur when the soil water content is 90% of saturation or greater. The denitrification rate is estimated using an exponential function involving temperature, organic carbon, and NO3-N. The N mineralization model is a modification of the PAPRAN mineralization model (Seligman and van Keulen 1981). The model considers two sources of mineralization: fresh organic N associated with crop residue and microbial biomass and the stable organic N associated with the soil humus pool. The mineralization rate for fresh organic N is governed by C:N and C.P ratios, soil water, temperature, and the stage of residue decomposition. Mineralization from the stable organic N pool is estimated as a function of organic N weight, soil water, and temperature. Like the mineralization model, the immobilization model is a modification of the PAPRAN model. Immobilization is a very important process in EPIC because it determines the residue decomposition rate and residue decomposition has an important effect on erosion. The daily amount of immobilization is computed by subtracting the amount of N contained in the crop residue from the amount assimilated by the microorganisms. Immobilization may be limited by N or P availability. Crop use of N is estimated using a supply and demand approach. The daily crop N demand is estimated as the product of biomass growth and optimal N concentration in the plant. Optimal crop N concentration is a function of growth stage of the crop. Soil supply of N is assumed to be limited by mass flow of NO3-N to the roots. Actual N uptake is the minimum of supply and demand.Fixation of N is an important process for legumes. EPIC estimates fixation by adding N in an attempt to prevent N stress that constrains plant growth. Plant growth is limited by the minimum of four factors (N, P, water, and temperature) each day. If N is the active constraint, enough N (a maximum of 2 kg/ha per day) is added to the plant to make the N stress factor equal the next most constraining factor if possible. The amount of N added is attributed to fixation. To estimate the N contribution from rainfall, EPIC uses an average rainfall N concentration for a location for all storms. The amount of N in rainfall is estimated as the product of rainfall amount and concentration. EPIC provides two options for applying fertilizer. With the first option, the user specifies dates, rates, and depths of application of N and P. The second option is more automated—the only input required is a plant stress parameter. At planting time, the model takes a soil sample and applies up to 15 kg/ha of N fertilizer if needed. The model also aplies enough P to bring the concentration of labile P in the top two layers up to the concentration level at the start of the simulation. There are two opportunities for applying additional N fertilizer during the growing season (at 25 and 50% of maturity). The amount of N applied at each of these two top dressings is determined by predicting the final crop biomass.

Phosphorus

The EPIC approach to estimating soluble P loss in surface runoff is based on the concept of partitioning pesticides into the solution and sediment phases as described by Leonard and Wauchope (Knisel 1980). Because P is mostly associated with the sediment phase, the soluble P runoff is predicted using labile P concentration in the top soil layer, runoff volume, and a partitioning factor. Sediment transport of P is simulated with a loading function as described in organic N transport. The loading function estimates the daily sediment phase P loss in runoff based on P concentration in the top soil layer, sediment yield, and the enrichment ratio. The P mineralization model developed by Jones, Cole, and Sharpley (C.A. Jones, C.V. Cole and A.N. Sharpley, 1982, A simplified soil phosphorus model, I. Documentation) is similar in structure to the N mineralization model. Mineralization from the fresh organic P pool is governed by C:N and C:P ratios, soil water, temperature, and the stage of residue decomposition. Mineralization from the stable organic P pool associated with humus is estimated as a function of organic P weight, labile P concentration, soil water, and temperature. The P immobilization model also developed by Jones et al. (1982) is similar in structure to the N immobilization model. The daily amount of immobilization is computed by subtracting the amount of P contained in the crop residue from the amount assimilated by the microorganisms. The mineral P model was developed by Jones et al. (1982). Mineral P is transferred among three pools: labile, active mineral, and stable mineral. When P fertilizer is applied, it is labile (available for plant use). However, it may be quickly transferred to the active mineral pool. Simultaneously, P flows from the active mineral pool back to the labile pool (usually at a much slower rate). Flow between the labile and active mineral pools is governed by temperature, soil water, a P sorption coefficient, and the amount of material in each pool. The P sorption coefficient is a function of chemical and physical soil properties. Flow between the active and stable mineral P pools is governed by the concentration of P in each pool and the P sorption coefficient.Crop use of P is estimated with the supply and demand approach described in the N model. However, the P supply is predicted using an equation based on soil water, plant demand, a labile P factor, and root weight.

Soil Temperature

Daily average soil temperature is simulated at the center of each soil layer for use in nutrient cycling and hydrology. The temperature of the soil surface is estimated using daily maximum and minimum air temperature, solar radiation, and albedo for the day of interest plus the 4 days immediately preceding. Soil temperature is predicted for each layer using a function of damping depth, surface temperature, mean annual air temperature, and the amplitude of daily mean temperature. Damping depth is dependent upon bulk density and soil water.

Crop Growth Model

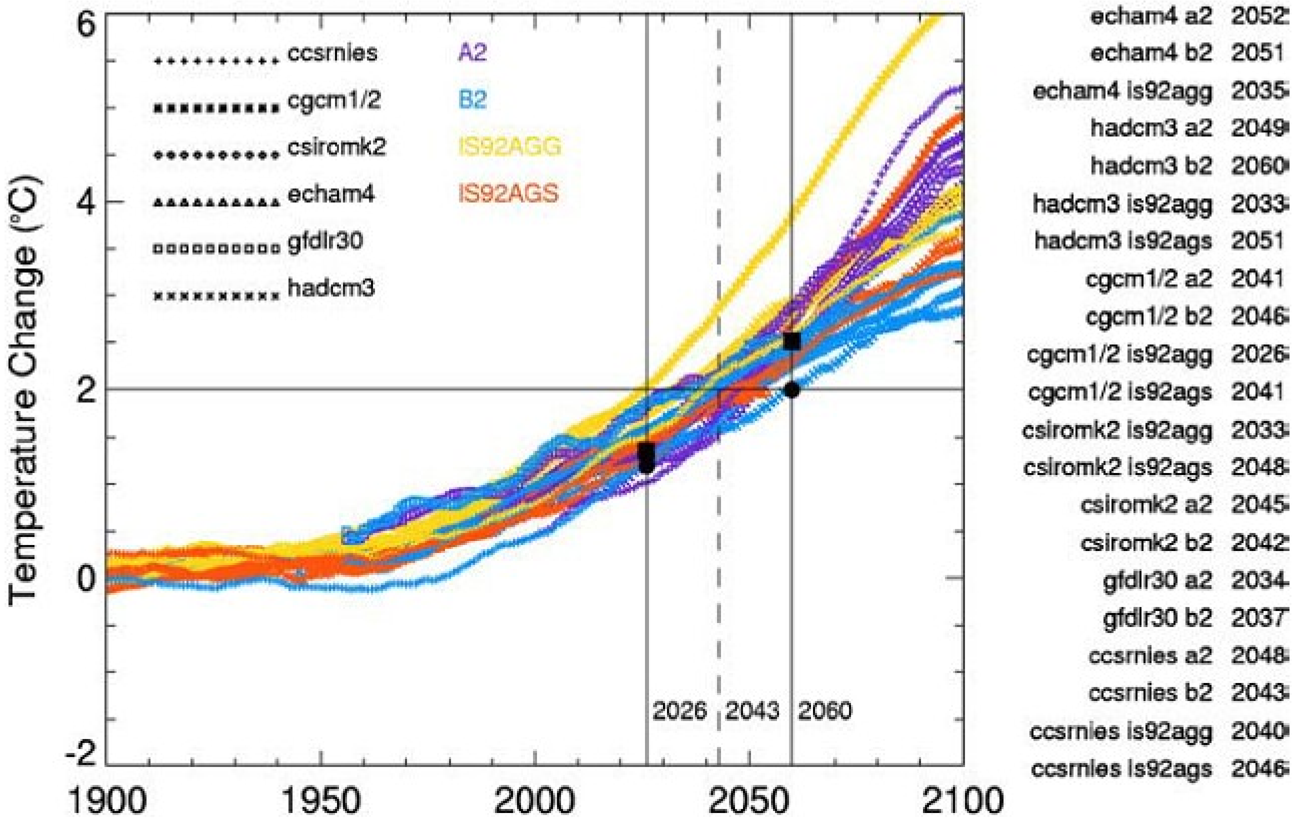
A single model is used in EPIC for simulating all the crops considered (corn, grain sorghum, wheat, barley, oats, sunflower, soybean, alfalfa, cotton, groundnut, and grasses). Of course, each crop has unique values for the model parameters. Energy interception is estimated with an equation based on solar radiation, daylight hours, and the crop's leaf area index. The potential increase in biomass for a day can be estimated by multiplying the amount of intercepted energy times a crop parameter for converting energy to biomass. The leaf area index, a function of biomass, is simulated with equations dependent upon the maximum leaf area index for the crop, the above-ground biomass, and a crop parameter that initiates leaf area index decline. The daily fraction of the potential increase in biomass partitioned to yield is estimated as a function of accumulated heat units and the ratio of total biomass to crop yield under favorable growing conditions. Since most of the accumulating biomass is partitioned to yield late in the growing season, late-season stresses may reduce yields more than early-season stresses. Root growth and sloughing are simulated using a linear function of biomass and heat units. The potential biomass is adjusted daily if one of the plant stress factors is less than 1.0 using the product of the minimum stress factor and the potential biomass. The water-stress factor is computed by considering supply and demand (the ratio of plant accessible water to potential plant evaporation). Roots are allowed to compensate for water deficits in certain layers by using more water in layers with adequate supplies. The temperature stress factor is computed with a function dependent upon the daily average temperature, the optimal temperature, and the base temperature for the crop. The N and P stress factors are based on the ratio of accumulated plant N and P to the optimal values. The stress factors vary nonlinearly from 1.0 at optimal N and P levels to 0.0 when N or P is half the optimal level. Root growth in a layer is affected by soil water, soil texture, bulk density, temperature, aeration, and aluminum toxicity. Potential root growth is a function of soil water in a layer. It is then reduced with a stress factor which is the minimum of stresses due to soil texture and bulk density, temperature, aeration, and aluminum toxicity. The soil texture-bulk density relationship was developed by Jones (1983). The aeration factor is based on percent air-filled porosity. The temperature factor is based on soil temperature and crop-specific temperature response curves. The aluminum toxicity factor is based on percent aluminum saturation and a crop-specific aluminum susceptibility relationship. Lime

EPIC simulates the use of lime to neutralize toxic levels of aluminum in the plow layer. Two sources of acidity are considered. KCI-extractable aluminum in the plow layer and the acidity associated with addition of ammonia-based fertilizers. The lime requirement due to KCI-extractable aluminum is estimated according to Kamprath (1970). All fertilizer N is assumed to be urea, ammonium nitrate, or anhydrous ammonium, all of which produce similar acidity when applied to the soil. When the sum of acidity due to extractable aluminum and fertilizer N sum to 4 tonnes lime/ha, the required amount of lime is added and incorporated into the plow layer.

Tillage

The EPIC tillage component was designed to mix nutrients and crop residue within the plow depth, simulate the change in bulk density, and convert standing residue to flat residue. Each tillage operation is assigned a mixing efficiency (0-1). Other functions of the tillage component include simulating row height and surface roughness. There are three means of harvest in the EPIC model—(1) traditional harvest that removes seed, fiber, etc. (multiple harvests are allowed for crops like cotton); (2) hay harvest (may occur on any date the user specifies); and (3) no harvest (green manure crops, etc.). When hay is harvested, the yield is computed as a function of mowing height and crop height. Tillage operations convert standing residue to flat residue using an exponential function of tillage depth and mixing efficiency. When a tillage operation is performed, a fraction of the material (equal the mixing efficiency) is mixed uniformly within the plow depth. Also, the bulk density is reduced as a function of the mixing efficiency, the bulk density before tillage, and the undisturbed bulk density. After tillage, the bulk density returns to the undisturbed value at a rate dependent upon infiltration, tillage depth, and soil texture [86]

GCMs and climate scenarios



The most appropriate approach to obtain information on global climate is the use of Atmospheric-Ocean Global Climate Models (GCMs). They can simulate the processes of the atmosphere-ocean system relevant at global and continental scale and, although there are many uncertainties in their formulation, they can be confidently used to assess climate changes resulting from increases of atmospheric greenhouse gases concentration. Recent advances in climate change modeling now enable better estimates than in the past and likely assess uncertainty ranges. In fact, in the ramework of intercomparison projects (e.g., EU FP6 Ensembles project), simulations of future climate are performed using different GCMs and for different emissions scenarios. Unfortunately, GCMs climate projections cannot be used directly in impact studies, due to difference between the coarse spatial (and temporal) resolution of GCMs (generally of order 100 km) and the small scale resolution needed by environmental impact models (typically of order 10 km or less), that are very sensitive to local climate. Thus, downscaling techniques have been developed, which use the large-scale predictions provided by a GCM to assess climate change information on a regional scale. This approach has been widely used in impact studies, such as the statistical evaluation of river flows (Diaz Nieto and Wilby, 2003), floods (Charlton et al., 2006), groundwater recharge (Holman et al., 2009), and, more in general, water resource planning (Prudhomme and Davies, 2009a,b). The downscaling models can be divided into two main categories: the statistical models, which are based on regression analysis used to derive semiempirical statistical relationships between the large-scale predictors and local (station) scale predictands; the dynamical models, which are high-resolution Regional Climate Models (RCMs) nested in a coarser resolution GCM. In the statistical approach, the empirical relationships are derived by using historical meteorological series defined at the coarse GCM grid resolution and historical series from a set of stations available in the area of interest, typically characterized by a small distance. The dynamical approach is similar to the grid one-way nesting technique used in weather forecast and other meteorological applications. However, both the downscaling approaches have some drawbacks. For example, the dynamical downscaling needs large computing resources and is strongly dependent on the boundary conditions that are provided by GCMs; also, it is based on the assumption that the actual parameterization schemes are still valid in a future climate; the statistical downscaling needs long time series (that are available for long periods only in limited regions) to build statistical relationships, that are supposed to be still valid in the future. Also, both methods inherit the inaccuracies present in the GCM outputs: Prudhomme and Davies (2009a,b) observed that the existing bias in reproducing the present climate is likely to be transferred to simulations in future time horizons. In order to partially overcome this problem, they suggest to use more than one downscaling technique and to compare the results to get a more reliable picture. Haylock et al. (2006) agreed with this consideration and noticed that the differences between different downscaling models are at least as large as the differences between different SRES (Special Report on Emissions Scenarios, the most widely used and cited scenarios , that form the basis for the IPCC assessments). As a consequence, they suggested to include different types of downscaling models and emission scenarios when developing climate-change projections at the local scale. One of the first comparisons between different downscaling models is given by Wilby et al. (1998). They compared only statistical models and found that neural networks were the last skilful in reproducing observed rainfall, mainly due to wrong estimation of wet-day occurrence. Kidson and Thomson (1998) found that dynamical and statistical approaches have similar skills in downscaling daily precipitation, minimum and maximum temperature. Murphy (1999) found that a Linear Regression Statistical Model (LRSM) has skills comparable to a Regional Climate Model (RCM) in downscaling monthly precipitation and temperature over Europe. Wilby et al. (2000) also compared the results obtained from a LRSM and a RCM relative to daily precipitation, runoff and temperature in the Animas River basin (Colorado) and reached a similar conclusion for daily data. Also, they noticed that both the methods were more skilful than the raw National Center for Environmental Prediction (www.cdc.noaa.gov) analysis precipitation data. Haylock et al. (2006) compared several statistical and dynamical downscaling models with a new version of a non-linear artificial neural network, finding that the latter was the best at reproducing inter-annual variability, but that also has the tendency to underestimate the extremes. Downscaling of GCM model output is particularly important for assessing regional climate change for a region like the Mediterranean area, which is characterized by high space variability and many climate types. This variability is due to a combination of different factors: the complex orography; the complicated land-sea patterns of the basin; the Mediterranean Sea itself, that influences the genesis and the distribution of cyclones through air-sea interaction mechanisms and latent heat release (Lionello et al., 2006, Moscatello et al., 2008). Also, the position of the Mediterranean region makes the regional climate dependent on both mid-latitude climate in the north and on tropical climate in the south. In fact, mid-latitude regimes, such as the North Atlantic Oscillation (NAO) and the East Atlantic pattern (Trigo and Palutikof, 2001), and tropical phenomena, like El Nino Southern Oscillation (ENSO), affect the weather regimes during Winter; the Asian and the African monsoon and geopotential blocking anomalies over central Europe influence the climate during Summer (Alpert et al., 2006). About historical records, trends from 1900 show that precipitation declined in the Mediterranean basin; also, a temperature increase larger than the global average (especially during Summer) as well as an increase in the number of heat waves have been recorded. Giorgi and Lionello (2008) show that GCMs generally agree on a substantial future drying of the Mediterranean region in all the different (SRES) scenarios, especially in the warm season. In IPCC (2007), the authors show that different GCM experiments agree in a regional mean temperature increase of 0.5-1°C for the period 2011-2030 (with respect to the period 1960-1990) which is insensitive to the choice of the SRES scenario. These results point out that, with high confidence, the Mediterranean basin will suffer from a decrease in water resources due to climate change in the near future. Thus, drought-affected areas are expected to increase in extent, with adverse impact on multiple sectors, such as water resources, energy production, agriculture, ecosystems. The projected changes are, however, not uniform in the whole region, stressing the need of downscaling techniques able to resolve internal differences in the basin and to reproduce the detailed spatial distribution. Statistical downscaling has been applied to precipitation climate change in several studies in different Mediterranean areas (e.g., von Storch et al., 1993; Corte- Real et al., 1995; Goodess and Palutikof, 1998; Palatella et al., 2010). More recently, different GCMs, scenarios and predictors, have been tested for statistical downscaling of precipitation during the wet season (Hertig and Jacobeit, 2008a), reporting different climate change signals in different areas and confirming the need of an analysis that is capable of resolving internal differences within the Mediterranean region. Statistical downscaling for temperature has shown a projected increase for the whole Mediterranean area for all months of the year in the period 2071-2100 compared to 1990-2019; the assessed temperature rise varies depending on region and season, but overall substantial temperature changes of partly more than 0.5-1C° have to be anticipated by the end of this century under enhanced greenhouse warming conditions (Hertig and Jacobeit, 2008b). For the European continent, a number of studies with regional climate models focused on future changes in extreme events (e.g., Frei et al., 2006; Beniston et al., 2007). In this context, the STARDEX project (the Statistical and regional dynamical downscaling of extremes for European regions; Gooddess, 2005) provided a rigorous and systematic inter-comparison and evaluation of statistical, dynamical and statistical-dynamical downscaling methods for the construction of scenarios of extremes for six different European regions. The EU project PRUDENCE (Prediction of Regional scenarios and Uncertainties for Defining European Climate change risks and Effects) provided an ensemble of high-resolution climate change scenarios for Europe at the end of the twenty-first century by means of dynamical downscaling (Christensen et al., 2007). The simulations in PRUDENCE have been compared with global simulations (Deque et al., 2005), and have been used to assess temperature and precipitation change signals, e.g. in Italy (Coppola and Giorgi, 2010) and Greece (Zanis et al., 2009), and changes in European drought characteristics (Blenkinsop and Fowler, 2007). The EU project ENSEMBLES (Hewitt, 2005) will further advance the state-of-the-art by comparing different methods for representing climate model uncertainty and linking these methods to downscaling techniques in order to improve the robustness of climate change impact assessments. (Pizzigalli et al., 2012). 56

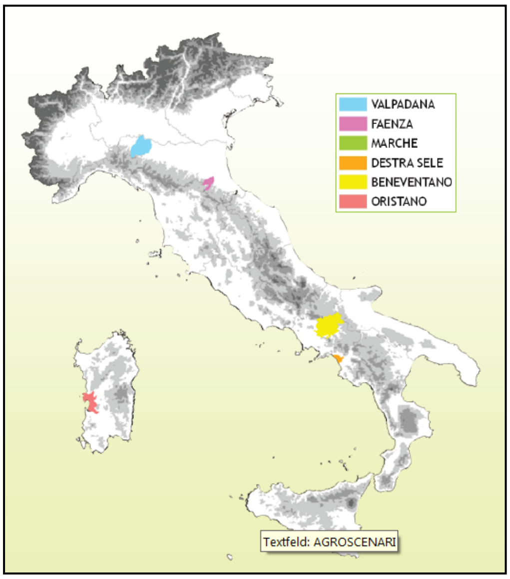
General circulation model (GCM) is the right and accurate toll for the prediction of future climatic condition and provides necessary data to run simulation models of the crops's growth and development under climate change condition (Jones and Thornton, 2003).

1.2 Research question

Today, there are still some of the key sources of uncertainties for future crop and productivity under climate change. The main are reviewed here:

1) Several key interaction are poorly described by crop models including:
   - non linearity and threshold effects in response to extreme weather events;
   - modification of weed pest and disease incidence;
   - field response of crops to elevated CO_2 concentration;
   - interactions of climate and management variables with elevated CO_2 (Tubiello et al., 2007);
   - interactions between abiotic factors and elevated CO_2;
   - genetic variability in plant CO_2 and temperature responses;
   - interactions with biotic factors;
   - the effects on harvest quality (Soussana et al., 2010)
   - absence of combination of integrated modeling from different disciplines and multi – factorial experimentation to understand and priorities of the challenges (Newton A.C. et al., 2010).
2) Stakeholders have increasing demands concerning adaptation to climate change of agriculture management (Soussana et al., 2010). Adaptation requires detailed understanding of the likely impacts of climate change in small agricultural regions, which further increases the need of modeling. Thus the main key of uncertainties are:
   - how they could be better reflected in model results;
   - how they could be reduced in the future;
   - the extent to which conclusions from these models can already be used to provide outlook and guidance for adapting agriculture to climate change (Soussana et al., 2010).

1.3 Research objectives



The research is part of the Italian research project "AGROSCENARI" - Scenarios of adaptation to climate change in Italian agriculture, funded by the Ministry of Agriculture and Forestry with DM 8608/7303/08 of 7 August 2008.

The project aims at developing cognitive and decision-making tools through an integrated analysis of Italian agricultural systems projected into possible future climate scenarios, to direct the agricultural activities towards forms of adaptation and/or mitigation of the Climate Change, following environmental and economic sustainability criteria, however, considering the increasing economic value of water resources.

Italian agriculture has a strong and immediate need to take strategic planning measures to mitigate or offset adverse impact of climate change already in progress.

The final results of the project "CLIMAGRI – Agriculture and Climate Change", published in 2006, had already showed, in several Italian districts, clear signs of climate change in terms of increased temperatures and lack of rain. Agroscenari proposes to answer the imperative need to look for interrelationships between climate change and agricultural systems, to evaluate potential productive/economic losses resulting from climate change and then appropriate strategies of adaptation. The purpose of Agroscenari is to identify and assess sustainability and modes of adaptation to climate changes of some major Italian agricultural systems such as viticulture, olive growing, grain crops in the hilly south-central Italy, intensive horticulture under irrigation in south-central Italy, grain growing for zootechnical feeding in the Po Valley and intensive fruit growing in the south-east Po Valley.

In the process of adaptation the Project will develop two separate time frames, a short-term one (5 years) and a long-term one (30 years). As for the short term adaptation, Agroscenari proposes strategies for limiting and reducing the impacts through a multidisciplinary and coordinated approach in view of the mutual interrelationships between factors such as climate, crops, pests, social, environmental and economic viability of farming. Regarding the long-term adaptation, Agroscenari aims at the construction of scenarios of climate change and evolution of production systems both nationally and locally. The research involves a set of study areas which can be taken as a symbol of the most important production systems.

Specifically research efforts will be directed to:

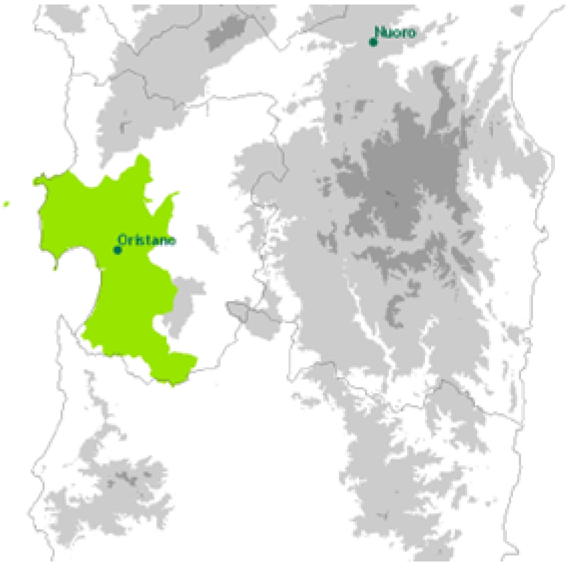
- investigate and quantify the increased weather-climate risk in the above mentioned important agricultural areas, with regard to various abiotic and biotic features;
- acquire knowledge for better supporting the future sustainability of agricultural practices through appropriate management of available resources;
- investigate the best achievement of the economic sustainability of farming practices to reduce losses and safeguard the quality and quantity of crops;
- study feeding systems for dairy cattle and pigs aimed at the production of typical products, using crops able to optimize the use of water resources;
- find the best strategies for disseminating knowledge and achievements in order to promote awareness and responsible behaviour at all levels of the production chain, in the agricultural world;

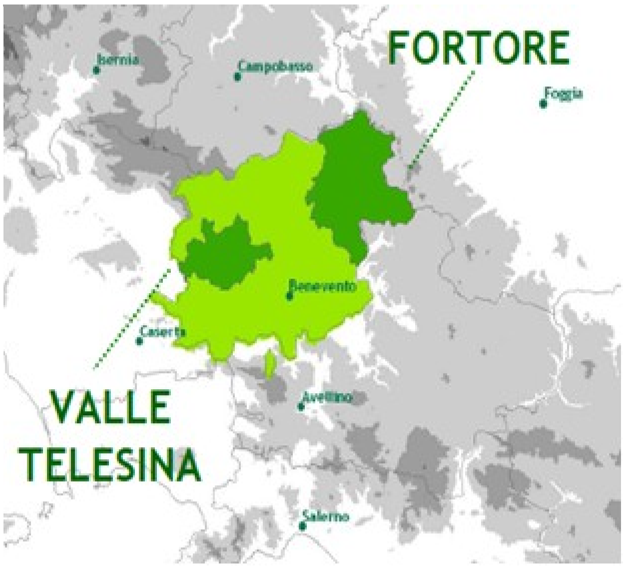
- develop solid scientific basis and reference information both for policymakers and farmers.

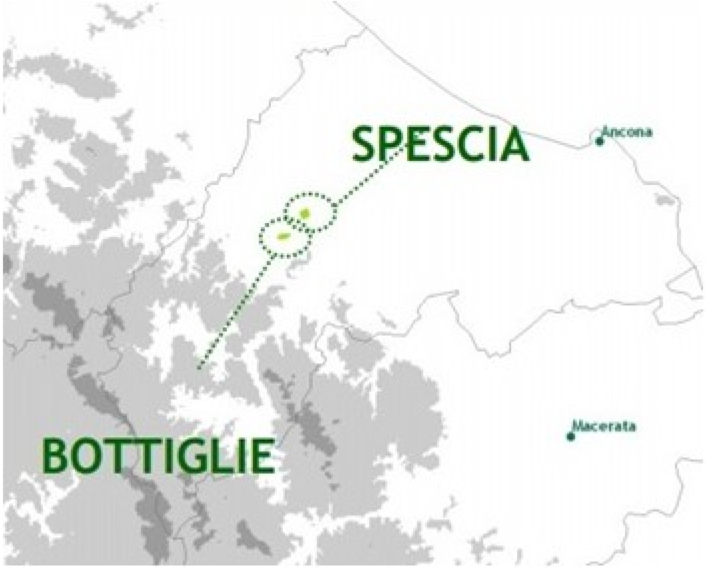
Expected results

The expected results by Agroscenari project include methodologies and operational schemes, which can be dynamically updated over time as a result of the monitoring of agricultural setting and climate evolution. Agroscenari will provide different products such as manuals, thematic cartography, phenological maps, basic material for training courses in agreement with local authorities, forecasting models of biotic and abiotic evolution factors, specific documents for either the stakeholders' operative purposes or the policy makers' agro-environmental strategies. In addition, it also provides forecasting tools about soil trafficability (http://www.agroscenari.it/).

Specific research objectives







The principal objective of this study was to evaluate the climate change impacts on durum wheat yields (Triticum turgidum ssp. durum) at field scale, in three sites of Mediterranean environments, characterized by different climatic and management conditions. A crop growth simulation model The approach for this purpose contemplated the use of a crop growth model. Epic model was the crop growth model used as useful tool to simulate climate change effects, through simulations [65].

In this way this study had the aim to :

- assess climatic change impacts on durum wheat yield, evapotranspiration (ET), water use efficiency (WUE), growing season precipitation (GSP), water stress (WS) and nitrogen stress (NS) in the context of three areas of Central Italy;
- evaluate the uncertaining of climatic projections on crops responces;
- give indication for potential adaptation strategies, useful to politics in order to choose mitigation strategies.

Furthermore was necessary to determine which of the main factors were likely to increase the vulnerability of durum wheat yields.

Chapter 2

2. Material and methods

2.1 Selection of models

This study was carried out to assess the effects of climate change on Durum wheat yields at field scale using a crop growth simulation model and a climatic scenarios in order to simulate the crop response in future weather conditions. The climate scenarios were generated by General Circulation Models (GCM) and adapted to the field scale through downscaling processes. Understanding the consequences of long-term climate change is important for the agricultural policies and the choice of mitigation strategies.

2.1.1 Crop growth model: Epic model description

The EPIC model was developed in the USA in the ’80s to investigate the relationships between erosion and soil productivity (William et al., 1984)[68] and for this reason its first acronym was Erosion-Productivity Impact Calculator. Subsequently, the model was enhanced by the further addition of modules to improve the simulation of plant growth and others routine as that for implementation of CO_2 enrichment (William et al., 1989; Sharpley and Williams, 1990; Stockle et al., 1992) [69-70-71]. Nowadays EPIC is a complete tool for the study of agro-ecosystem processes. EPIC is programmed to simulate, on a daily scale, the dynamics and the interactions between the components of a soil-plant-atmosphere system and is able to simulate processes as weather, soil erosion, hydrological and nutrient cycling, tillage, crop management and growth/yield. Crop growth is calculated on a daily base and requires, as weather inputs, precipitation, maximum and minimum daily temperature, solar radiation and wind speed as well as numerous crop parameters (morphology, phenology, physiology, etc.). The crop growth routine calculates the potential daily photosynthetic production of biomass and this is decreased by stresses caused by shortages of radiation, water and nutrients, by temperature extremes, and by inadequate soil aeration. The value of the most severe stress is used to reduce biomass accumulation, root growth, harvest index and crop yield. WinEPIC is a user-friendly interface for the EPIC crop simulation model and a windows-based application. It combines many features of the CroPMan (Crop Production and Management) (Gerik et al., 2003)[72] model, in which single or a limited number of comparisons are executed and displayed, with the possibility to manage multiple runs. WinEPIC was developed with a focus on research applications for analyses of cultural practices and cropping systems on production, soil quality, water quality, water and wind erosion, and profits.

In this study the Epic model was used to assess the effects of climate change on Durum wheat at field scale in three different sites in Mediterranean area under different climatic scenarios.

The Epic model was calibrated using experimental data sampled from a long term experiment of durum wheat in the experimental farm of the CRA-Foggia and validated in other three site (Oristano, Benevento and Ancona) using different series data.

2.1.2 Climate models: ECHAM 5.4 and RAMS

To run Epic under climate change conditions, a General Circulation Model (GCMs) was selected to generate climatic projections (Farina et al., 2011)[73]: ECHAM 5.4, an atmospheric global model, managed by the Centro Euro Mediterraneo per i Cambiamenti Climatici (CMCC), for the A1B emission scenario in the framework of CIRCE EU-Project.

Two different approaches have been developed: a statistical downscaling technique, applied to the ENSEMBLE EU-Project global climate simulations, and a numerical technique base on a regional model directly forced by an Atmospheric - Ocean coupled model, both approaches for the A1B emission future scenario. The statistical approach is based on the climate change scenarios of seasonal maximum, minimum temperature and precipitation over the period 2021-2050 against 1961-1990. The method consists of a multivariate regression, based on Canonical Correlation Analysis, using as possible predictors mean sea level pressure, geopotential height at 500hPa and temperature at 850 hPa. The observational data set (predictands) for the selected regions is composed by a reconstruction of minimum, maximum temperature and precipitation daily data on a regular grid with a spatial resolution of 35 km, for 1951-2009 period (managed by the Meteorological and Climatological research unit for agriculture – Agricultural Research Council, CRA – CMA). A statistical weather generator is then applied in order to compute, from the identified seasonal anomalies, an ensemble of synthetic daily time series for temperature and precipitation. The second downscaling approach, based on the Regional Atmospheric Modelling System (RAMS), has been applied to compute numerical future scenarios for the whole Mediterranean Basin and the Italian peninsula. The non – hydrostatic numerical model RAMS is forced by the ECHAM 5.4 atmospheric global model, managed by the Centro Euro Mediterraneo per i Cambiamenti Climatici (CMCC), for the A1B emission scenario in the framework of CIRCE EU-Project. RAMS model is also forced with the sea surface temperature coming from the CMCC ocean coupled model that has a specific component for the Mediterranean sea basin. Two 11-years-long experiments were computed representing a contemporary climate period 2000 – 2010 and a future one 2020 – 2030. The RAMS model calibration was performed with a third similar experiment in which the forcings are respectively the atmospheric NCEP-DOE Reanalysis-2 and the observed sea surface temperatures from Hadley Centre (Met Office - HadISST 1.1 - Global sea-Ice coverage and SST) for the 2000 – 2010 period. This alternative downscaling technique has been performed in order to compute high spatio – temporal resolution timeseries of atmospheric variables (50km of horizontal grid spacing and 1 hour of temporal resolution).

All produced time series for the specific target areas were used as input for applications managed by other research groups in the Agroscenari Project (Agroscenari Project Description)[74]. Observed climatic data set were used by ECHAM 5.4 model to obtain present and future scenarios for Oristano and Benevento sites, while an interpolation of weather data set from three weather stations were used to simulate climatic scenarios for Ancona site.

Bias correction

The daily weather data are maximum and minimum air temperature (°C), precipitation data (mm), Global solar radiation (MJ/m2) data and wind speed measured at 2 m (m/s). These data are collected by automatic weather stations. Specifically, for the three sites (Marche, Sardinia and Campania) a bias correction was applied to all the climate projections (present and future scenarios) for reducing the downscaling bias. In particular for the precipitation, a monthly coefficient was obtained with a mathematical operation.

Kr (Rainy days Obs/ Rainy days Sim)* rainy days + 1.5 mm

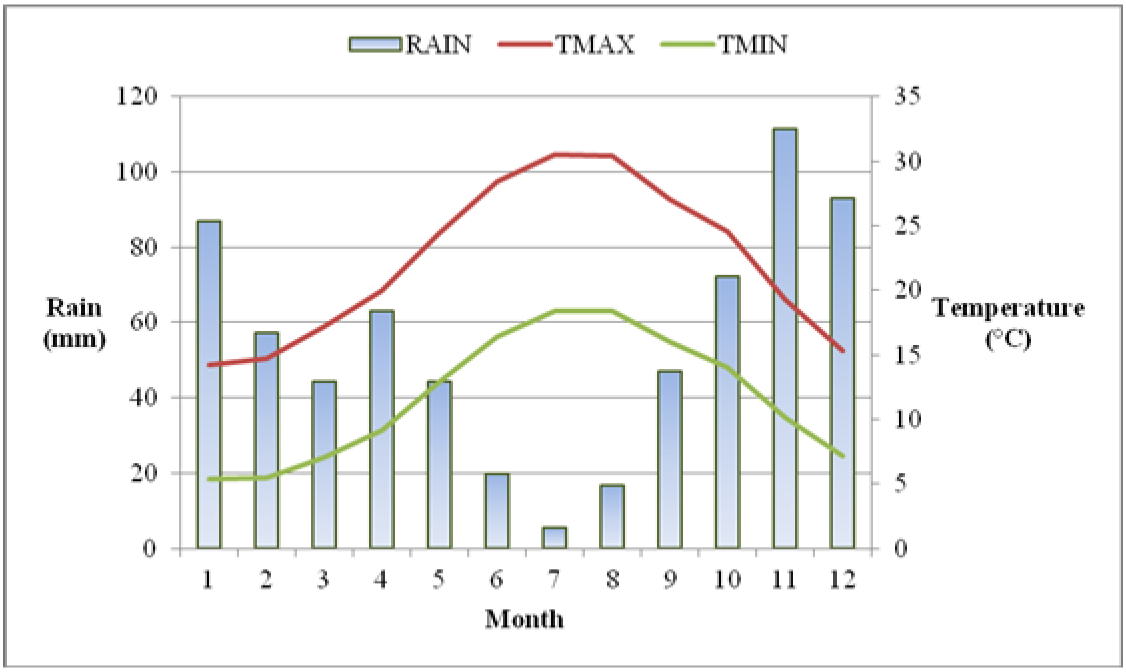
The same operation was repeated for each climate scenario of each site.

2.2 Baseline and future climatic scenarios over the study areas

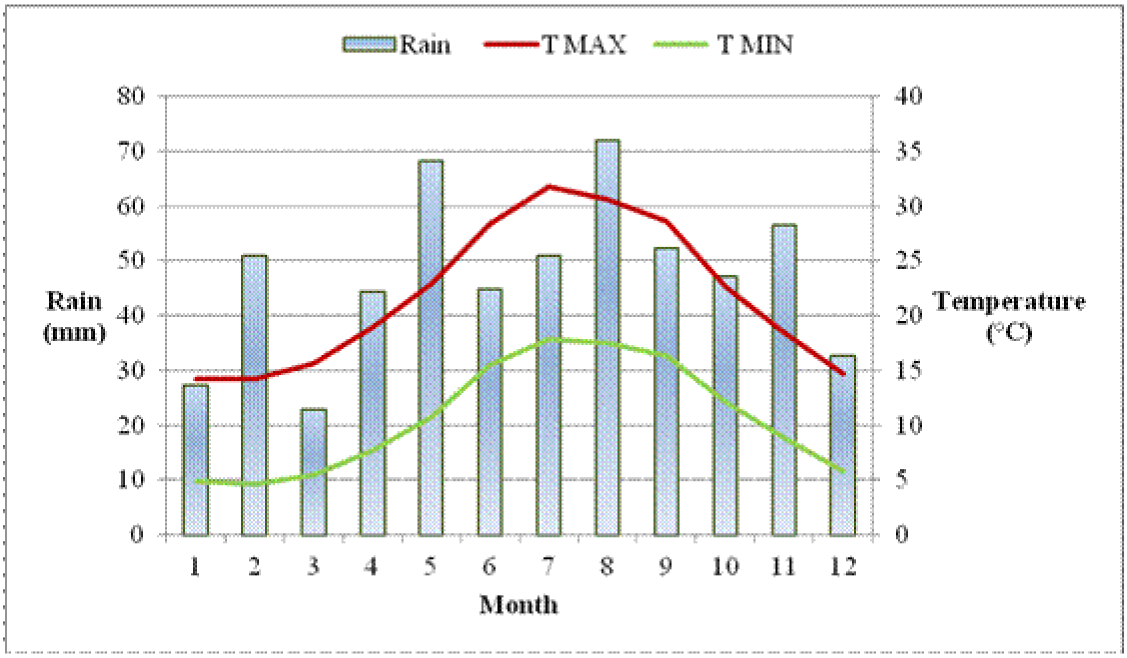
The simulations were performed for two different periods, a short period (2000-2010) and a long-term period (2020-2030). All daily data were obtained from climatic projections generated by the ECHAM 5.4 and by a statistical downscaling process on the study area (Pizzigalli et al., 2012)[75], called RAMS, considered as an experimental methodology. For the baseline and future climatic scenarios of each site a climatic data set was used to generate the baseline and future data by mean of a statistical downscaling process (Pizzigalli et al., 2012)[75]. Daily data of rainfall, maximum temperature and minimum temperature and global radiation were used as Epic model input variables, together to atmospheric humidity and wind speed. To calculate the potential evapotranspiration, the Penman-Monteith equation was used. Only in Oristano site, as in the observed data, all the variables requested by Epic model were completely available. For the other two, radiation, relative humidity and wind speed were generated by Epic model.

2.2.1 Oristano

Climatic baseline and future scenarios

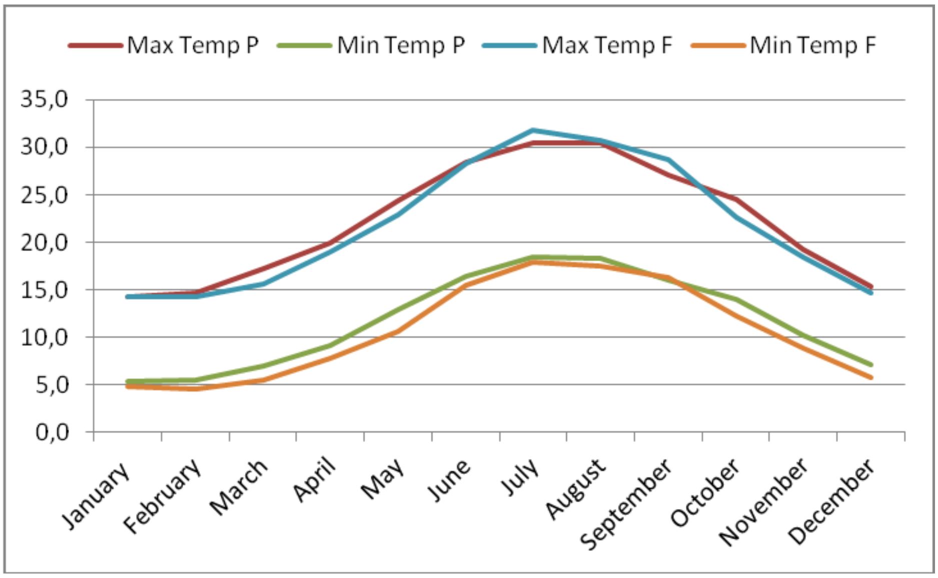


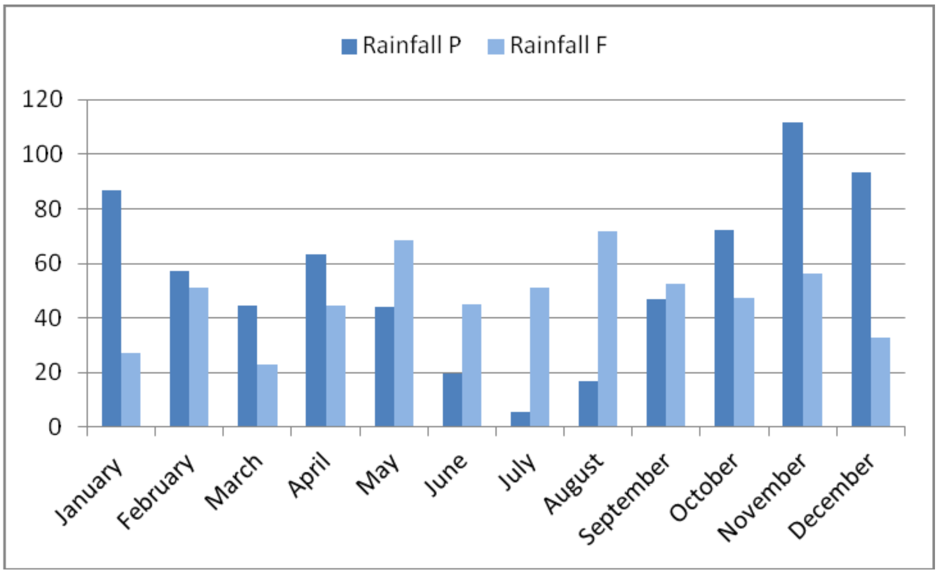
Graphic – Present climate: average monthly rainfall, maximum and minimum temperature at Oristano site.



Graphic – Future climate: average monthly rainfall, maximum and minimum temperature at Oristano site.

Changes in climatic variables





Analysis of the two climatic scenarios showed importants changes on the principal climatic variables (Rainfall, Maximum and minimum temperature) (table). In 2020-2030 on average, maximum temperature changes varied of 0.4 °C, with a range from -1.6 to 1.9 °C, respect the baseline condition, while the minimum temperature changed with an increase of 1.1 °C and ranged from -0.3°C to 2.3°C. The rainfall was expected changing, decreasing from 662 mm under baseline conditions to 570 mm under future conditions: an important difference on the two scenarios inter-annual variability was also shown through the CV, that passed from 0.56 under CP to 0.29 under CF.

If consider each scenario, the present climate (Graphic) was characterized by a maximum temperature that ranged from 14.2 °C to 30.5 ° C, respectively in January and July (Dev.st.= 5.8; CV=0.26), whereas minimum temperature passed from 5.4 °C to 18.4 °C (Dev.st=4.7; CV=0.40), always in the same previous months. Rainfall ranged from 5 mm in July to 111 in November (dev.st. 30.94).

Under future condition (Graphic) the maximum temperature ranged from 14.2 to 31.7 °C (Dev.st.=6.39; CV=0.29) in January and July, while the minimum changed from 4.6 °C in February to 17.9 °C in Dev.st.=4.92; CV=0.46). Rainfall ranged from 23 mm in March to 72 mm in August.

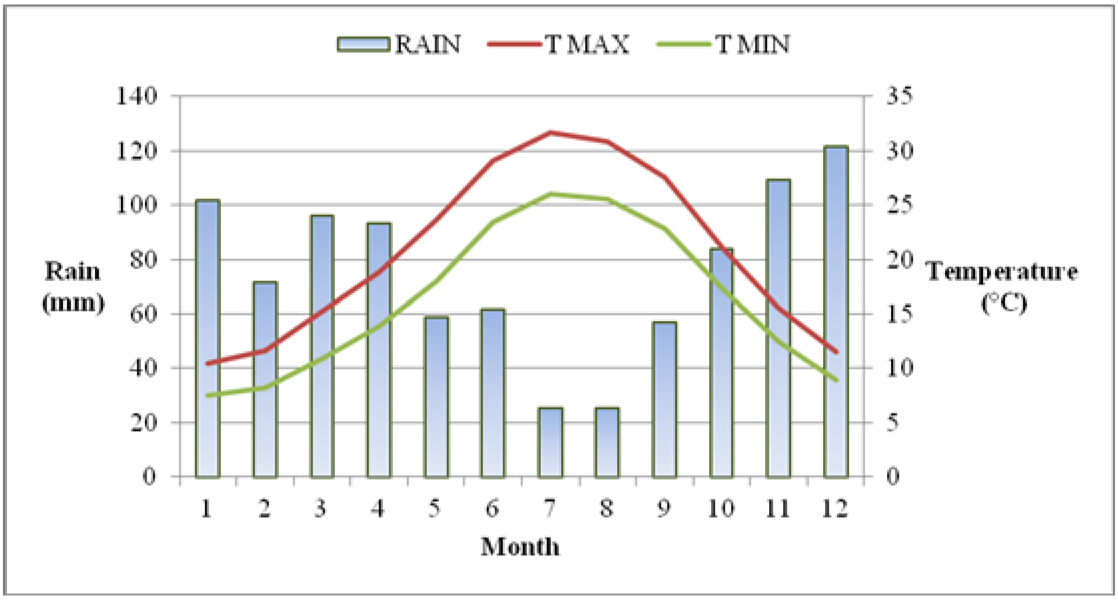
Table – Comparison between baseline and future conditions on Oristano site

Baseline conditions				Future conditions		
Month	RAIN	T MAX	T MIN	RAIN	T MAX	T MIN
January	87	14,2	5,4	27	14,2	4,9
February	57	14,7	5,4	51	14,3	4,6
March	44	17,2	7,0	23	15,7	5,4
April	63	19,9	9,2	44	19,0	7,7

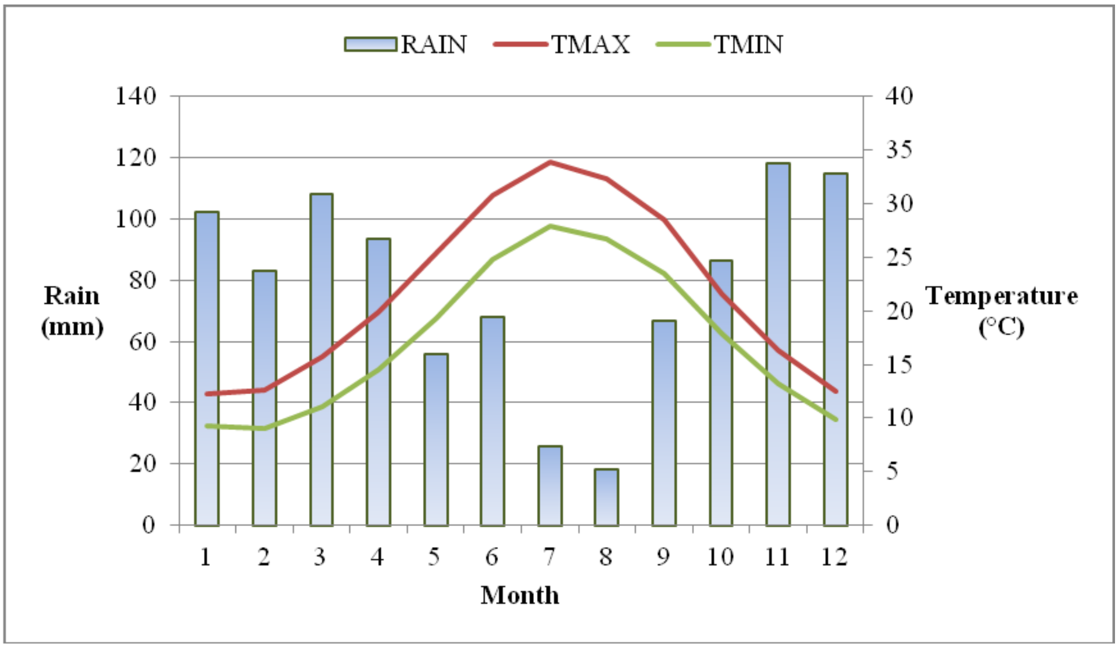
May	44	24,4	12,9	68	22,9	10,7
June	20	28,4	16,4	45	28,4	15,5
July	5	30,5	18,4	51	31,7	17,9
August	17	30,4	18,3	72	30,7	17,5
September	47	27,0	16,0	52	28,6	16,3
October	72	24,6	14,0	47	22,7	12,2
November	111	19,2	10,2	56	18,4	8,9
December	93	15,3	7,1	33	14,7	5,8
Year	**662**	**22,2**	**11,7**	**570**	**21,8**	**10,6**

2.2.2 Benevento

Climatic baseline and future scenarios

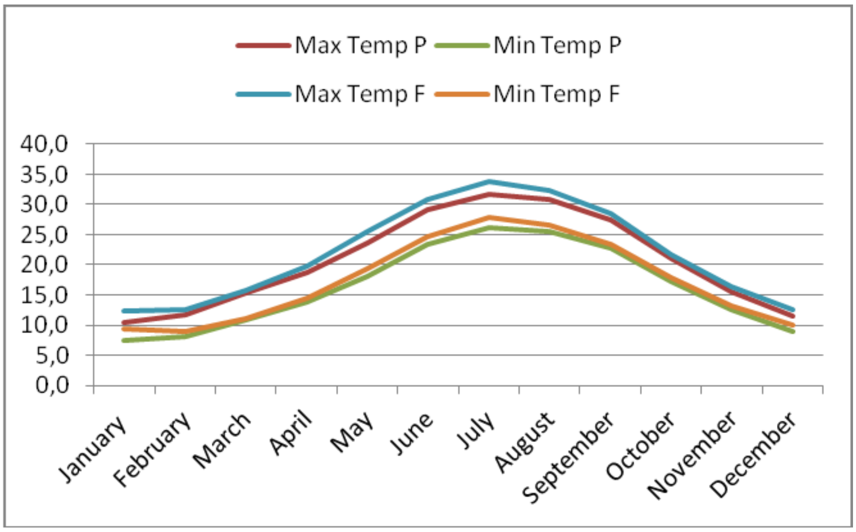


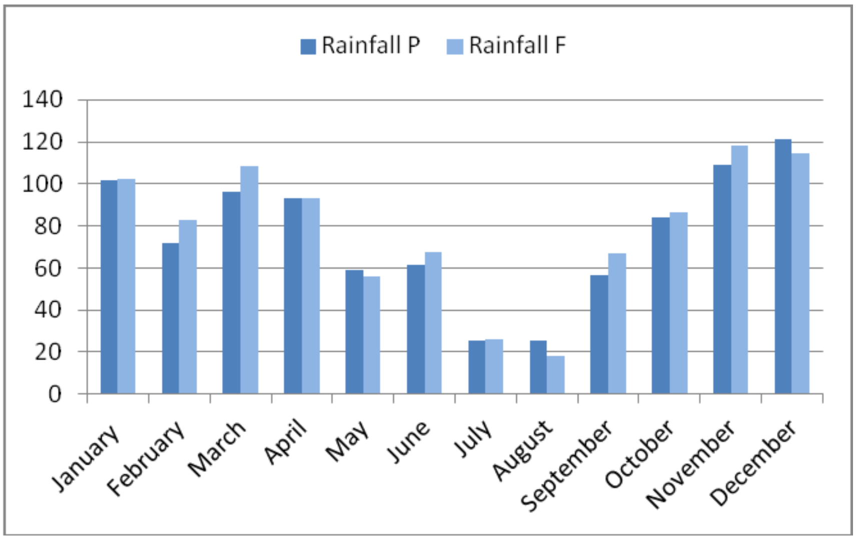
Graphic – Present climate: average monthly rainfall, maximum and minimum temperature at Benevento site.



Graphic – Future climate: average monthly rainfall, maximum and minimum temperature at Benevento site .

Changes in climatic variables





Analysis of the two climatic scenarios showed importants changes on the principal climatic variables (Rainfall, Maximum and minimum temperature) (table). In 2020-2030 on average, maximum temperature changes varied of 1.23 °C, with a range from -0.3 to 2.1 °C, respect the baseline condition, while the minimum temperature changed with an increase of 1 °C and ranged from -0.2°C to 1.8°C. The rainfall was expected changing, increasing from 905 mm under baseline conditions to 941 mm under future conditions: there was not important difference on the two scenarios inter-annual variability, where CV ranged from 0.39 under CP to 0.40 under CF. If consider each scenario, the present climate (Graphic) was characterized by a maximum temperature that ranged from 10.4 °C to 31.7 ° C, respectively in January and July (Dev.st.= 7.52; CV=0.36), whereas minimum temperature passed from 7.5 °C to 26.1 °C (Dev.st=6.6; CV=0.40), always in the same previous months. Rainfall ranged from 25 mm in August to 121 in December (dev.st. 29.71).

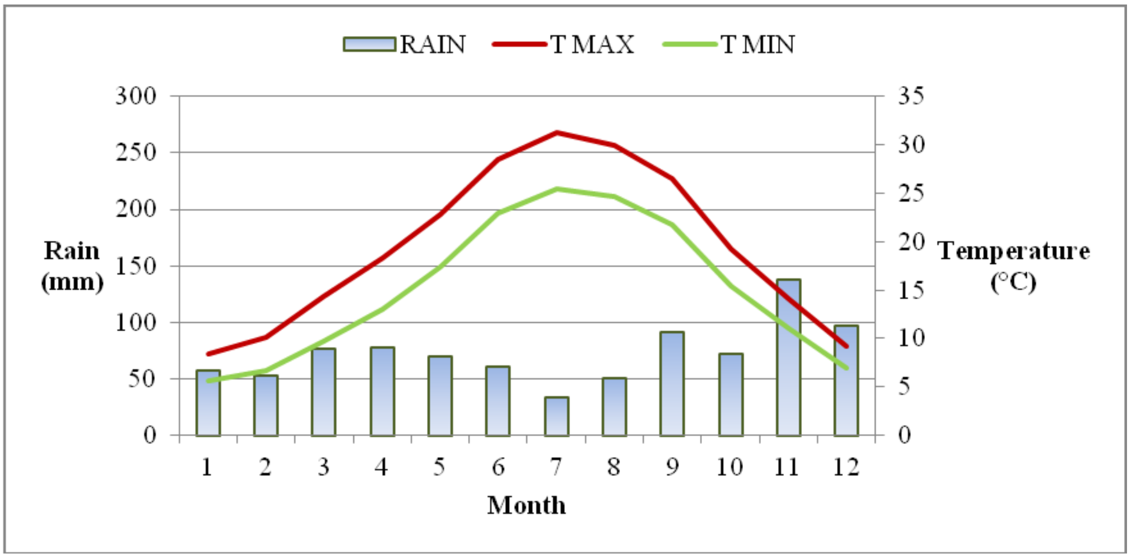
Under future condition (Graphic) the maximum temperature ranged from 12.3 to 33.8 °C (Dev.st.=7.78; CV=0.36) in January and July, while the minimum changed from 9 °C in February to 27.9 °C in July (Dev.st.=6.76; CV=0.39). Rainfall ranged from 18 mm in August to 118 mm in November.

Table – Comparison between baseline and future conditions in Benevento site.

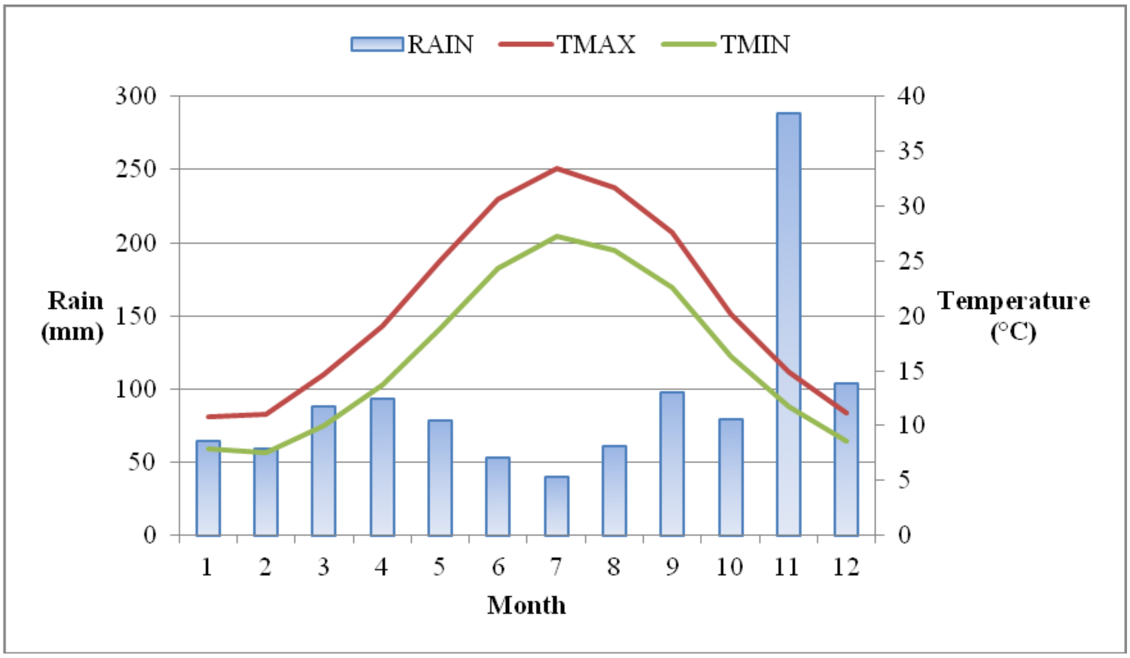
Baseline				Future		
Month	RAIN	T MAX	T MIN	RAIN	T MAX	T MIN
January	102	10,4	7,5	102	12,3	9,3
February	72	11,7	8,2	83	12,6	9,0
March	96	15,4	10,9	108	15,7	11,1
April	93	18,8	13,8	93	19,9	14,5
May	59	23,7	18,0	56	25,4	19,3
June	62	29,0	23,5	68	30,8	24,8
July	26	31,7	26,1	26	33,8	27,9
August	25	30,8	25,5	18	32,3	26,7
September	57	27,5	22,8	67	28,5	23,5
October	84	21,0	17,3	86	21,6	17,9
November	109	15,5	12,5	118	16,4	13,2
December	121	11,5	9,0	115	12,5	9,9
Year	**905**	**20,6**	**16,3**	**941**	**21,9**	**17,3**

2.2.3 Ancona

Climatic baseline and future scenarios



Graphic – Present climate: average monthly rainfall, maximum and minimum temperature at Ancona site.

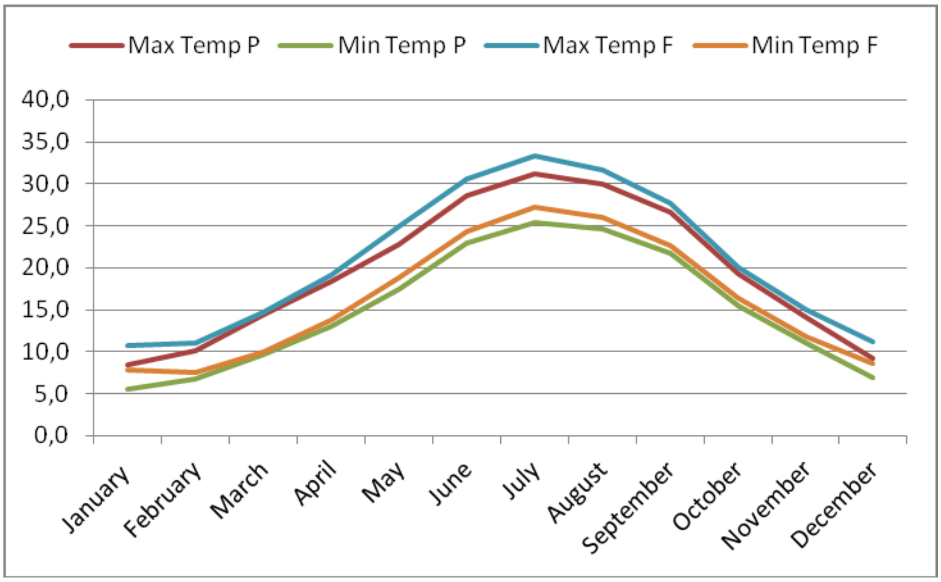


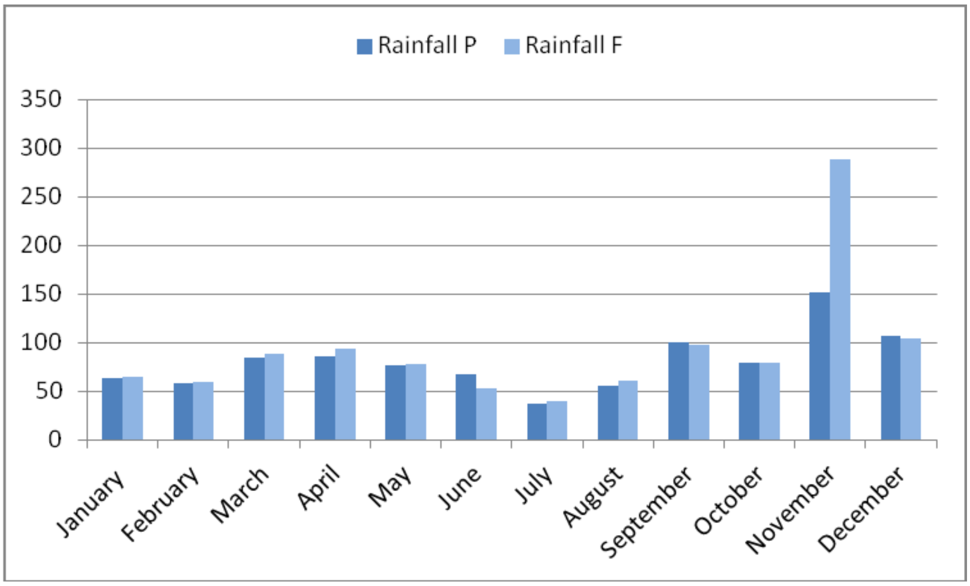
Graphic – Future climate: average monthly rainfall, maximum and minimum temperature at Ancona site.

Table – Comparison between Baseline and future conditions on Ancona site

Baseline conditions				**Future conditions**		
Month	**RAIN**	**T MAX**	**T MIN**	**RAIN**	**T MAX**	**T MIN**
January	63	8,5	5,6	65	10,8	7,8
February	59	10,2	6,7	59	11,1	7,5
March	84	14,3	9,7	88	14,7	10,0
April	85	18,3	13,1	94	19,1	13,8
May	77	22,9	17,4	78	25,0	18,9
June	67	28,5	23,0	53	30,6	24,3
July	37	31,2	25,4	40	33,4	27,3
August	55	30,0	24,7	61	31,7	25,9
September	100	26,5	21,7	98	27,6	22,6
October	79	19,3	15,5	79	20,1	16,3
November	151	14,1	11,1	288	14,9	11,7
December	106	9,2	6,9	104	11,2	8,6
Year	**963**	**19,5**	**15,1**	**1107**	**20,9**	**16,3**

Changes in climatic variables





Analysis of the two climatic scenarios showed importants changes on the principal climatic variables (Rainfall, Maximum and minimum temperature) (table). In 2020-2030 on average, maximum temperature changes varied of 1.43 °C, with a range from -0.3 to 2.3 °C, respect the baseline condition, while the minimum temperature changed with an increase of 1.18 °C and ranged in the same way. The rainfall was expected changing, increasing from 963 mm under baseline conditions to 1107 mm under future conditions: an important difference on the two scenarios inter-annual variability was also shown through the CV, that passed from 0.35 under CP to 0.67 under CF. If consider each scenario, the present climate (Graphic) was characterized by a maximum temperature that ranged from 8.5 °C to 30.5 ° C, respectively in January and July (Dev.st.= 7.97; CV=0.41), whereas minimum temperature passed from 5.6 °C to 25.4 °C (Dev.st=6.9; CV=0.46), always in the same previous months. Rainfall ranged from 37 mm in July to 151 in November (dev.st. 28.31). Under future condition (Graphic) the maximum temperature ranged from 10.8 to 33.4 °C (Dev.st.=8.16; CV=0.39) in January and July, while the minimum changed from 7.5 °C in February to 27.3 °C in July (Dev.st.=7.05; CV=0.43). Rainfall ranged from 53 mm in June to 288 mm in November.

2.3 Creation of the Epic model files

Soil, climate, agronomic and management data were collected from the three experimental sites, as main inputs required by Epic model.

2.3.1 Soil data file

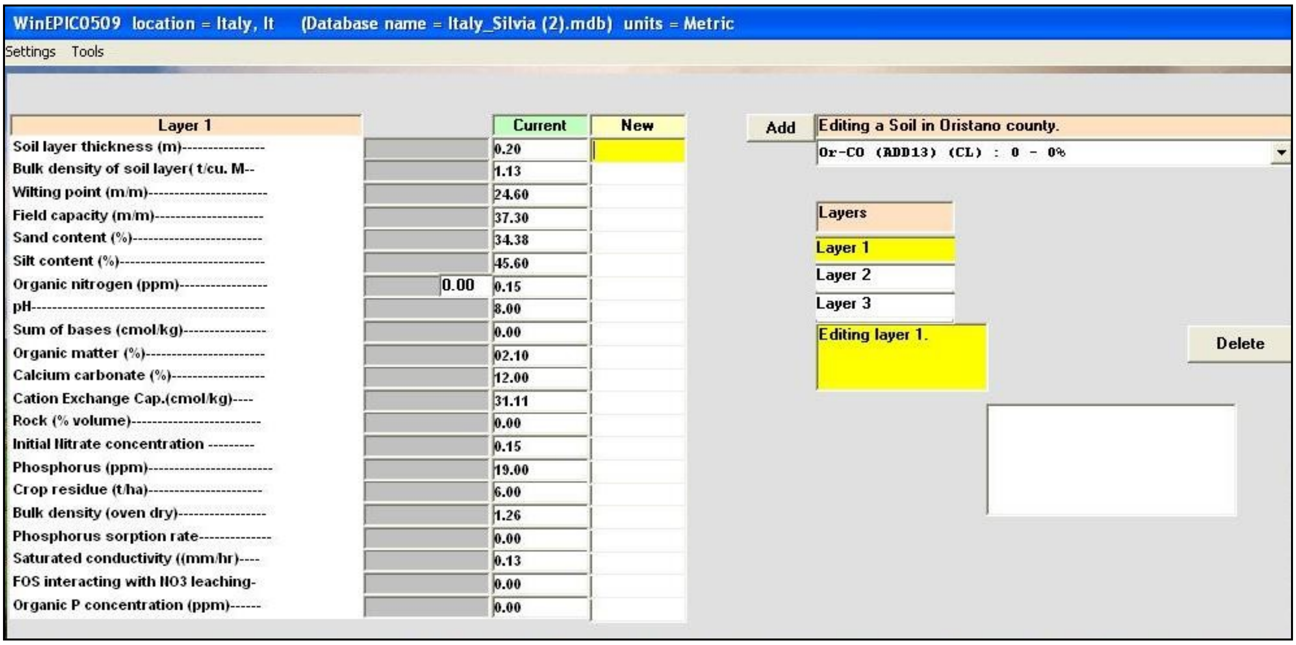
In the WinEpic window, used for the creation of new soils, soil layers data were inserted. Soil data concerned texiture, identified through chemical and physical analysis. All the soil profiles were considered "clay – loam" and belonged to the hidrological group C. This characteristics is correlated to the water infiltration speed and the model used it to simulate the surface runoff. This classification was in according to the SPAW model[76] results, used for the generation of the hydrological characteristics of soils. Soils in this group have moderately high runoff potential when thoroughly wet. Water transmission through the soil is somewhat restricted. Group C soils typically have between 20 percent and 40 percent clay and less than 50 percent sand and have loam, silt loam, sandy clay loam, clay loam (as Oristano and Benevento sites), and silty clay loam textures. Some soils having clay, silty clay (as Ancona site), or sandy clay textures may be placed in this group if they are well aggregated, of low bulk density, or contain greater than 35 percent rock fragments.The limits on the diagnostic physical characteristics of group C are as follows. The saturated hydraulic conductivity in the least transmissive layer between the surface and 50 centimeters [20 inches] is between 1.0 micrometers per second and 10.0 micrometers per second . The depth to any water impermeable layer is greater than 50 centimeters. The depth to the water table is greater than 60 centimeters. Soils that are deeper than 100 centimeters to a restriction or water table are in group C if the saturated hydraulic conductivity of all soil layers within 100 centimeters of the surface exceeds 0.40 micrometers per second but is less than 4.0 micrometers per second.[77]

Some of the main soil physical and chemical characteristics of each experimental field and horizon were reported in Table 2. Basic soil features requested as input by the model were obtained by analysis conducted in the fields considered within the project study, while other values, for example those concerning to bulk density of soil layer (t/cu. M), bulk density oven dry, wilting point, field capacity (m/m), were estimated by Soil Water Characteristics Program - SPAW, performed by USDA – Natural Resources Conservation Service. This tool estimates soil water tension, conductivity and water holding capability based on the soil physical properties of texture, organic matter, gravel , salinity, and compaction. Soil data were referred to the same fields were experimental proof were conducted.

Data inserted in the model database for the creation of the new soil were:

- soil layer depth (m);
- bulk density of soil layer (t/m3);
- wilting point (m/m);
- field capacity (m/m);
- sand content (%);
- silt content (%);
- Organic nitrogen (ppm);
- pH;
- sum of bases (cmol/kg);
- organic matter (%);
- calcium carbonate (%);
- cation exchange cap. (cmol/kg);
- rock (%);
- initial nitrate concentration;
- phosphorus sorption rate contenuto di fosforo (ppm);
- crop residue (t/ha);
- bulk density oven dry;
- saturated conductivity (mm/h).

For the parameters with unknown value, Epic model generated it considering other available inputs.



WinEPIC0509 location = Italy, It (Database name = Italy_Silvia (2).mdb) units = Metric

Layer 1		Current	New
Soil layer thickness (m)----------------		0.20	
Bulk density of soil layer(t/cu. M--		1.13	
Wilting point (m/m)----------------------		24.60	
Field capacity (m/m)--------------------		37.30	
Sand content (%)------------------------		34.38	
Silt content (%)---------------------------		45.60	
Organic nitrogen (ppm)----------------	0.00	0.15	
pH---		8.00	
Sum of bases (cmol/kg)---------------		0.00	
Organic matter (%)----------------------		02.10	
Calcium carbonate (%)-----------------		12.00	
Cation Exchange Cap.(cmol/kg)----		31.11	
Rock (% volume)------------------------		0.00	
Initial Nitrate concentration ---------		0.15	
Phosphorus (ppm)-----------------------		19.00	
Crop residue (t/ha)---------------------		6.00	
Bulk density (oven dry)----------------		1.26	
Phosphorus sorption rate-------------		0.00	
Saturated conductivity ((mm/hr)----		0.13	
FOS interacting with NO3 leaching-		0.00	
Organic P concentration (ppm)------		0.00	

Editing a Soil in Oristano county.

Or-CO (ADD13) (CL) : 0 - 0%

Editing layer 1.

Figure – Example of EPIC soil layer

2.3.2 Weather data file

The weather data used by Epic model and obtained from observed series data were:

- net radiation (Mj),
- maximum daily air temperature (°C);
- minimum daily air temperature (°C);
- rainfall daily data (mm);
- relative humidity (%);
- wind speed (m/s).

Epic model created a new Weather station for the organization of daily weather data. Each new weather station was added to the default weather stations contained inside Epic model, but with data concerned to weather area studio. For this purpose, the first step was the creation of Excel files where were reported, in each column, daily values of the requested parameters. The file was saved as tab-delimited text (*.txt). For continuing the creation of the weather file was necessary to use the software Weather Analyzer. This tool allowed to convert the file (*.txt)previously created in a .DLY file, as useful format for Epic simulations. With an apposite utility inside the software, the .DLY file was checked, for delete any possible mistaked concerded to out line values, misses values or minimum temperature values not lower than maximum temperature values. The correct file was inserted inside Epic database.

The same procedure was followed for each weather station created. In the study project three weather stations were created for each site, considering three different weather database: observed data and present and future scenario data simulated by GCM.

The observed weather data were recorded by automatic weather stations located near the study areas. For Oristano site, the weather data were provided, for the period 1959-2011, by the experimental station of Santa Lucia (39°58' N; 8°37' E; 15 m a.s.l.) of the Department of Agronomy Sciences and Plant Breeding, University of Sassari.
Benevento weather data were collected for the period 2000-2010 by the experimental station of Piano Cappelle (41°11’ N; 14°83’ E; 152 m a.s.l), as one of the climatic station monitored by Ministry of agriculture (http://www.politicheagricole.it/flex/FixedPages/Common/miepfy200_reteAgrometeorologica.php/L/IT). Net radiation, relative humidity and wind speed were estimated by Epic model. Ancona

weather data were collected from the weather station of Agugliano (13°22’ N; 43°32' E; 140 m a.s.l) for the period 1959-2011. Relative humidity and wind speed were estimated by Epic model.

2.3.3 Management and crop data file

Management data were collected through farmers and owners interviews, with questions about historical managing, as the previous cropping systems, tillage treatments, fertilization, irrigation etc. Specifically, agronomic data regarded:

1. Tillage: treatments conducted for seedbed preparation, considering the type of plow, date and depth. This last parameter represented an important information because modified soil bulk density, incorporated crop residue and influenced the dynamical cyle and the distribuition of nutrients through the plowed layer.

2. Plant: dates and quantity of seeds were collected, generally farmers used about 350 kg/ha..

3. Secondary tillage: effectuated for perfecting seed bed. Also for this operations were collected informations about type of plow, depth and date.

4. Fertilization: type of fertilize, rates and dates were identified.

5. Harvest: yields concerned the previous cropping system were raised on the whole cropping system that included durum wheat in the last four years.

For the collection of all the other agronomical informations, was monitored the crop growth trend during through periodical samples in the experimental fields. Direct surveys were conducted on three areas of 1 m^2 on each Oristano and Benevento experimental fields, while for Ancona site field data were collected from No Tillage and Conventional Tillage plots of 500 m^2 in size under rainfed two year crop rotations. These samples were conducted near the soil profile were chemical and physical analysis were carried out.

The samples areas were delimited placing metallical square of ½ m^2 (twice for each of the three areas on every field), guaranting that all the biomass was out of the square.

After that harvested biomass was removed and preserved for further analysis conducted at the Dipartimento di Scienze Agronomiche e Genetica Vegetale Agraria and at the Centro di ricerca per la cerealicoltura, Consiglio per Ricerca e la Sperimentazione in agrocoltura (CRA) of Foggia (FG). For each sample biomass and leaves were separated and counted. Also stocks were counted, both to know the density of plants for surface (ha) and to compensate for the inability of EPIC model to simulate tillering. Also leaves surface was measured in order to calculate the Leaf Area Index (LAI): this values was obtained through a distructive method and the use of a planimeter.

Biomass (500 g) was later dryed for the determination of dry weight, using an official methodology where sample was maintained at 60°C until to reach a constant dry weight. Other 500 g of leaves were minced for the chemical analysi. Analysis esults were shown in Annexes.

For simulations agronomical treatments adopted in each experimental fiels were created, modifying some parameters contained in the existing database on the basis of values gained directly in the fields. Management was called the window used by Epic model to insert the cited data: this window was contained within an other one, called “Data/Setup" that allowed to insert a new cropping system (for a maximum of 4 annual crops). For each site, type of tillage (conventional, minimum or no tillage), type of irrigation (sprinkler irrigation was choosed for the irrigated sites; dryland for the no – irrigated sites) and the crops were selected. The generated cropping system would be modified considering the real agricultural treatments conducted.

The main information inserted concerned:

1. soil tillage;
2. plant (n. of seeds/ha);
4. fertilizer;
5. harvest.

Furthermore, in order to obtain the correct model working, “kill” operation was inserted for interrupting definitively the crop development.

Below were reported, for each experimental field, le main information procured (le inserisco o le metto nell’allegato alla fine?)

Site

Coordinate

Elevation

Surface

Cropping system in the last 4 years (2008-2011)

Tillage (type, depth and date)

Fertilzer (type, rate and date)pari a 3,2

Irrigation

Phytosanitary treatments

Harvest

Presence of other desease

2.3.5 Control table

This function allowed to set up the parameter that guided the simulation. Different "Control table" could be created, in order to use each of them in bases of the type of simulation. In the project study, five Control Table were created for each site. The default values modified were:

- period of the simulation (years): 13 years;
- year of beginning of the simulation: 1998;
- Evapotranspiration equation used during the simulation: Penman-Monteith equation, that cared of CO_2 concentration during simulation, useful in climate change effects studies;
- atmospheric CO_2 concentration at the beginning of the simulation: 378 and 408 ppm were the two CO_2 concentration used;
- Irrigation and fertilization: 0, 0.9 and 1 were the three values used for allowing the model to simulate without any distribution (values=0), total distribution (values=1) or partial distribution (valus=0.9) of water and fertilize. The three different values consented the manual or drived distribution of water and fertilize in case of stressed crop.

A description of the experimental sites is reported in the following sections.

2.4 Experimental site description

Three Italian sites were used for this study which comprises some of the different types of Mediterranean climate. Uras, with three experimental fields is located on the west cost of Sardinia Region, San Bartolomeo in Galdo and Castelfranco, with three experimental fields, are located on the Campania region, on the border with Apulia region and Ancona, with one experimental field, is localized on Marche region (Table 1).

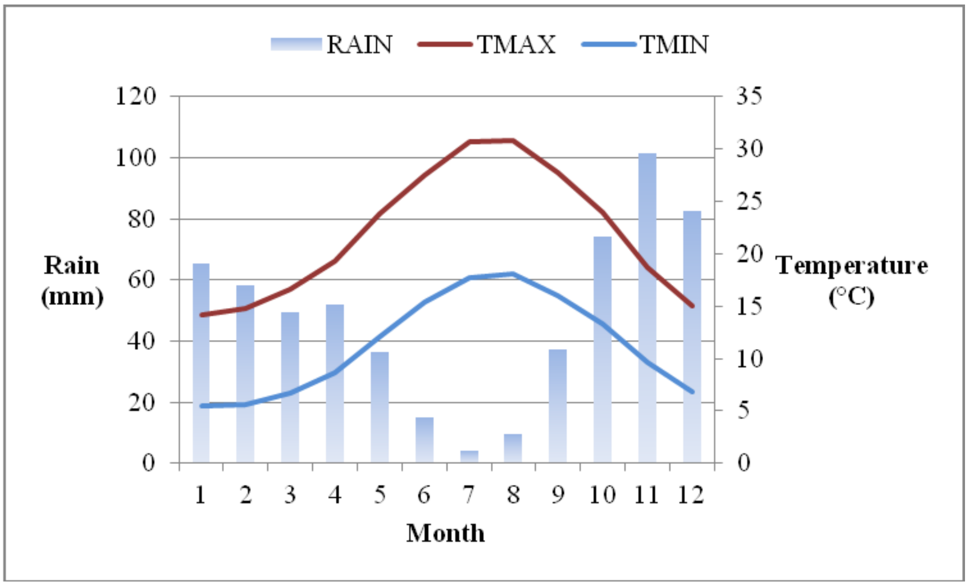
Table 1 – Experimental fields

Region	Site	Field	Latitude	Longitude	Altitude
Sardinia	Uras (OR)	OR1	39.6889467° N	8.7102306° E	31 m. s.l.m.
Sardinia	Uras (OR)	OR2	39.6977099° N	8.6961985° E	17 m. s.l.m.
Sardinia	Uras (OR)	OR3	39.6889467° N	8.7102306° E	24 m. s.l.m.
Campania	San Bartolomeo in Galdo (BN)	BN1	41.24 57.6 N	15 02 53.9 E	786 m. s.l.m.
Campania	San Bartolomeo in Galdo (BN)	BN2	41.28044 N	15.01374 E	550 m. s.l.m.
Campania	Castelfranco (BN)	BN3	41.16 108 N	15.06287 E	550 m. s.l.m
Marche	Agugliano (AN)	AN	43.8320 N	13.8220 E	88 m. s.l.m.

2.4.1 Oristano

The first location is localized in Uras, Sardinia region. The climate is typically Mediterranean, with a long-term average annual rainfall of 585 mm, mainly occurring between October and April. It is characterized by mean annual maximum temperature of 22 °C, with monthly means ranging from 14.1 °C in January to 30.8 °C in August, while mean annual minimum temperature was around 11.3 °C, with a monthly range from 5.5 °C in January to 18.1 °C in August. Climatic data are also shown in Table 1.

Observed climatic data



Graphic – Average monthly rainfall, maximum and minimum temperature at Oristano site.

Table 1 - Monthly pattern of measured rainfall, maximum and minimum temperature

Month	Rainfall	Max Temperature	Min Temperature
January	65	14,1	5,5
February	58	14,7	5,6
March	49	16,7	6,7
April	52	19,3	8,6
May	36	23,9	12,1
June	15	27,5	15,4
July	4	30,7	17,7
August	10	30,8	18,1
September	37	27,8	16,0
October	74	23,9	13,3
November	102	18,6	9,6
December	83	15,0	6,9
Year	**585**	**22,0**	**11,3**

Below are the trends of maximum and minimum temperature averages per year and the total annual rainfall related to the fifthy-two year time series (1959-2011) of the meteorological station of Santa Lucia (OR).

Figure – Time series (1959-2011) metereological station of Santa Lucia: trends of total yearly of maximum and minimum temperature

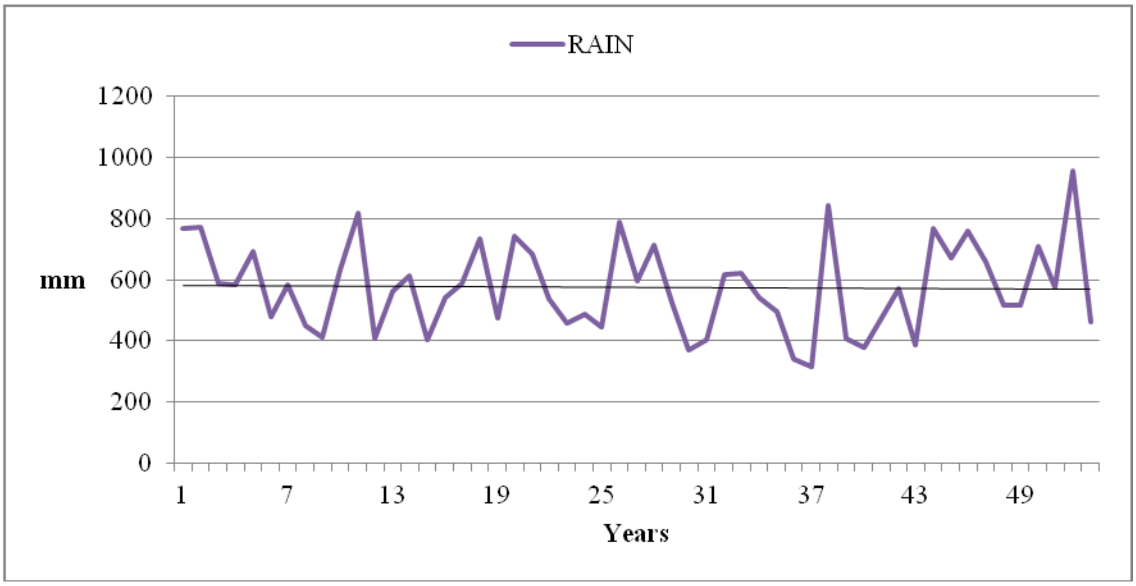


Figure – Time series (1959-2011) metereological station of Santa Lucia: trends of total yearly rainfall

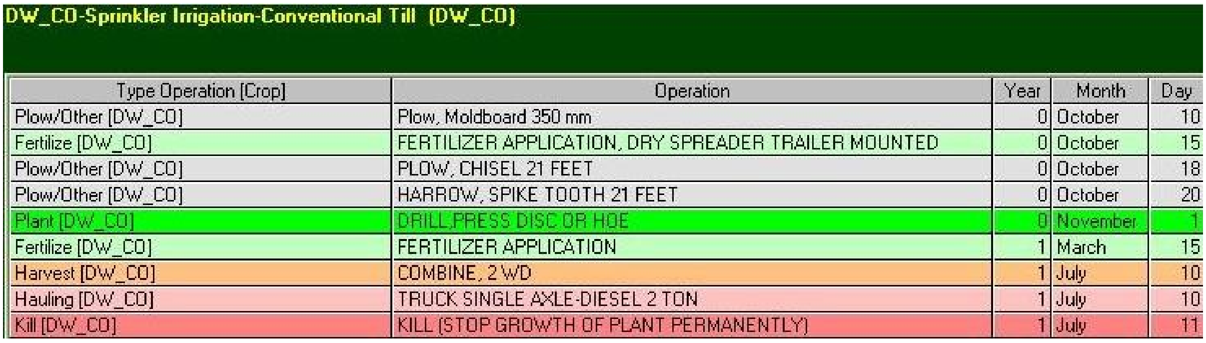
Soil data

For the Epic model simulations, in 2010 soils parameters were obtained on samples collected at 0 – 20, 20-40 and 40-60 cm. Some details of soil properties in the experimental fields, which were also used for Epic Model settings, are reported in Table 2 (detailed soil characteristics are shown in Annexes 1).

Table 2 – Soil characteristics on the site of Oristano (

Parameter		**OR 1**			**OR 2**			**OR 3**	
Layer	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Sand (%)	34.38	48.66	46.48	61.26	62.43	60.82	36.31	36.31	36.02
Silt (%)	25.02	38.41	40.16	15.78	14.36	15.39	22.90	22.20	22.24
Clay (%)	40.60	62.94	63.37	22.96	23.21	23.79	40.79	41.49	41.74
Skeleton	0.73	0.76	0.58	8.61	11.24	10.48	0.39	0.69	1.26
pH	8.09	8.14	8.22	8.33	8.11	8.27	8.37	8.16	8.15
Total N_2	0.16	0.21	0.19	0.08	0.08	0.07	0.10	0.11	0.12
Organic carbon	1.25	1.93	1.60	0.66	0.70	0.66	1.60	1.76	1.80
Organic matter (%)	2.10	3.33	2.80	1.14	1.21	1.14	2.76	3.33	3.09
Bulk density	1.13	1.13	1.17	0.73	0.75	0.58	0.63	0.75	1.17
Field capacity	37.30	41.70	26.80	25.50	25.30	16.00	37.70	37.70	38.20
Wilting point	24.60	30.40	13.70	15.40	15.50	10.48	25.20	25.20	25.70

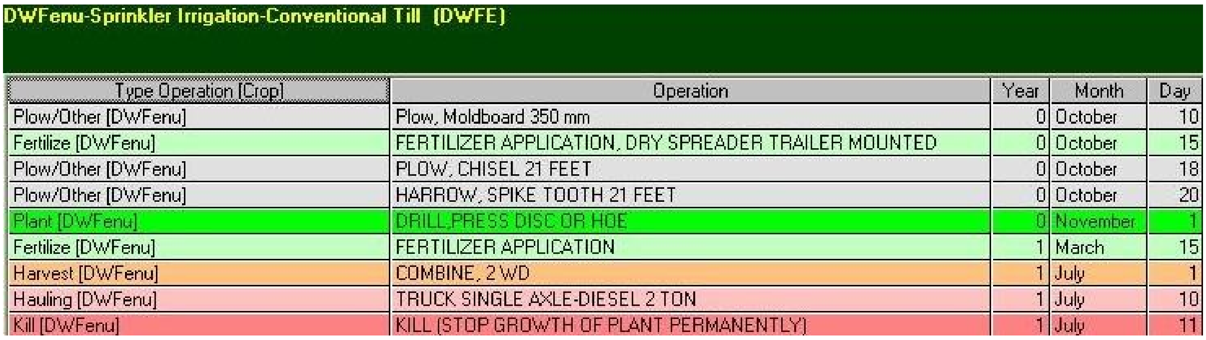
Crop data and management



DW_CO-Sprinkler Irrigation-Conventional Till (DW_CO)

Type Operation [Crop]	Operation	Year	Month	Day
Plow/Other [DW_CO]	Plow, Moldboard 350 mm	0	October	10
Fertilize [DW_CO]	FERTILIZER APPLICATION, DRY SPREADER TRAILER MOUNTED	0	October	15
Plow/Other [DW_CO]	PLOW, CHISEL 21 FEET	0	October	18
Plow/Other [DW_CO]	HARROW, SPIKE TOOTH 21 FEET	0	October	20
Plant [DW_CO]	DRILL,PRESS DISC OR HOE	0	November	1
Fertilize [DW_CO]	FERTILIZER APPLICATION	1	March	15
Harvest [DW_CO]	COMBINE, 2 WD	1	July	10
Hauling [DW_CO]	TRUCK SINGLE AXLE-DIESEL 2 TON	1	July	10
Kill [DW_CO]	KILL (STOP GROWTH OF PLANT PERMANENTLY)	1	July	11

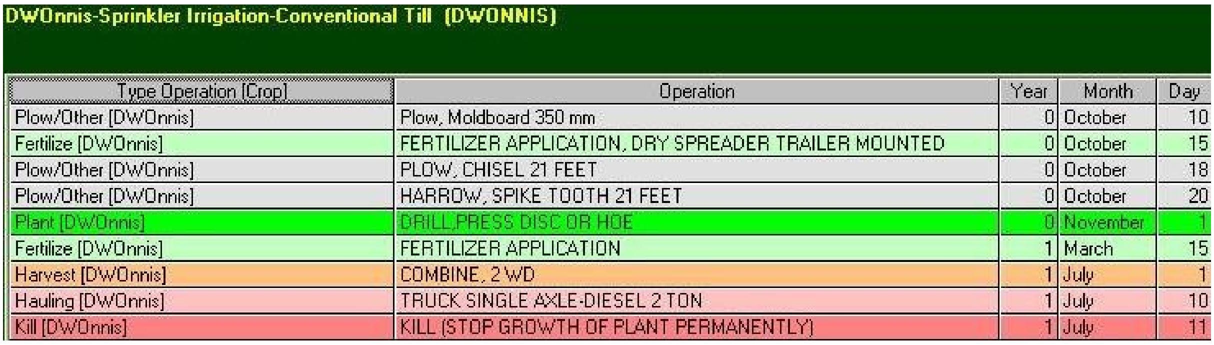
Figure – Cropping management of OR1 site



DWFenu-Sprinkler Irrigation-Conventional Till (DWFE)

Type Operation [Crop]	Operation	Year	Month	Day
Plow/Other [DWFenu]	Plow, Moldboard 350 mm	0	October	10
Fertilize [DWFenu]	FERTILIZER APPLICATION, DRY SPREADER TRAILER MOUNTED	0	October	15
Plow/Other [DWFenu]	PLOW, CHISEL 21 FEET	0	October	18
Plow/Other [DWFenu]	HARROW, SPIKE TOOTH 21 FEET	0	October	20
Plant [DWFenu]	DRILL,PRESS DISC OR HOE	0	November	1
Fertilize [DWFenu]	FERTILIZER APPLICATION	1	March	15
Harvest [DWFenu]	COMBINE, 2 WD	1	July	1
Hauling [DWFenu]	TRUCK SINGLE AXLE-DIESEL 2 TON	1	July	10
Kill [DWFenu]	KILL (STOP GROWTH OF PLANT PERMANENTLY)	1	July	11

Figure - Cropping management of OR2 site



DWOnnis-Sprinkler Irrigation-Conventional Till (DWONNIS)

Type Operation [Crop]	Operation	Year	Month	Day
Plow/Other [DWOnnis]	Plow, Moldboard 350 mm	0	October	10
Fertilize [DWOnnis]	FERTILIZER APPLICATION, DRY SPREADER TRAILER MOUNTED	0	October	15
Plow/Other [DWOnnis]	PLOW, CHISEL 21 FEET	0	October	18
Plow/Other [DWOnnis]	HARROW, SPIKE TOOTH 21 FEET	0	October	20
Plant [DWOnnis]	DRILL,PRESS DISC OR HOE	0	November	1
Fertilize [DWOnnis]	FERTILIZER APPLICATION	1	March	15
Harvest [DWOnnis]	COMBINE, 2 WD	1	July	1
Hauling [DWOnnis]	TRUCK SINGLE AXLE-DIESEL 2 TON	1	July	10
Kill [DWOnnis]	KILL (STOP GROWTH OF PLANT PERMANENTLY)	1	July	11

Figure - Cropping management of OR3 site

Durum wheat (Triticum durum L.) crop yield data for the 2010-2011 were obtained from samples in the experimental fields. Measured yields were obtained considering biomass harvested in 3 mq. At the same time number of spikes, glumes, stocks and leaves were collected. Leaf Area Index was measured with the AccuPAR LP-80 Ceptometer (Decagon Device, Inc.). Further crop data were collected through farmers interviews about the last four years, with specific questions about the management conducted in the last year where the durum wheat has been under (cropping systems, depth of tillage, cultivar, fertilization management). Details of data are in Annexes 1.

Table - Cropping system: period 2007-2011

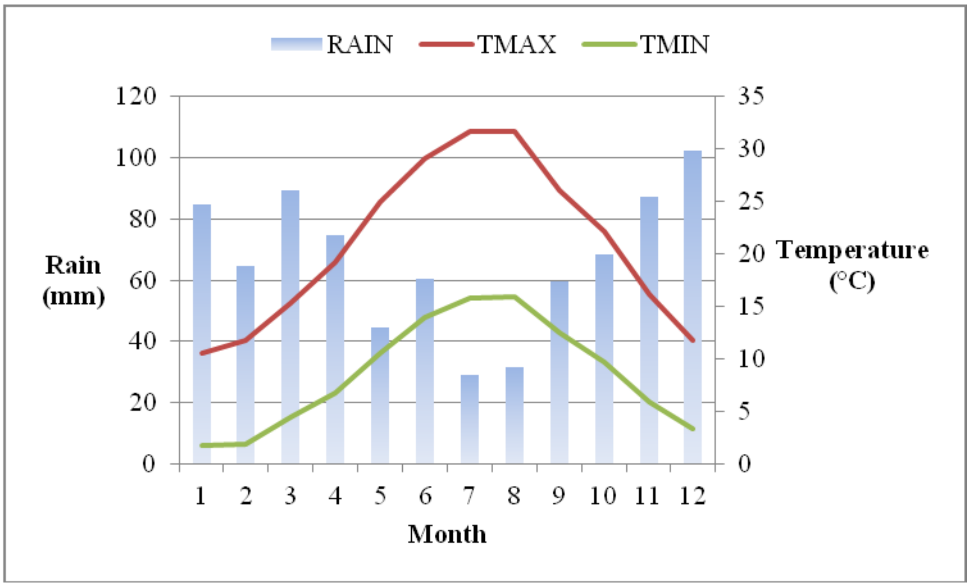
Field	Crop
OR1	Italian Ryegrass – Italian Ryegrass - Italian Ryegrass – Durum wheat
OR2	Italian ryegrass – Durum wheat – Italian ryegrass – Durum wheat
OR3	Italian ryegrass – Durum wheat – Italian ryegrass – Durum wheat

Plinio, Rusticano, Saragolla and Svevo were the principal varieties of durum wheat used in the experimental fields. Agricoltural operations were: moldboard ploughing to 35 cm depth, a fertilize application by dry spreader trailer mounted (18-46-0 - 400 kg ha-1), followed by a chisel 21 feet ploughing and a flexible harrow seedbed preparation in October. In November were planted 400 vital seed m2 and the second fertilization was applied as ammonium nitrate (400 kg ha-1) in March. As pest control, Atlantis (0.500 kg ha-1) was carried out in March on the crops.

2.4.2 Benevento

The second location were localized in San Bartolomeo in Galdo (BN1 and BN2) and Castelfranco (BN3), Campania region. The climate of the location is characterized by mean annual maximum temperature of 21 °C, with monthly means ranging from 10.5 °C in January to 31.7 °C in August and July, while mean annual minimum temperature was around 8.6 °C, with a monthly range from 1.8 °C in January to 15°.9 in August. Mean annual rainfall is 797 mm. Soil is clay (Table). Further soil data details were described in Annexes 1.

Observed climatic data



Graphic – Average monthly rainfall, maximum and minimum temperature at Benevento site.

Table - Monthly pattern of measured rainfall, maximum and minimum temperature

Month	Rainfall	Max Temperature	Min Temperature
January	85	10,5	1,8
February	65	11,8	1,9
March	89	15,4	4,4
April	75	19,2	6,8
May	45	24,9	10,5
June	60	29,1	14,0
July	29	31,7	15,8
August	32	31,7	15,9
September	60	26,1	12,6
October	68	22,2	9,7
November	87	16,2	5,9
December	102	11,8	3,4
Year	**797**	**21,0**	**8,6**

Below are the trends of maximum and minimum temperature averages for year and the total annual rainfall related to the once year time series (2000-2011) obtained by interpolation of the data collected from three metereological station.

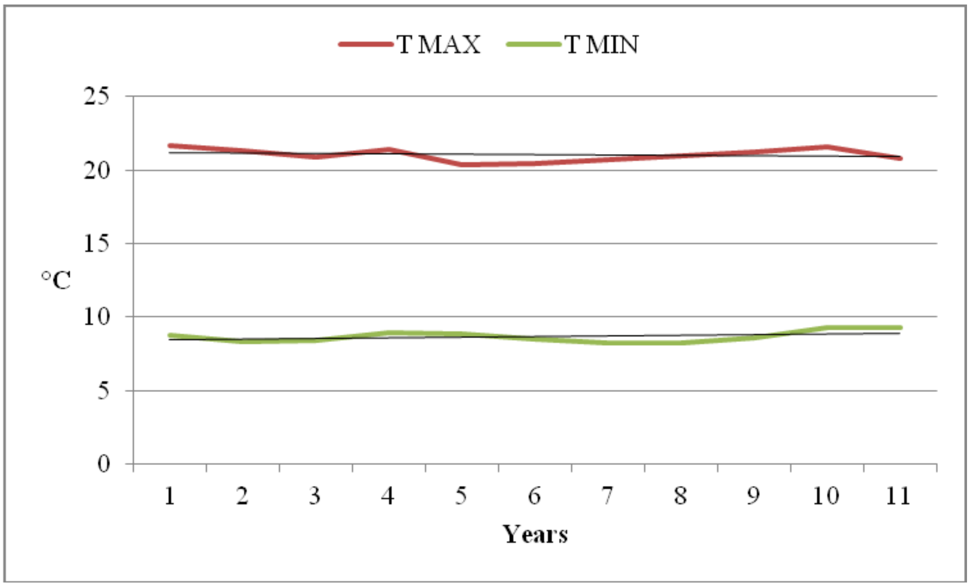


Figure – Time series (1959-2011) metereological station of Santa Lucia: trends of total yearly of maximum and minimum temperature

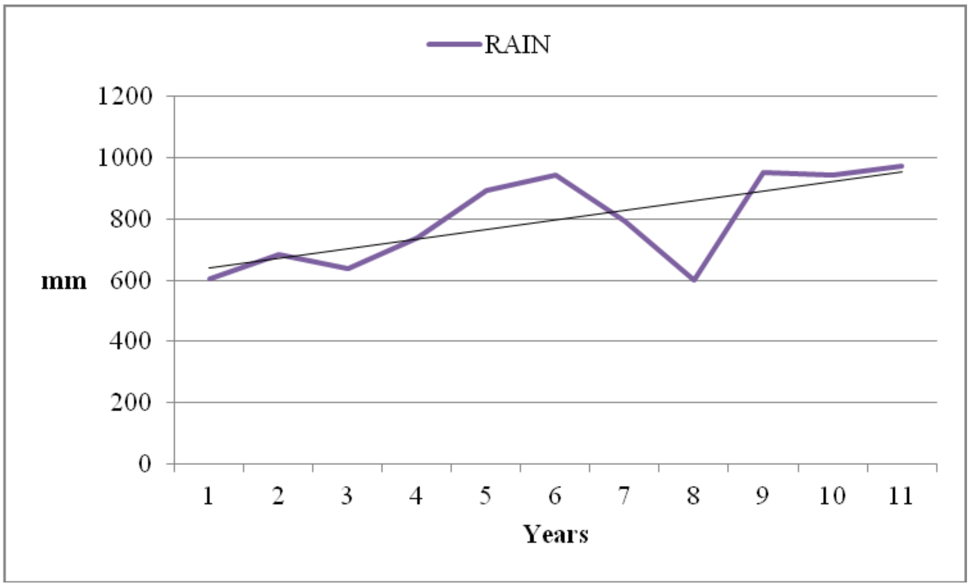


Figure – Time series (1959-2011) metereological station of Santa Lucia: trends of total yearly rainfall

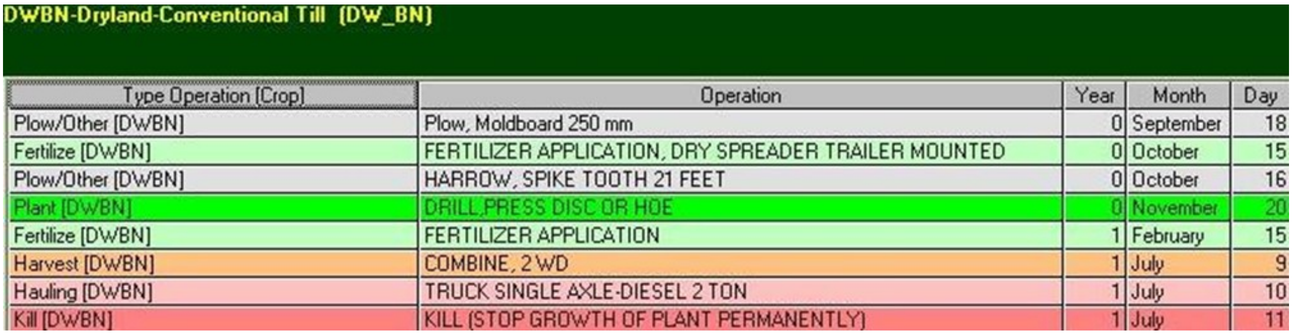
Soil data

For the Epic model simulations, in 2010 soils parameters were obtained on samples collected at 0 – 20, 20-40 and 40-60 cm. Soil characteristics of each horizon were determined from soil profiles (Table). Further soil characteristics details were shown in Attached 1. Chemical analysis were carried on by the University of Tuscia, Viterbo (Dipartimento di tecnologie, ingegneria e scienze dell'Ambiente e delle Foreste).

Table - Soil properties of the topsoil in the experimental fields in 2010.

	BN 1			**BN 2**			**BN 3**		
Parameter Layer	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Sand (%)	36.02	35.61	36.99	16.26	26.43	26.00	36.81	36.31	36.02
Silt (%)	24.50	23.29	35.61	45.60	47.70	60.82	45.60	47.70	37.00
Clay (%)	39.48	41.10	41.11						
pH	8.00	12.40	12.50	8.33	8.11	8.27	8.37	8.16	8.15
Organic matter (%)	2.10	3.33	2.80	1.14	1.21	1.14	2.76	3.33	3.09
Bulk density	1.13	1.13	1.17	0.73	0.75	0.58	0.63	0.75	1.17
Field capacity	37.30	41.70	26.80	25.50	25.30	16.00	37.70	37.70	38.20
Wilting point	24.60	30.40	13.70	15.40	15.50	10.48	25.20	25.20	25.70

Crop and management data



DWBN-Dryland-Conventional Till (DW_BN)

Type Operation [Crop]	Operation	Year	Month	Day
Plow/Other [DWBN]	Plow, Moldboard 250 mm	0	September	18
Fertilize [DWBN]	FERTILIZER APPLICATION, DRY SPREADER TRAILER MOUNTED	0	October	15
Plow/Other [DWBN]	HARROW, SPIKE TOOTH 21 FEET	0	October	16
Plant [DWBN]	DRILL,PRESS DISC OR HOE	0	November	20
Fertilize [DWBN]	FERTILIZER APPLICATION	1	February	15
Harvest [DWBN]	COMBINE, 2 WD	1	July	9
Hauling [DWBN]	TRUCK SINGLE AXLE-DIESEL 2 TON	1	July	10
Kill [DWBN]	KILL (STOP GROWTH OF PLANT PERMANENTLY)	1	July	11

Fig. – Management of the BN sites

Durum wheat (Triticum durum L.) crop yield data for the 2010-2011 were obtained from samples in the experimental fields. Measured yields were obtained considering biomass harvested in 3 mq. At the same time number of spikes, glumes, stocks and leaves were collected. Leaf Area Index was measured with the AccuPAR LP-80 Ceptometer (Decagon Device, Inc.). Further crop data were collected through farmers interviews about the last four years, with specific questions about the management conducted in the last year where the durum wheat has been under (cropping systems, depth of tillage, cultivar, fertilization management). Details of data are in Annexes 1.

Table - Cropping system: period 2007-2011

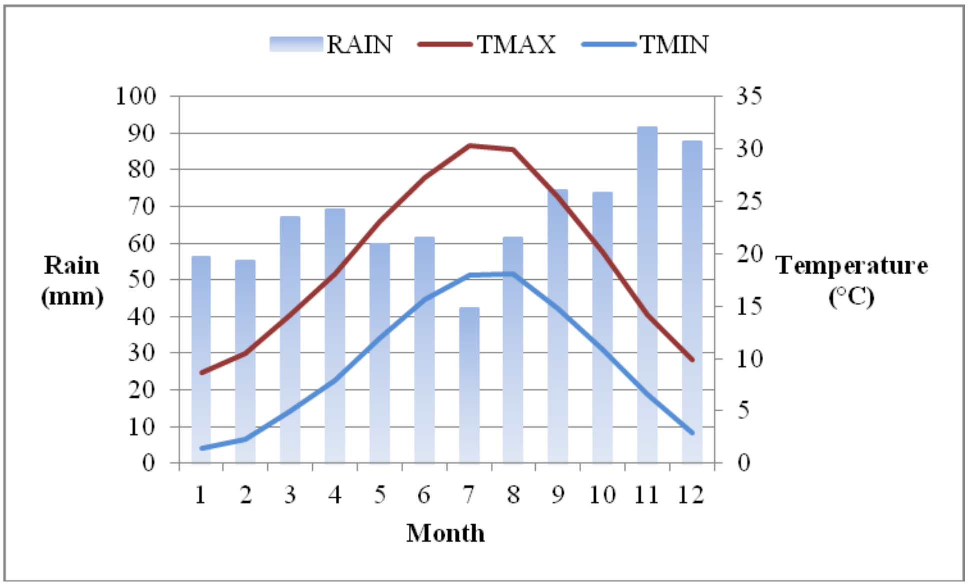
Field	Crop
BN1	Durum wheat – Chick bean – Durum wheat – Durum wheat
BN2	Chick bean – Durum wheat – Tomatoe – Durum wheat
BN3	Clover – Durum wheat – Clover – Durum wheat

Oro bello and Svevo were the cultivar used in the experimental fields. The fields were ploughed by moldboard at 25 cm depth in September, at the end of summer. With dry spreader trailer mounted 32-00-00 was applied at a rate of 200 kg N ha $^{-1}$ split in October, while in February a second fertilize was applied as Urea 46-00-00. Crops, planted in November with about 350 vital seeds m2 were harvested at crop maturity in July.

2.4.3 Ancona

The first location is localized in Agugliano, Marche region, at the experimental farm ‘‘P. Rosati’’ of Marche University with a slope of 12% (Iezzi et al., 2002). Mean annual temperature is 14.4 °C, with monthly means ranging from 4.9 8C in January to 24.0 8C in August. Mean annual rainfall is 700 mm. Soil is silty-clay (Table), and was classified as Calcaric Gleyic Cambisols (FAO, 2006).55. Field data for model calibration and validation were collected from the same experimental farm.

Observed climatic data



Graphic – Average monthly rainfall, maximum and minimum temperature at Ancona site.

Table - Monthly pattern of measured rainfall, maximum and minimum temperature

Month	Rainfall	Max Temperature	Min Temperature
January	56	8,7	1,5
February	55	10,5	2,4
March	67	14,2	5,0
April	69	18,0	7,9
May	60	23,1	11,9
June	62	27,2	15,7
July	42	30,3	18,0
August	62	30,0	18,1
September	74	25,5	14,7
October	74	20,1	10,9
November	92	14,2	6,6
December	88	9,8	2,9
Year	800	19,4	9,7

Below are the trends of maximum and minimum temperature averages for year and the total annual rainfall related to the fifthy-one year time series (1959 - 2010) of the meteorological station of Jesi (AN).

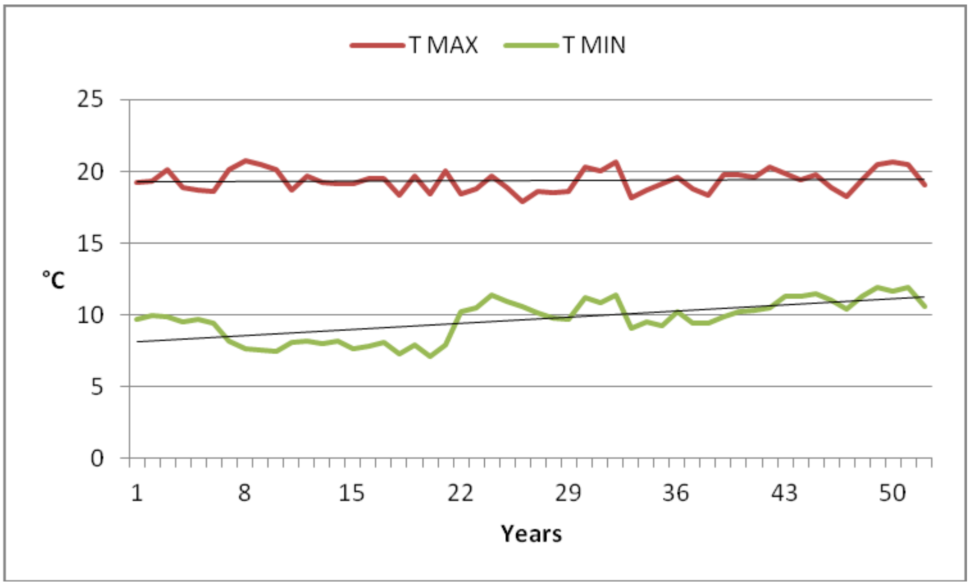


Figure – Time series (1959-2010) metereological station of Jesi (AN): trends of total yearly of maximum and minimum temperature

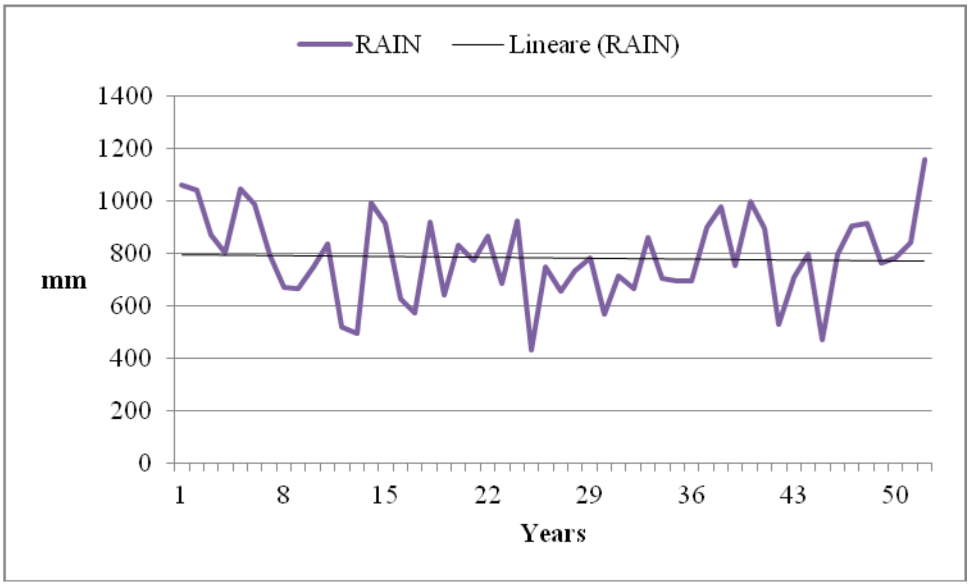


Figure – Time series (1959-2010) metereological station of Jesi (AN): trends of total yearly rainfall

Soil data

For the Epic model simulations, soils parameters were obtained on samples collected at 0 – 10 and 10 – 30 cm in. In 2006, soil characteristics of each horizon were determined from soil profiles (Table). Further soil characteristics details were shown in Attached 1.

Table - Soil properties of the topsoil and standard deviation (*in italics*) in the conventional tillage plots in 2006

Parameters	CT plots		NT plots	
	0–10	10–30	0–10	10–30
Sand (2 mm to 50 μm) ($g\,kg^{-1}$)	91 ± *21*	87 ± *19*	89 ± *35*	80 ± *33*
Silt (50–2 μm) ($g\,kg^{-1}$)	413 ± *23*	423 ± *2*	452 ± *40*	418 ± *37*
Clay (<2 μm) ($g\,kg^{-1}$)	496 ± *6*	490 ± *18*	459 ± *13*	502 ± *16*
pH	8.3 ± *0.1*	8.3 ± *0.0*	8.1 ± *0.1*	8.3 ± *0.1*
Total Ca carbonate (%)	31.1 ± *1.7*	31.4 ± *1.2*	30.3 ± *1.4*	31.0 ± *1.9*
Organic C ($g\,kg^{-1}$)	7.49 ± *1.02*	7.53 ± *0.71*	12.53 ± *3.32*	7.41 ± *0.64*
Total N ($g\,kg^{-1}$)	0.93 ± *0.09*	0.92 ± *0.06*	1.37 ± *0.29*	0.95 ± *0.04*
Available P ($mg\,kg^{-1}$)	10.7 ± *1.9*	11.1 ± *2.0*	22.5 ± *6.4*	6.1 ± *0.9*

Crop data and Management

Durum wheat crop yield data for the (57) 1995 – 2007 period were collected from the experimental farm ‘‘P. Rosati’’ of Marche University. The trial was established in 1994, in two contiguous fields of 6,000 m^2 (24 m x 250 m) where continuous durum wheat (CDW) has been grown under: (i) conventional tillage (CT), i.e. moldboard ploughing to 30 cm depth followed by a disc-harrow and flexible harrow seedbed preparation; and (ii) no-tillage (NT).

Table - Mean grain yield (t ha^{-1}) and standard deviations (in italics) of maize, sunflower and durum wheat for two crop rotations (MaDw, maize–durum wheat; SfDw, sunflower–durum wheat) and tillage techniques (CT, conventional tillage; NT, no tillage).

Crop rotation	Crop	CT	NT
MaDw	Maize	2.15 ± 1.47	1.45 ± 0.43
	Durum wheat	4.58 ± 1.30	3.75 ± 0.78
SfDw	Sunflower	1.58 ± 0.51	0.81 ± 0.53
	Durum wheat	3.00 ± 0.49	2.6 3± 0.64

The wheat straw was removed from field after the harvest in both plots, leaving only the stubble. The stubble was chopped and left on the surface of the NT plots and incorporated in the CT plot, with the addition of 1 kg N per 100 kg of dry straw both in NT and CT treatments. In the CT and NT plot 36 kg N ha-1 plus 96 kg P2O5 ha-1, as diammonium phosphate (18-46-0) were applied before the secondary tillage for seedbed preparation, whilst in NT plot the same fertilizer dose was spread on the surface. The seeding rate was set to 350 vital seeds m^{-2}. Top dressing (64 kg N ha-1 as ammonium nitrate) was applied in both plots at 21-29 tillering stage, according to BBCH scale, followed by an application of specific herbicides. In NT the weeds were controlled before sowing with glyphosate.

In 2009, both NT and CT plots were split in two plots of 3,000 m2 each. In one plot it was introduced a two-year rotation consisting of tick bean (TB, i.e. Vicia faba L., var. minor) - durum wheat (DW) while the other was maintained under continuous durum wheat (CDW). As a result the original total area of 12,000 m^2 was divided in 4 plots (3,000 m^2 each): NT-CDW, NT-TB/DW, CT-CDW and CT-TB/DW. TB was desiccated in May, at the 65 full flowering stage according to BBCH scale (Hess et al., 1997) and was chopped and scattered on the soil surface in NT plot whereas it was incorporated with tillage in CT plot. No pest control was carried out on the crops.

2.5 Statistical data analysis

As one of the objective of this study was to assess the ability of the model to simulate the measured data from the different experiments, several statistical methods were used to compare the modeled and measured data of crop yields (indicated in t ha $^{-1}$). The ability of the model to simulate wheat yields was first quantified using the relative root mean square error (RMSE). The better is the simulation, the lower is the value of RMSE (Smith et al., 1997)[78].

To test model accuracy we used correlation coefficient (r) between X and Y, linear regression of Y on X to check whether the intercept was near 0 and slope near 1, in conjunction with difference-based statistics (Addiscott and Whitmore, 1987[79]; Ventrella and Rinaldi, 1999[80]; Kobayashi and Salam, 2000[81]). Difference-based statistic indices were calculated with the software IRENE, acronym standing for Integrated Resources for Evaluating Numerical Estimates (Fila et al., 2003)[82], using:

Root Mean Squared Error; given by RMSE and Simulation Bias. For an unbiased simulation both RMSE and SB should be close to zero, which means full adherence between measures and model estimates (Farina R., Soil and Tillage Research 2011).

Calculations were made using MODEVAL (Smith and Smith, 2007; Smith et al., 1997) and the software IRENE (Fila et al., 2003)[82]. (Farina R., Geoderma 2013)[83].

2.6 Multivariate analysis

In order to highlight relationships among variables, Principal Component Analysis (PCA) was used to separate spatially coherent variability from spatially incoherent, i.e. local variability and to extract common variability among the series.

PCA is a mathematical procedure that uses orthogonal transformation to convert a set of observations of possibly correlated variables into a set of values of linearly uncorrelated variables called principal components. The number of principal components is less than or equal to the number of original variables. This transformation is defined in such a way that the first principal component has the largest possible variance (i.e. accounts for as much of the variability in the data as possible), and each succeeding component in turn has the highest variance possible under the constraint that it be orthogonal to (i.e., uncorrelated with) the preceding components. Principal components are guaranteed to be independent if the data set is jointly normally distributed. PCA is sensitive to the relative scaling of the original variables.

The main advantage of using PCA is that each statistics can be assigned to one group only (Ezatollah Farshadfar et al., 2012)[84].

	Factor 1	Factor 2
SITE	**-0,743517**	-0,022379
CLIMATE	0,157062	**-0,844510**
Yields	**-0,905015**	0,013406
WUE	**-0,804961**	0,306539
ET	**-0,767327**	-0,497245
GSP	**-0,778710**	-0,238033
WS	**0,911459**	-0,167850
NS	0,090054	-0,433458
Var. Sp.	4,078547	1,327816
Prp.Tot.	0,509818	0,165977

Table – Principal Components Analysis

Fig. – Biplot analysis of the principal components

http://documentation.statsoft.com/STATISTICAHelp.aspx?path=MSPC/PCA/PCA

2.7 Running of the model: calibration and validation

2.7.1 Calibration

The calibration was made by direct observations of crop parameters, through experimental trials, with the aim to minimize the difference between measured and corresponding simulated data by the crop parameters of the EPIC model.

Due to the small number of data coming from the experimental sites used for this study, the calibration of the model was made using data from a long term experiment in Southern Italy.

The set of data from the experimental farm of the CRA-Cereal Research Centre (41° 27′ N, 15° 30′ E, altitude 79 m above sea level), located in Apulia region, was made with 16 years of yield data, with different varieties of durum wheat obtained in the framework of the SIC, the national cereal's varieties comparison (http://qce.entecra.it/frduro/dblist4.asp).

The grain yield (kg ha^{-1}) as main variable was considered in model calibration. For the calibration of the model some crop parameters were modified, either because the values where measured in the field harvest index (HI), root's depth, leaf area index (LAI), leaf area duration) or because the parameter could be used to regulate with more precision the response of the crop to environmental conditions (i.e. energy to biomass conversion factor (WA),the lower harvest index, etc.).

Some parameters, that pertain the site, and consequently when changed affect all the crops included in the rotation, were modified to consider the Mediterranean conditions, as:

1) fraction of the growing season when water stress starts to affect the harvest index;

2) the pest damage-rain threshold, that indicate the amount of rain that cause the possibility of fungal diseases;

3) how much crop biomass will be affected by the fungal diseases.

Additional modifications were made to take in account the degradation of soil organic matter and the consequent mineralization and availability of elements to crops.

2.7.2 Validation

Once the model has been calibrated, we run it to simulate the yields of wheat in our sites, making also a fine tuning with measured parameters.

Thus for model validation, durum wheat experimental data, regarding production characteristics and management techniques, were collected for the period 2008-2011 for the three experimental fields of Oristano, Benevento and Ancona, described in detail in the material and method section. Initial conditions, such as previous crop, planting depth and dates, row spacing, plant population, fertilizer applications, harvest schedule were collected through farmers' interviews for the first two years and through direct observations for the last two years (number of stocks, number of leaves, LAI, crop yields). See Annexes. All these data were then set as input in the model.

For each site, Epic model was run for a time series of 8 years with the cropping system conducted in the field in the last four years, as reconstructed from interviews of the farmers.

Comparison with modeled data were made using the following sets of data, for the years 2008-2011:

- for the first two years, i.e. 2008 and 2009 cropping seasons data were provided by farmers;
- for the last two years (2010-2011) wheat yields were directly measured through samples.

The comparison between observed and simulated crop yields were conducted considering the data obtained from the simulation of the whole cropping system, including all crops used in the field.

The calibrated and validated Epic model was then run for 13 years only with wheat crop, with different combinations of CO_2 and climate scenarios and using the technique, as suggested by some researcher of the Blackland Research and Extension Center (BREC).

This methodology allowed to realized a pre-simulation, called pre-run, that proceded the real simulation. In our case, a thirty years pre-run was carried out (1968-1998): with this operation, Epic model subdivided automatically total organic carbon contained in the soil among the different organic matter pools. Thus Epic model was run for each site with different levels of CO2 concentration, and also considering different type of crop management (irrigation and fertilization), as follows.

Atmospheric CO2 concentration was set to:

- 378 ppm for the baseline period (2000-2010)
- 378 and 408 ppm in the future scenario (2020–2030).

For the running of model both irrigation and fertilization operations were set up to evaluate water stress and nitrogen stress days:

- irrigation and fertilization = 0;
- irrigation and fertilization = 1;
- irrigation and fertilization = 0.9
- irrigation = 0 – fertilization=1;
- irrigation = 1 – fertilization = 0.

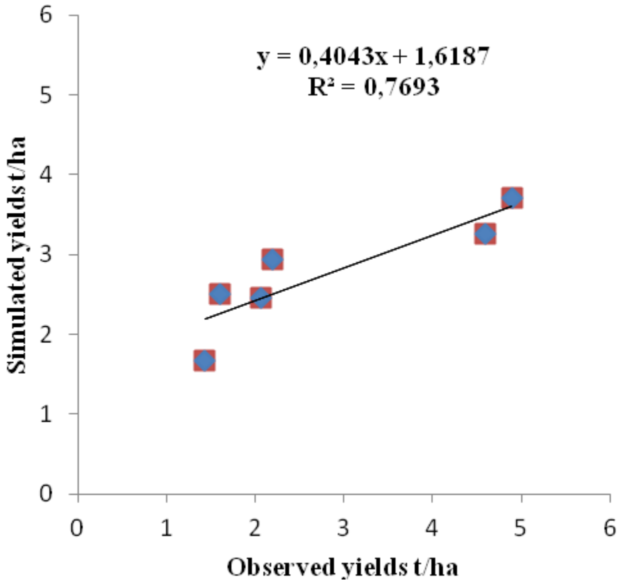
For the validation, a first set of results concerned the ability of the Epic model to simulate (Ozdogan M., 2011) wheat yields in Mediterranean area were shown in the sequence below.
Model validation, in its simplest form, is a comparison between simulated and observed values. Beyond comparisons, there are several statistical measures available to evaluate the association between predicted and observed values, among them are the Pearson correlation coefficient (r) and its square, the coefficient of determination (R^2) and RMSE (Root Mean Square Error).

The results obtained from validation were good for crop yields at all experimental sites, as shown by statistical indices considered. So, the model can be considerated validated for this variable. However for Oristano showed a general tendency of the model to understimate the yield. This is probably due to the high inter-annual variability, that the model could not reproduce. Anyway, despite the underestimation, the model is able to reproduce the observed trend in yield also for this site, and can be considerated validated also for yield simulation.

2.7.2.1 Oristano

Validation

To this aim, a comparison was made between measured and simulated yields for the 2 observed years (2010-2011) for Oristano, Sardinia.



Graphic – Comparison of observed wheat yield to estimates from the Epic model under contemporary climate conditions.

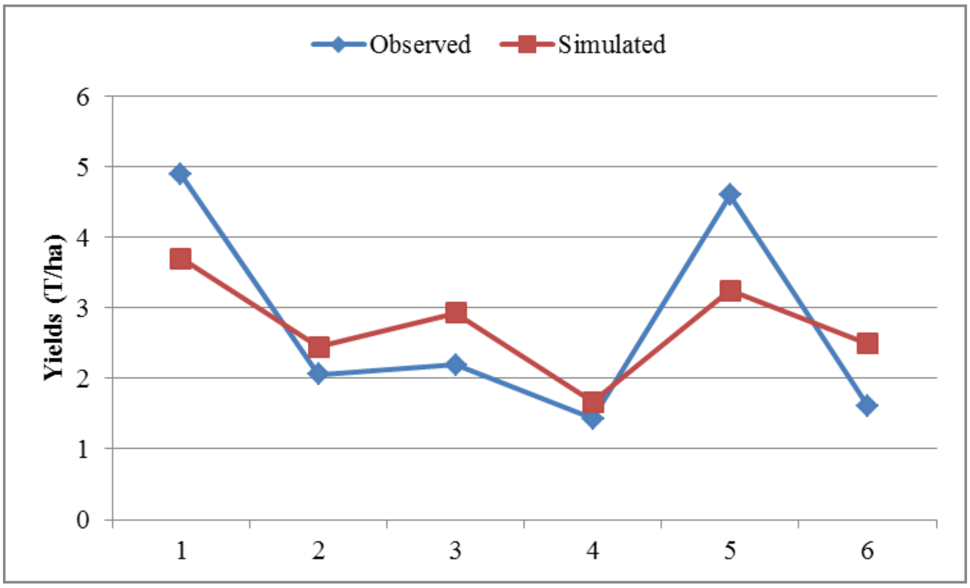


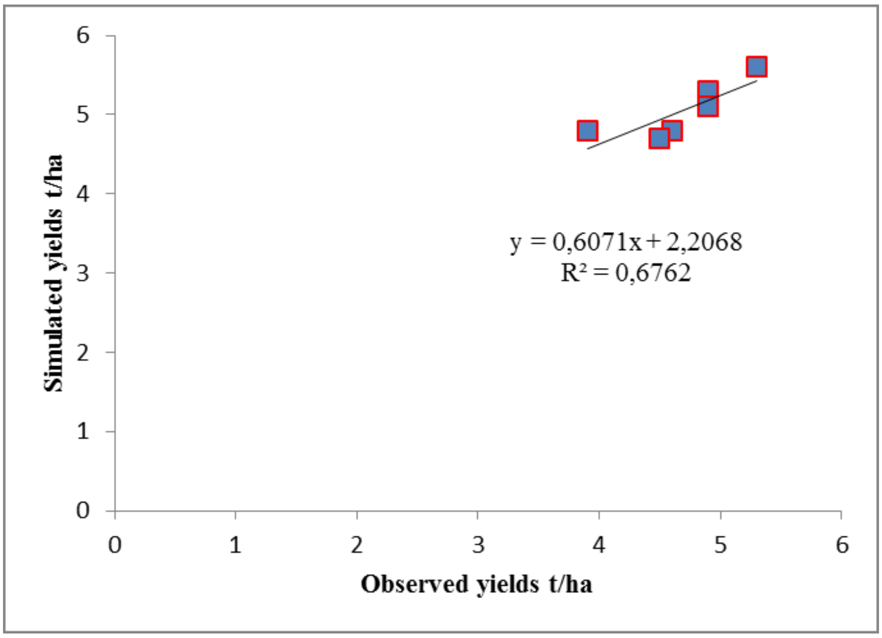
Figure - Comparison between simulated (red) and observed (blue) wheat yields in the site of Oristano in the form of a time series.

Quantitatively, the fit between observed and simulated values is intermediate, as indicated by a large RMSE (0.89) and r (0.77). Observation of the Figure, concerned the differences in inter annual variability. The Epic model predicts large swings in yields on an inter-annual basis, associated with different climatic conditions each year. While these limitations and the results of the goodness-of-fit tests suggest that the Epic model did not always perform well, the current model was retained and used to predict yield response to climate change since it was a good and reliable tool capable to predict wheat yields under Mediterranean conditions.

2.7.2.2 Benevento

Validation

The second validation concerned the second site, Benevento, localized in Campania region. A comparison was made between measured and simulated yields for the 2 observed years (2010-2011).



Graphic – Comparison of observed wheat yield to estimates from the Epic model under contemporary climate conditions.

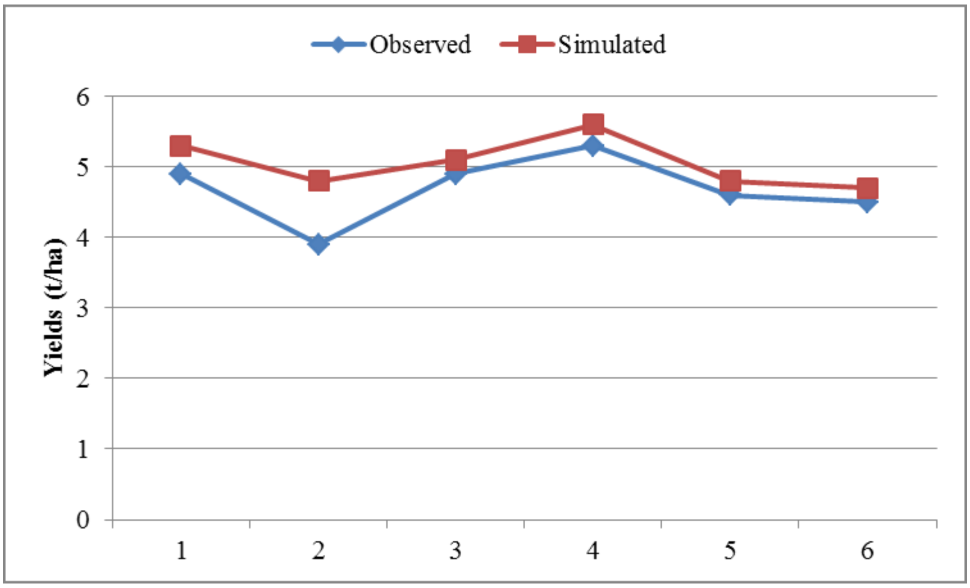


Figure - Comparison between simulated (red) and observed (blue) wheat yields in the site of Benevento in the form of a time series.

Quantitatively, the fit between observed and simulated values was low, as indicated by a low RMSE (0.44) and r (0.67). Observation of the Figure, concerned minor differences in inter annual variability respect to Oristano site. While the results of the goodness-of-fit tests suggest that the Epic model did not always perform well, the current model was retained and used to predict yield response to climate change since it was a good and reliable tool capable to predict wheat yields under Mediterranean conditions.

2.7.2.3 Ancona

Validation

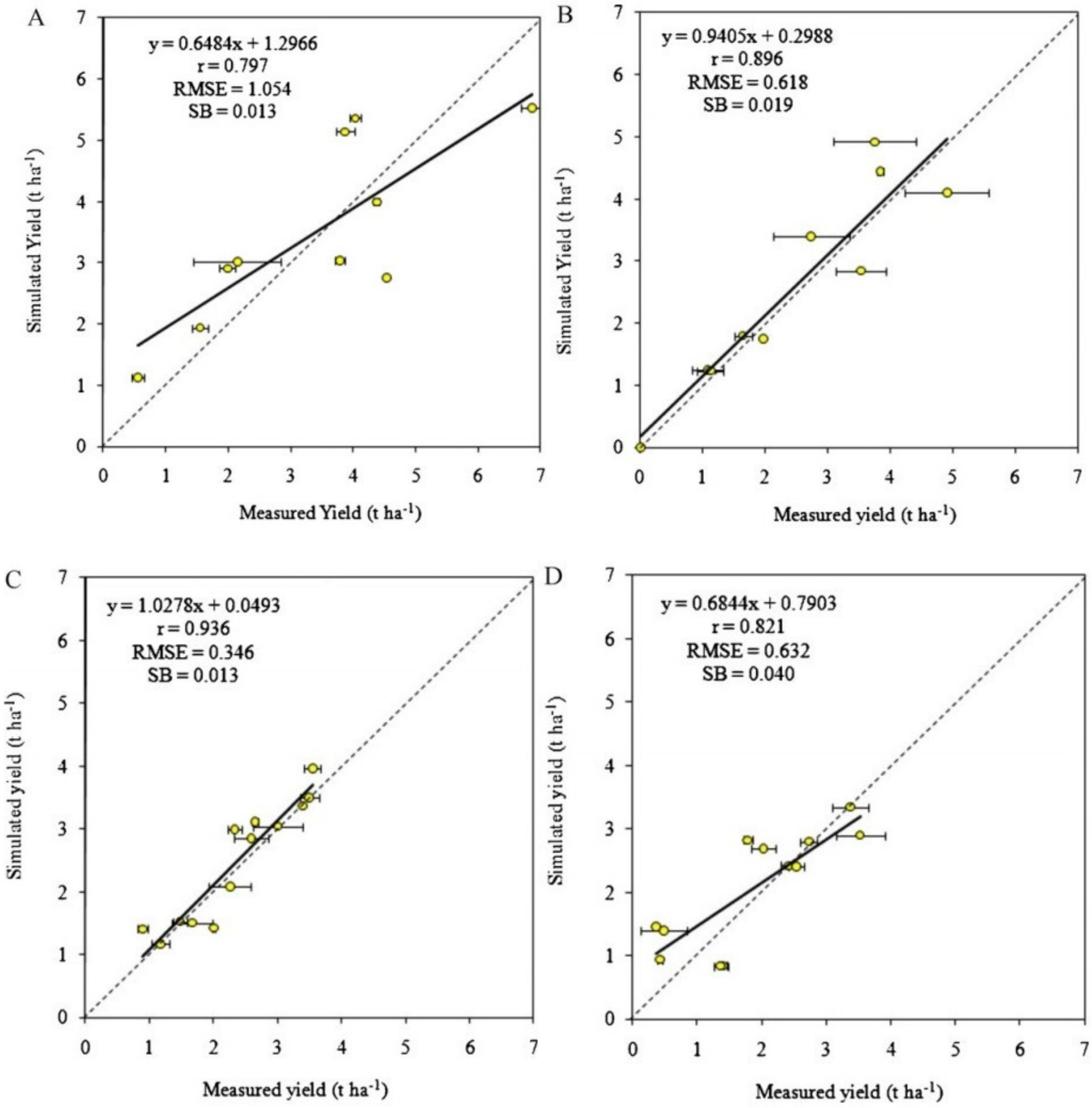


Fig. Regression between simulated and observed grain yield and indices of agreement (r, RMSE and SB) for (A) maize–durum wheat crop rotation (MaDw) in the conventional tillage (CT), (B) maize–durum wheat crop rotation (MaDw) in the no tillage (NT), (C) sunflower–durum wheat crop rotation (SfDw) in the conventional tillage (CT), and (D) sunflower–durum wheat crop rotation (SfDw) in the no tillage (NT)

The model performance indices, such as RMSE and SB, indicated that the bias of estimated vs. measured values is acceptable considering the purpose of the study. In fact, SB indices were close to 0, and RMSE indices were within the range of the standard deviations of the observed values. Considering that results served for long term simulation, the accuracy of simulated mean yields are satisfactory.

Chapter 3

Results

Crop yields, Water use efficiency, Evapotranspiration, Growing Season Precipitation, Water and Nitrogen stress were the principal Epic model outputs considered.

For each of the three site, the Epic model was run for 15 times: two different CO2 concentrations level (378 ppm and 408 ppm), two climatic projections (baseline and future), with the same two level of CO2 for the future condition, three different soil profiles and three different cropping systems. Auto fertilization, auto irrigation and different combinations of the two type of management were other discriminants examined for crop production.

All the results were analysed by:

- normal statistical analysis;
- principal component analysis.

The second was used to carry out the correlation analysis between mean of the characters measured and principal component analysis (PCA), based on the rank correlation matrix were performed by STATISTICA.

3.1 Climate change effects with different CO2 concentrations and crop stress

The first set of results was obtained considering:

- climatic baseline condition with a concentration of CO_2 in the amount of 378 ppm;
- climatic future condition with a concentration of CO_2 in the amount of 408 ppm;
- water and nitrogen stress imposed (autoirrigation and autofertlization with zero value).

3.1.1 Oristano

Impacts of climate change on yield

The simulated average durum wheat yield for the baseline period was 3.5 t/ha, with a CV of 0.32, and ranged from 2.2 to 5.3 t/ha. while under future climate conditions was 2.84 t/ha, with a CV of 0.28, and ranged from 1.31 to 4.33 t/ha, showing a decrease of 15% (ranging from -21.8% to + 44.9 %), respect to baseline conditions. Considering the two series of data, the Pearson's correlation coefficient was 0.70 ($p<0.001$). Results are also showed throught the box plot in Figure 1.

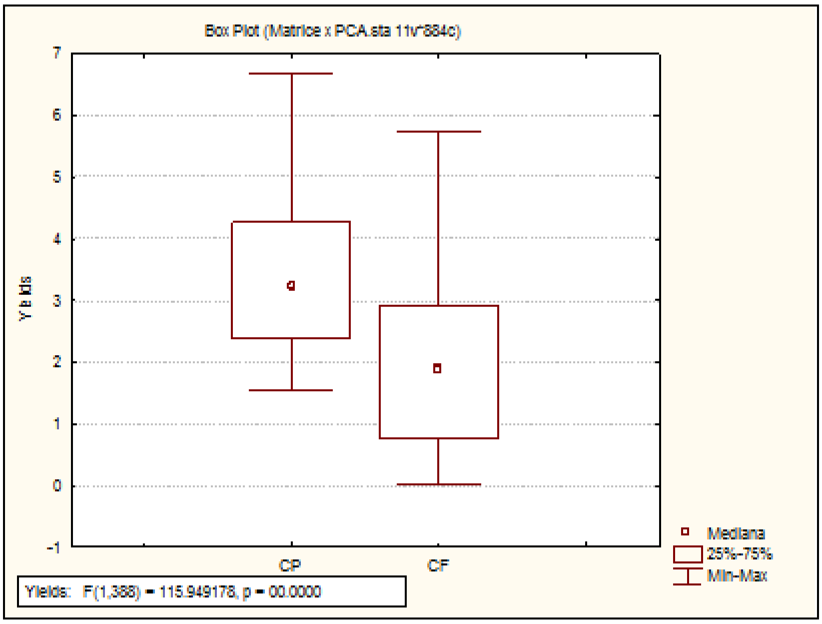


Figure 1 – Durum wheat yields under baseline and future climate in Oristano site.

Water Use Efficiency

Considering the Water Use Efficiency, there was a decrease in the future of 19 % respect to the baseline conditions, with a range from – 42.4 to 2.78%. Analysis of interannual variability under baseline condition indicated an average WUE of 11.71 kg biom/mm H_2O and a range from 7.35 to 17.59 kg biom/mm H_2O. Under future climate, the average WUE was 9.22 kg mm^{-1} ha $^{-1}$, and it ranged from 6.03 to 12.8 kg biom/mm H_2O. Respect to CP, in the CF was registered a minor variation for WUE, that maybe found a stabilization. Comparison of values under the two climatic scenarios showed a Pearson's correlation coefficient of 0.78 (p< 0.001). Figure 2 and 3 showed the correlation between Yields and WUE in the baseline and future conditions respectively. Results are also showed in Graphic 4 and 5.

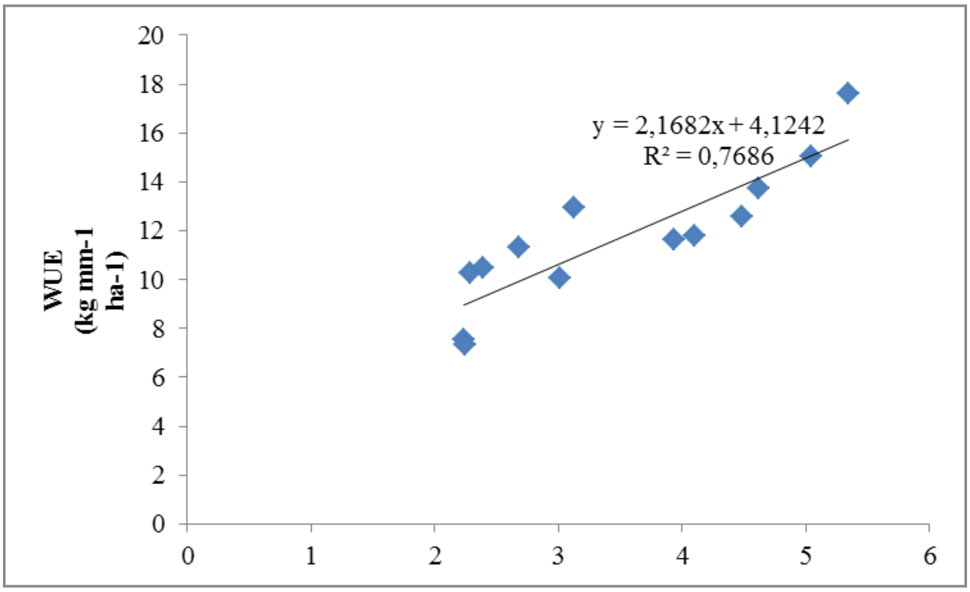


Figure 2 – Correlation between crop and WUE under climatic baseline conditions

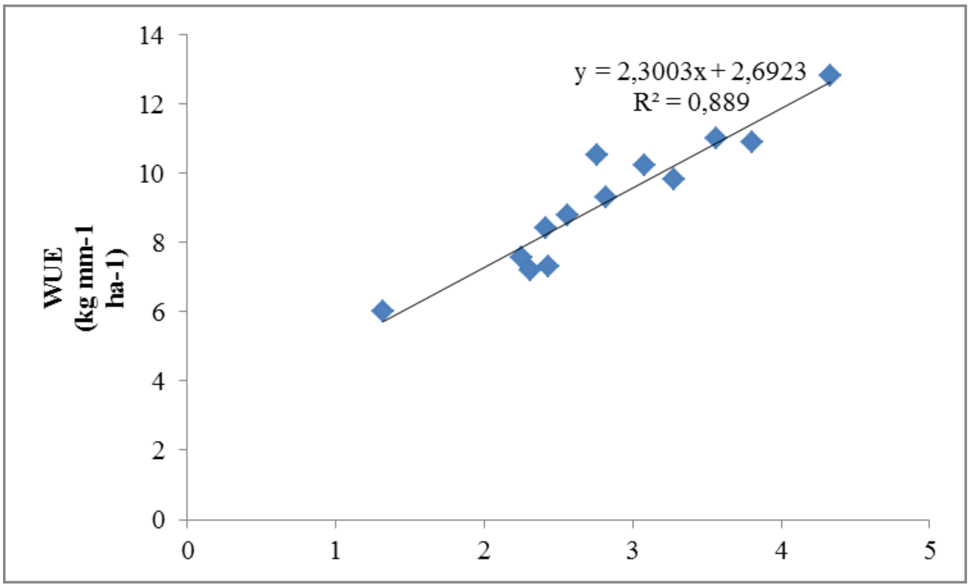
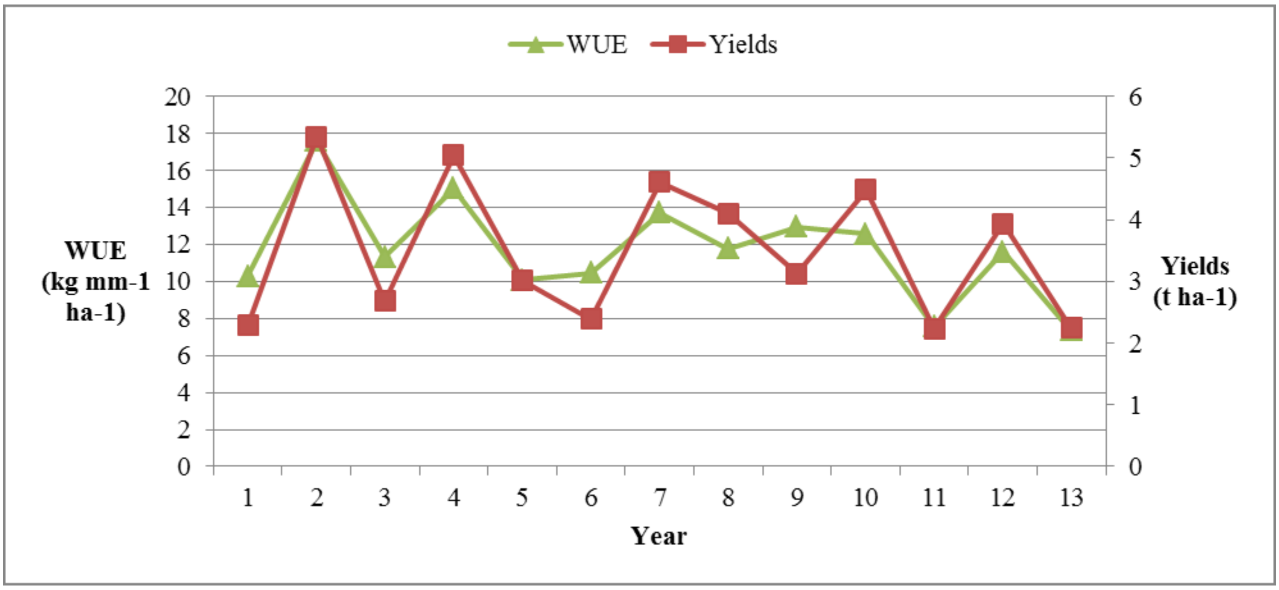
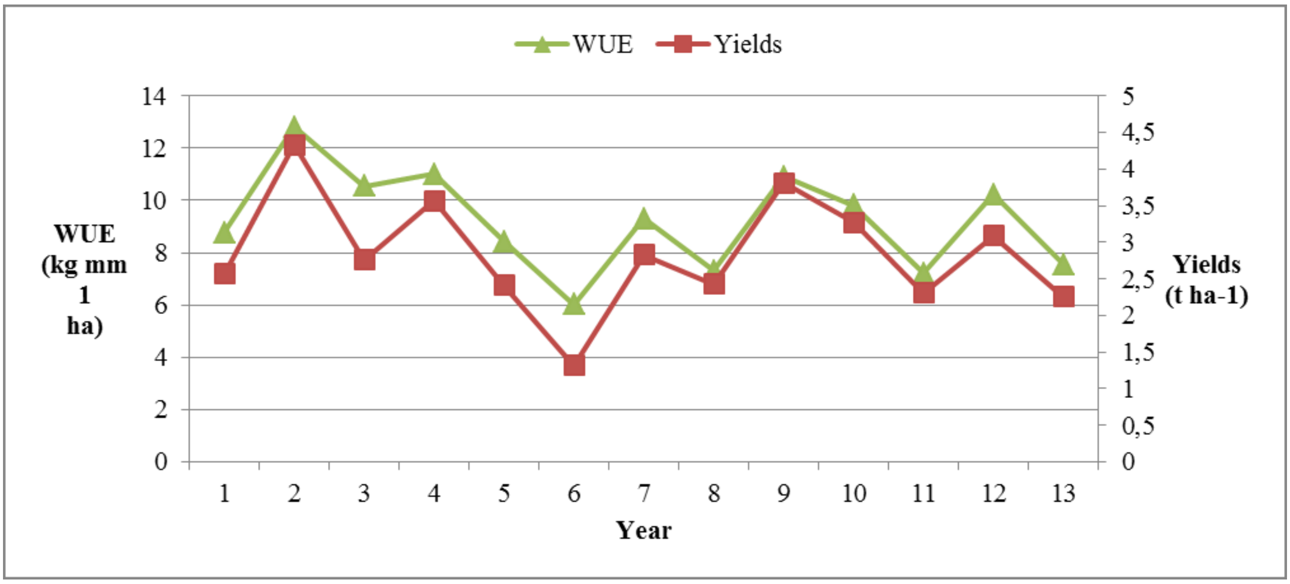


Figure 3 – Correlation between crop yields and wue under climatic future conditions



Graphic 1 – Relation between average Water Use Efficiency and crop yields under climate baseline conditions.



Graphic 2 – Relation between average Water Use Efficiency and crop yields under climate future conditions.

Evapotranspiration

Deviations between baseline climate and future have been observed also for Evapotranspiration. Under baseline climatic conditions average ET was 296,44 mm, with a CV of 0.24 , and a range from 222.47 to 357.17 mm. Respect to the previous conditions, future ET, with an average of 293.8 mm, increased of 1.21 % (-27.7 - + 53.7) and ranged from 164,66 to 371.28 mm, with a CV of 0.17. Comparison of values under the two climatic scenarios showed a Pearson's correlation coefficient of 0.20 ($p< 0.44$). Analysis among wheat yields and evapotranspiration show a higher correlation under future climate ($R^2 = 0.67$). Figure 4 and 5 showed the correlation between Yields and ET in the baseline and future conditions respectively. Results are also showed in Graphic 3 and 4.

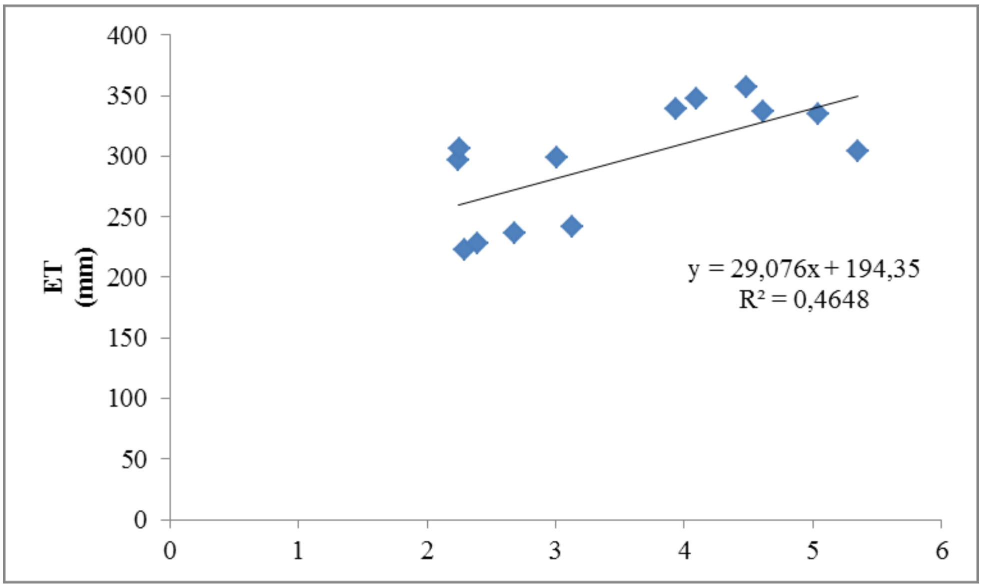


Figure 4 – Correlation between crop and ET under climatic baseline conditions

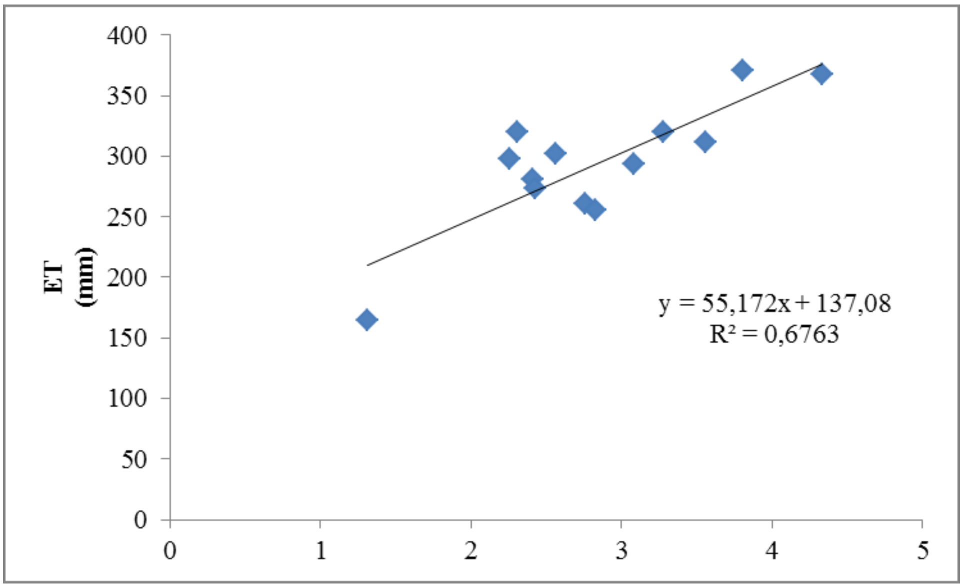
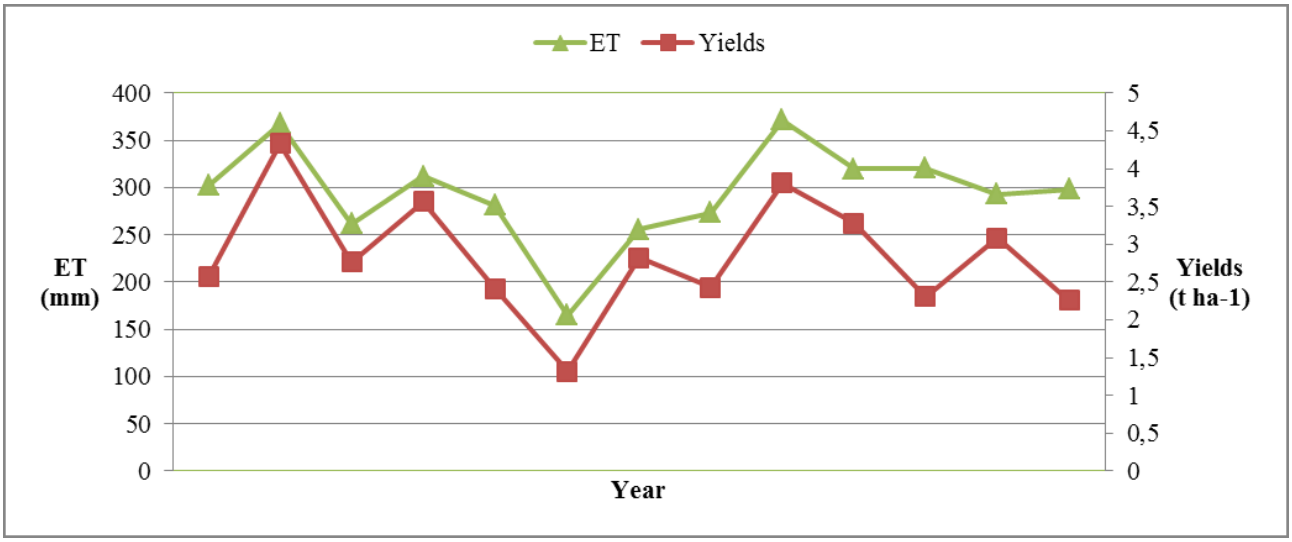


Figure 5 – Correlation between crop and ET under climatic future conditions

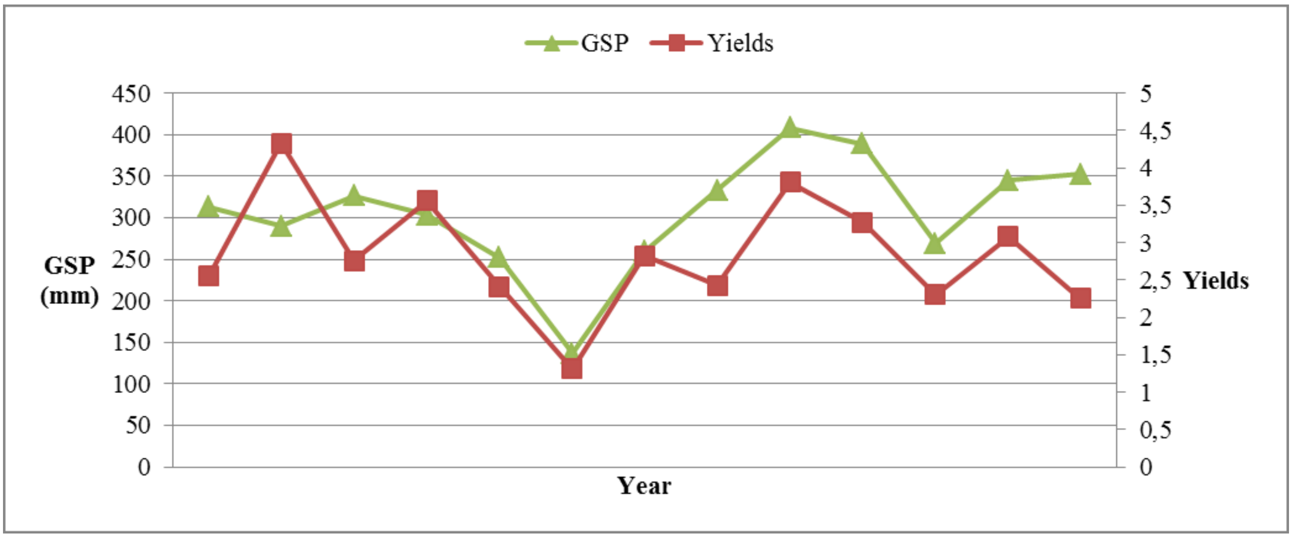
Graphic 3 – Relation between average Evapotranspiration and crop yields under climate baseline conditions.



Graphic 4 – Relation between average Evapotranspiration and crop yields under climate future conditions.

Changes in Growing Season Precipitation

Graphic 5 – Relation between average GSP and crop yields under climate baseline conditions.



Graphic 6 – Relation between average GSP and crop yields under climate future conditions.

Considering GSP, baseline scenario showed an average of 338.5 mm, slightly higher respect to future scenario, when 306 mm were observed. GSP ranged from 206.2 to 506.8 mm in CP, while from 137 to 408 mm in CF. In % values, a decrease of about 6 % was observed in the CF, ranging from – 33.3 to + 53.3 %. Also CV and dev.st. were higher in the CP respect to CF: 0.27 and 93.5 respectively in the fist case, and 0.22 and 66.4 in the second case. Results are also showed in Graphic 5 and 6.

Water Stress

In contrast with ET, future water stress decreased, with a increasing of 107 % (range from 9.16 to 330 %). In fact under baseline climatic condition resulted higher than under future climatic conditions: in CP the average was 41.32 days while in CF was 72.6 days. Also the range changed, so in first situation ET was in the interval 15.32 and 67.67 days, while from 51.70 to 11.46 days. If consider CV passed from 41.32 to 72.56. The correlation of Pearsons as result of comparison enter CP and CF was 0.40 (P<0.001). Figure 6 and 7 showed the correlation between Yields and ET in the baseline and future conditions respectively. Results are also showed in Graphic 7 and 8.

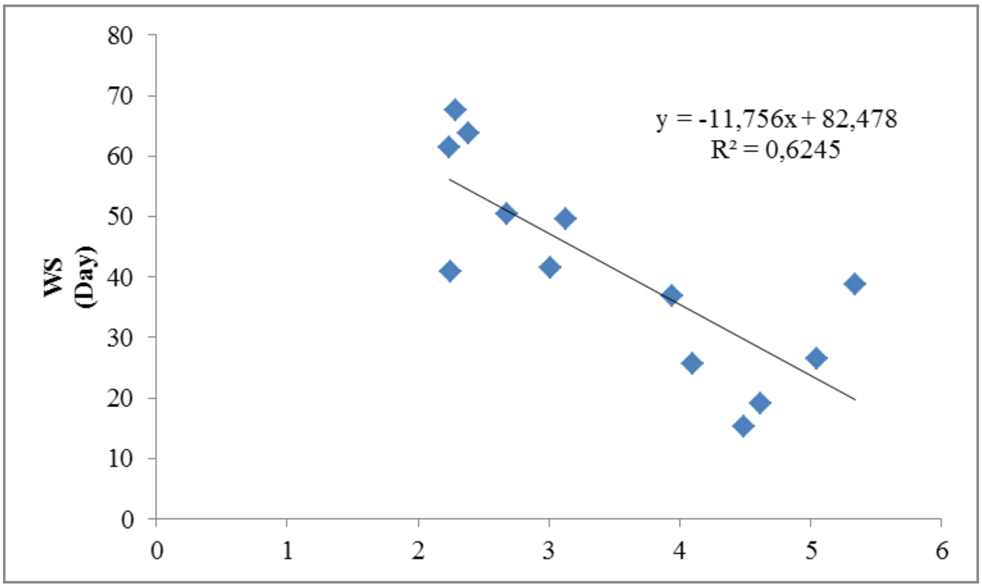


Figure 6 – Correlation between crop and WS under climatic baseline conditions

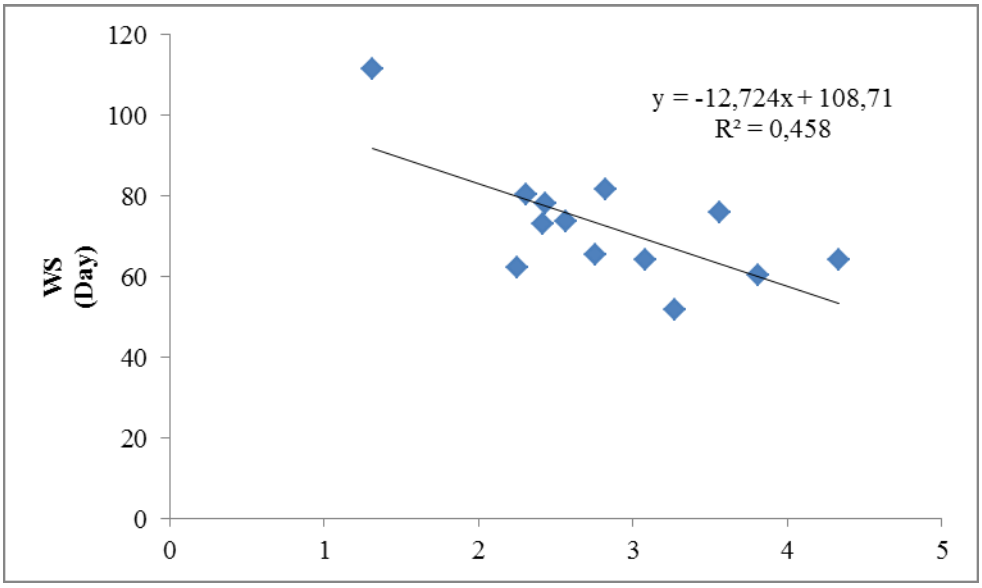
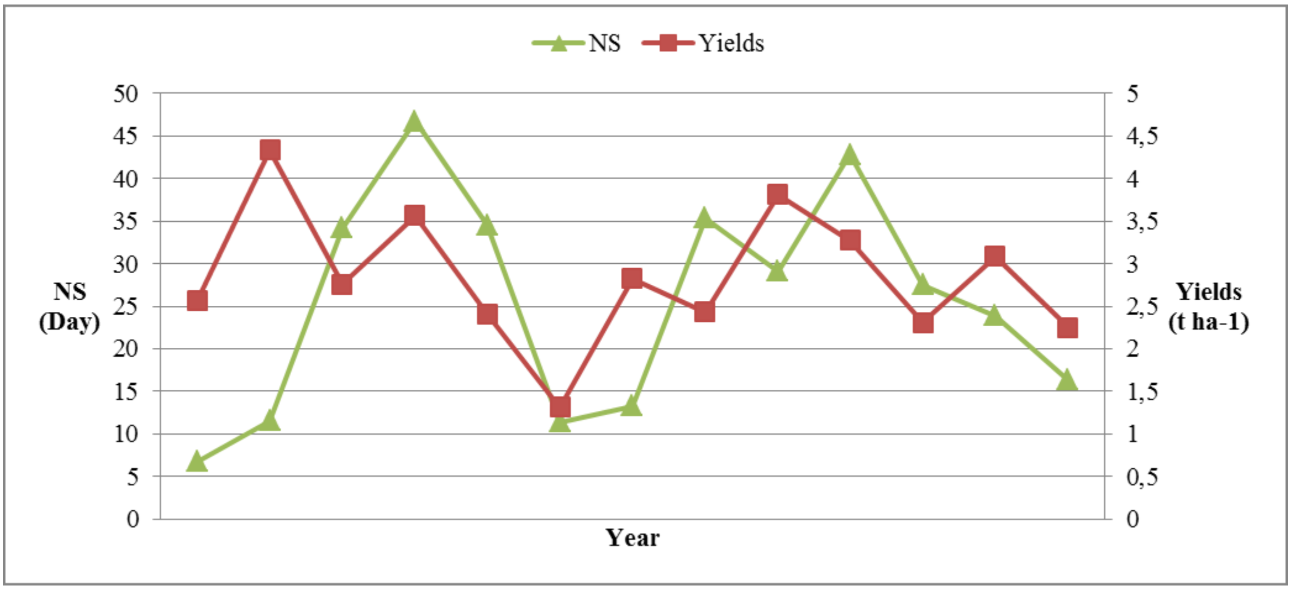


Figure 7 – Correlation between crop and WS under climatic future conditions

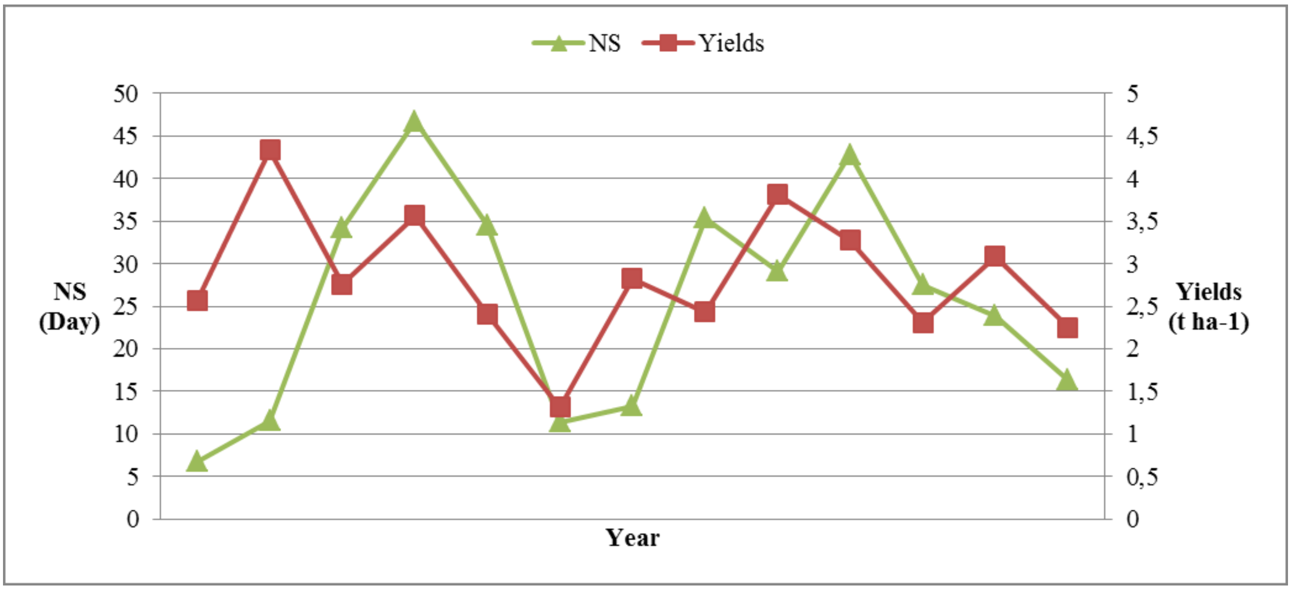
Graphic 7 – Relation between average Water Stress Day and crop yields under climate baseline conditions.

Graphic 8 – Relation between average Water Stress Day and crop yields under climate future conditions.

Nitrogen stress



Graphic 9 – Relation between average Nitrogen stress and crop yields under climate baseline conditions.



Graphic 10 – Relation between average Nitrogen stress and crop yields under climate future conditions.

Future nitrogen stress decreased, with a decreasing of 13.2 % (range from -56 to + 125 %). In fact under baseline climatic condition resulted higher than under future climatic conditions: in CP the average was 10.51 days while in CF was 9 days. Also the range changed, so in first situation NS was in the interval 3.3 and 23.26 days, while from 2.65 to 17.77 days in the second case. If consider CV passed from 0.59 to 0.46. The correlation of Pearsons as result of comparison enter CP and CF was 0.40 (P<0.001). Results are also showed in Graphic 9 and 10.

3.1.2 Benevento

Impacts of climate change on yields

The simulated average durum wheat yield for the baseline period was 3.4 t/ha, with a CV of 0.16, and ranged from 2.4 to 4.4 t/ha, while under future climate conditions was 4 t/ha, with a CV of 0.12, and ranged from 3.15 to 5.03 t/ha, showing an increase of 21% (ranging from 7.33 % to + 43.9 %), respect baseline conditions. Considering the two series of data, the Pearson’s correlation coefficient was 0.94 ($p<0$). Results are also showed throught the box plot in Figure 1.

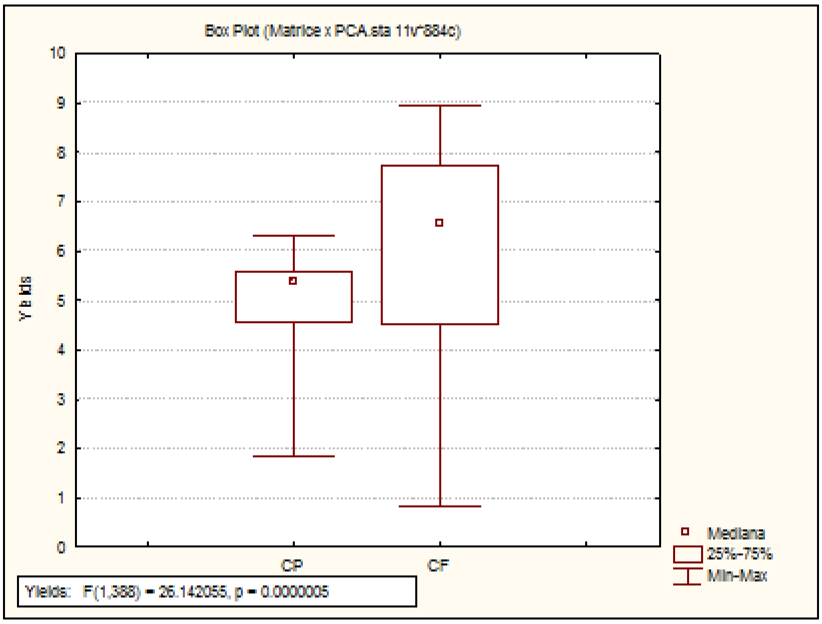
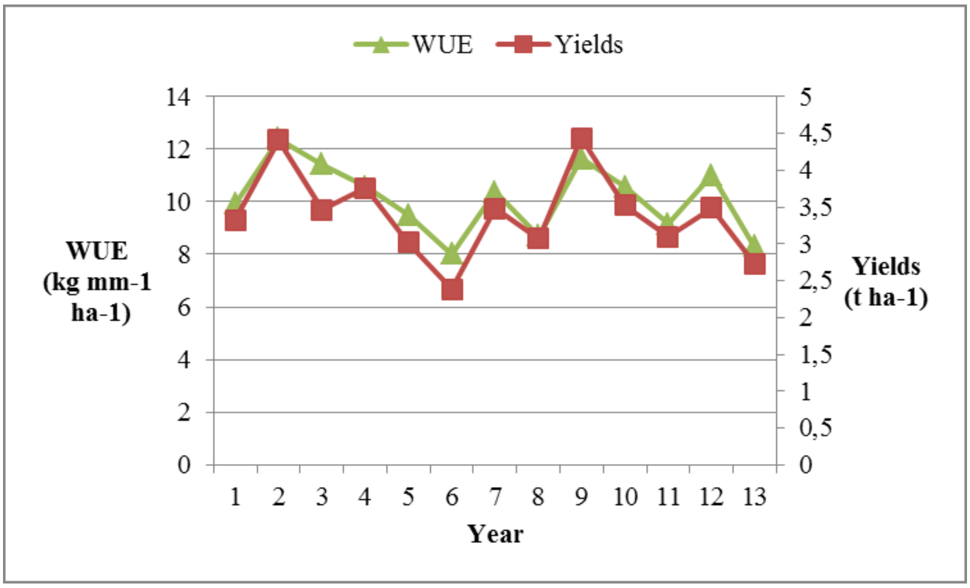


Figure 1 – Durum wheat yields under baseline and future climate in Benevento site.

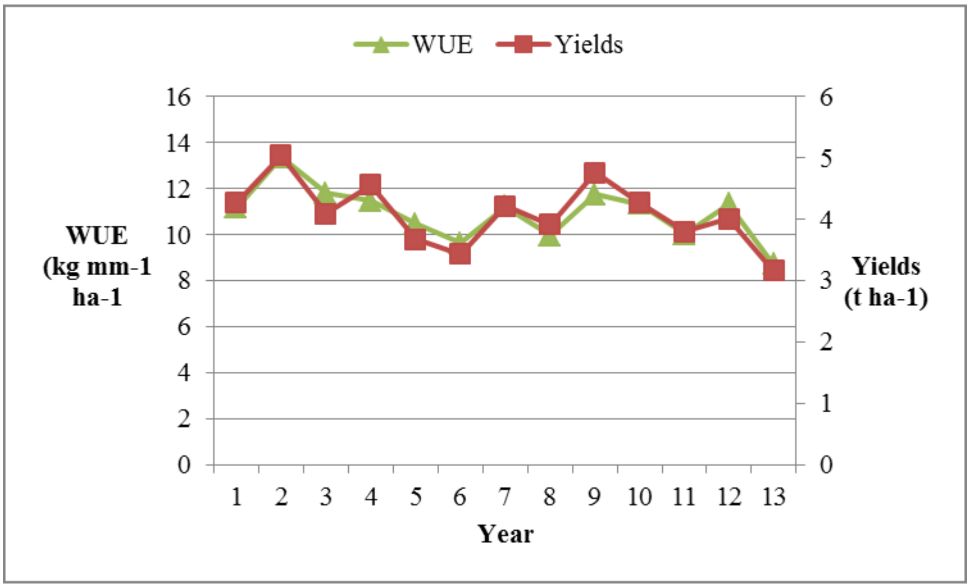
Water Use Efficiency

Considering the Water Use Efficiency, there was an increase in the future of 4.83 % respect to the baseline conditions, with a range from 1 to 20.2 %. Analysis of interannual variability under baseline condition indicated an average WUE of 10.11 kg biom/mm H_2O and a range from 8.01 to 12.38 kg biom/mm H_2O. Under future climate, the average WUE was 10.93 kg biom/mm H_2O , and it ranged from 8.71 to 13.35 kg biom/mm H_2O. Comparison of values under the two climatic scenarios showed a Pearson's correlation coefficient of 0.98 ($p< 0.001$). Figure 2 and 3 showed the correlation between Yields and WUE in the baseline and future conditions respectively. Results are also showed in Graphic 1 and 2.

An increased productivity from increased water-use efficiency is the major response to elevated atmospheric CO_2 concentrations in C3- or C4-crops that are exposed frequently to water stress.



Graphic 1 – Relation between average Water Use Efficiency and crop yields under climate baseline conditions.



Graphic 2 – Relation between average Water Use Efficiency and crop yields under climate future conditions.

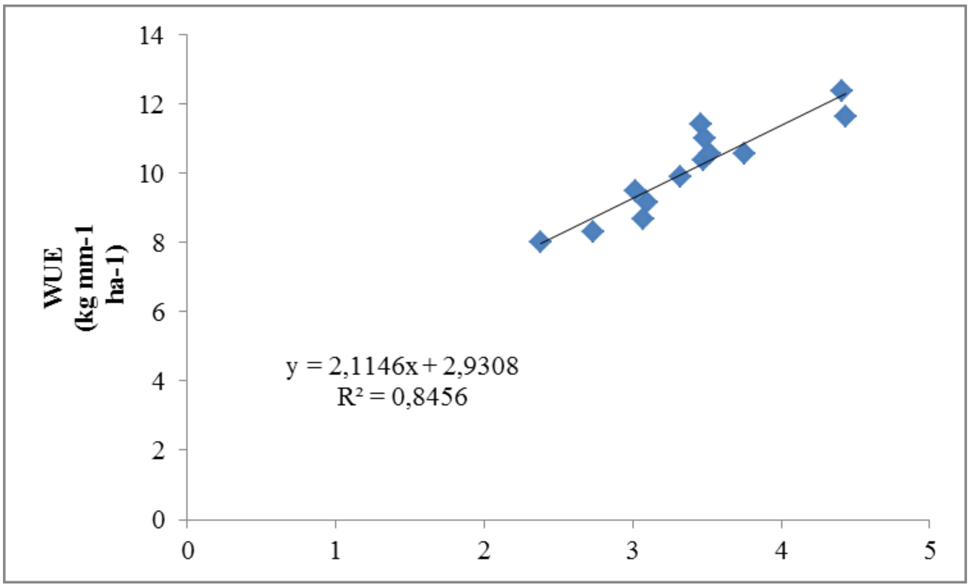


Figure 2 – Correlation between crop yields and WUE under climatic baseline conditions

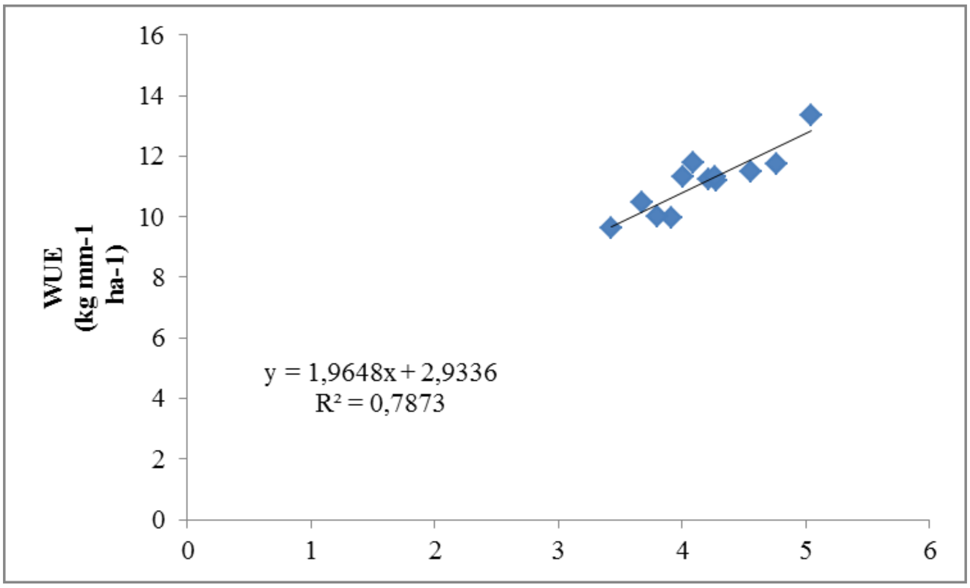


Figure 3 – Correlation between crop yields and wue under climatic future conditions

Evapotranspiration

Deviations between baseline climate and future have been observed also for Evapotranspiration. Under baseline climatic conditions average ET was 316,37 mm, with a CV of 0.13 %, and a range from 212.2 to 396.61 mm. Respect to the previous conditions, future ET, with an average of 351.4 mm, increased of 12 % (2.94-29.67 %) and ranged from 275,16 to 413.47 mm, with a CV of 0.09. Comparison of values under the two climatic scenarios showed a Pearson's correlation coefficient of 0.98 ($p < 0$). Analysis among wheat yields and evapotranspiration show a normal correlation under future climate ($R^2 = 0.52$). Figure 4 and 5 showed the correlation between Yields and WUE in the baseline and future conditions respectively. Results are also showed in Graphic 3 and 4.

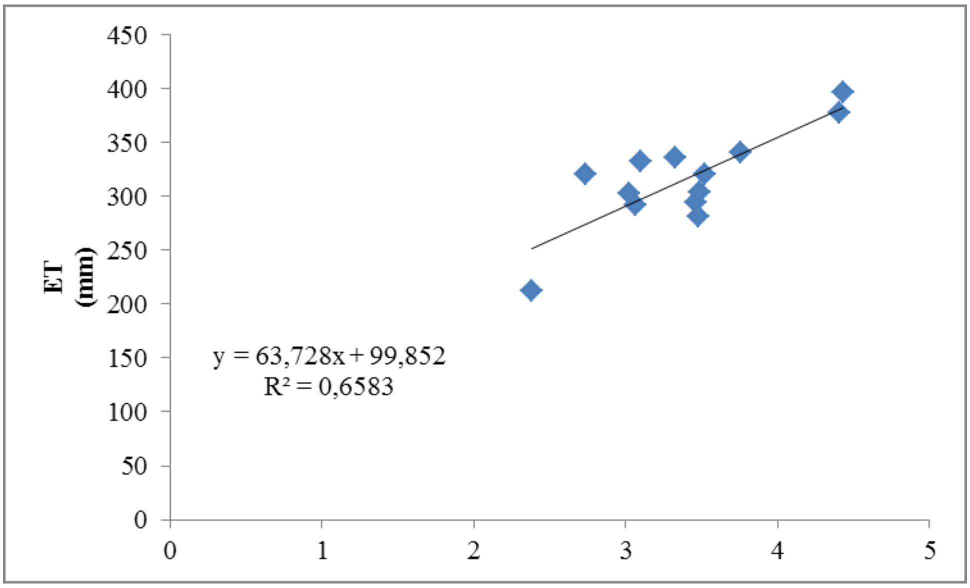


Figure 4 – Correlation between crop yields and ET under climatic baseline conditions

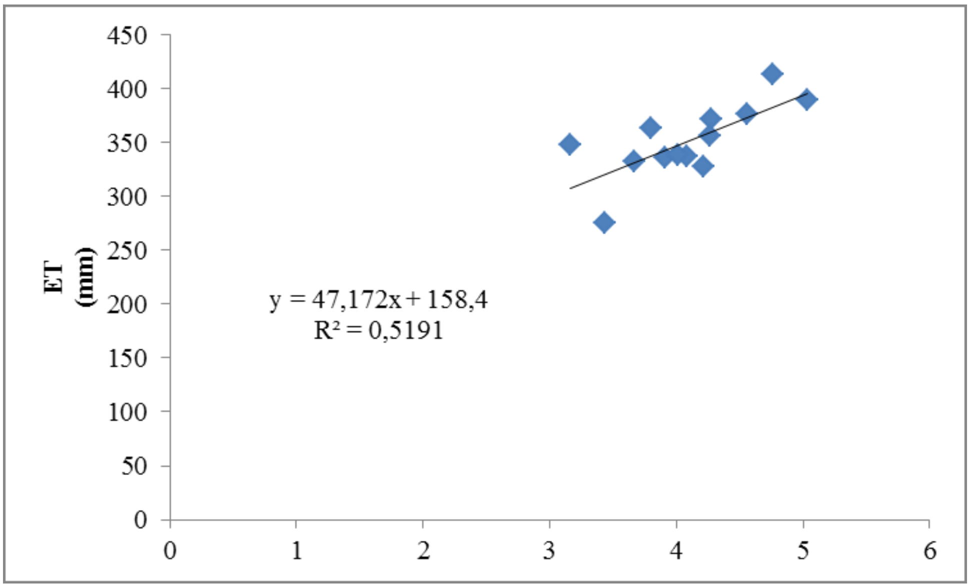
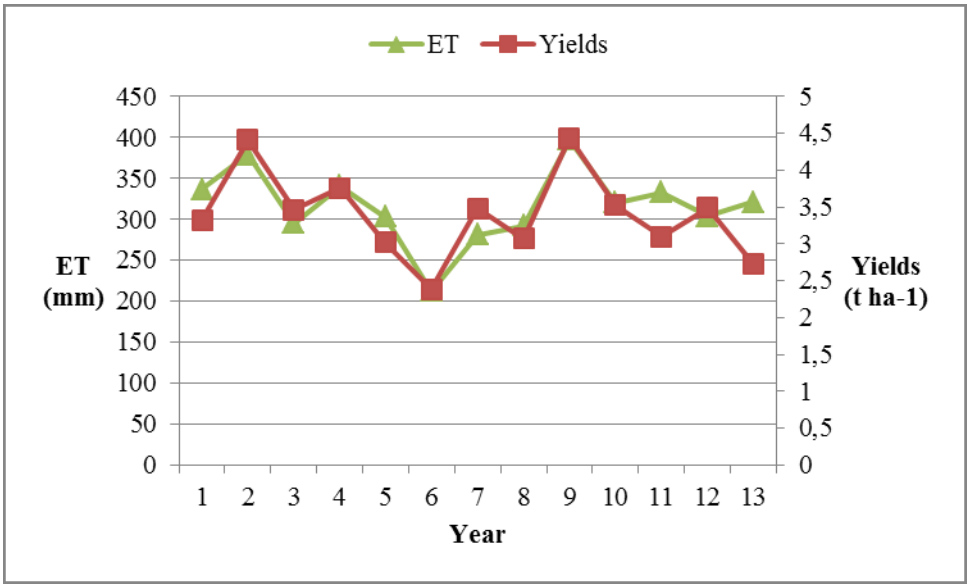
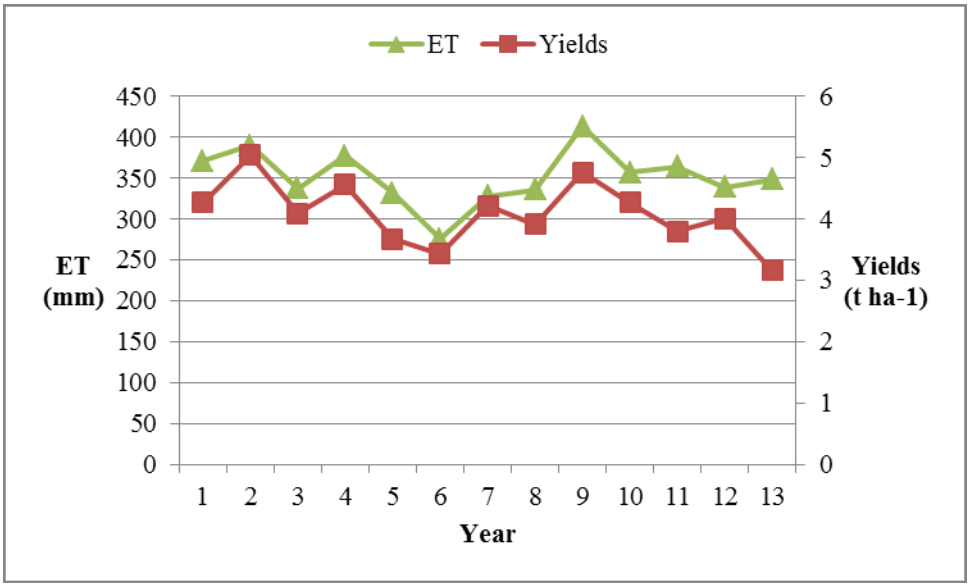


Figure 5 – Correlation between crop yields and ET under climatic future conditions

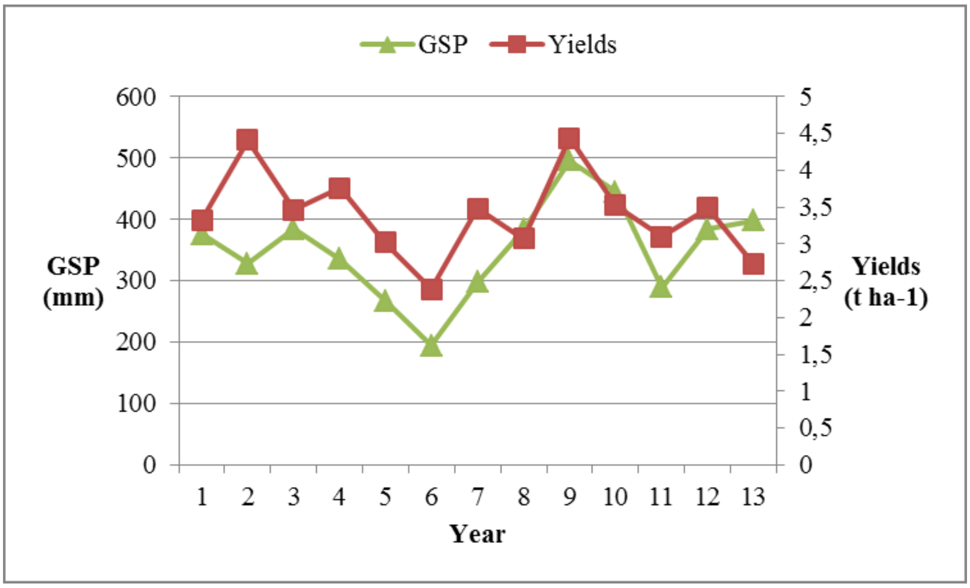


Graphic 3 – Relation between average Evapotranspiration and crop yields under climatic baseline conditions.

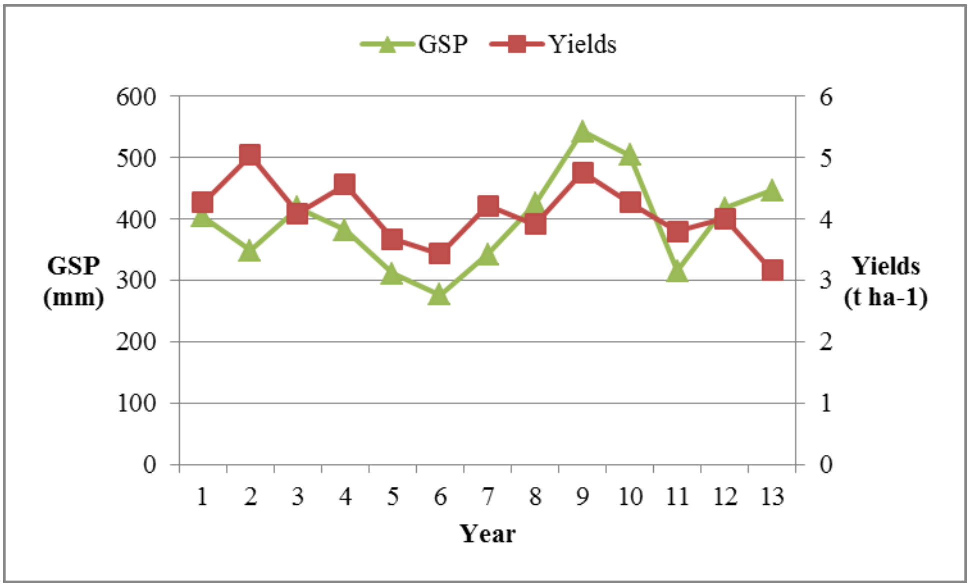


Graphic 4 – Relation between average Evapotranspiration and crop yields under climatic future conditions.

Changes in Growing Season Precipitation



Graphic 5 – Relation between average GSP and crop yields under climatic baseline conditions

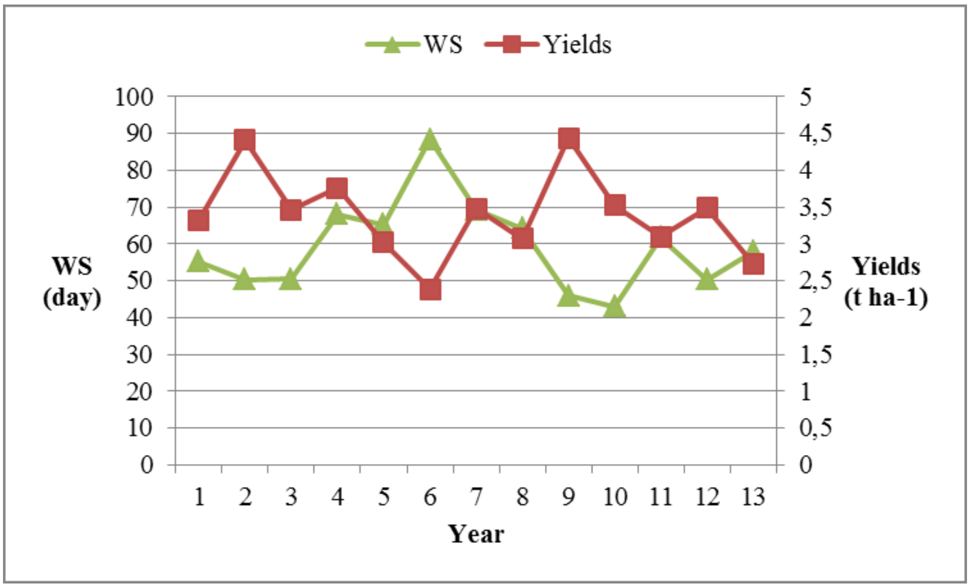


Graphic 6 – Relation between average GSP and crop yields under climatic future conditions.

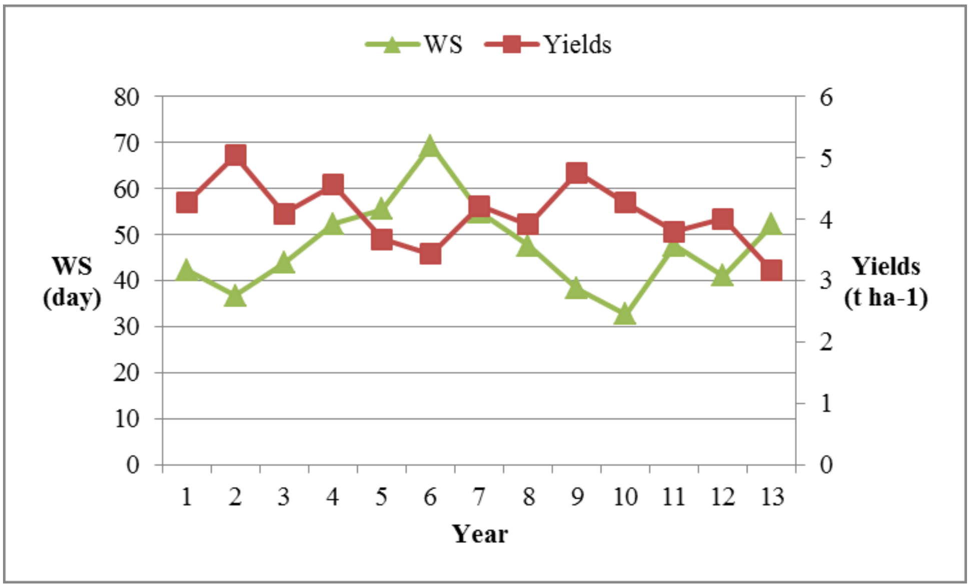
Considering GSP, baseline scenario showed an average of 352 mm, slightly slower respect to future scenario, when 394.8 mm were observed. GSP ranged from 194.5 to 495.8 mm in CP, while from 276.8 to 542.2 mm in CF. In % values, an increase of about 14 % was observed in the CF, ranging from – 6.5 to + 42.3 %. Instead CV and dev.st. were higher in the CP respect to CF: 0.21 and 75.8 respectively in the fist case, and 0.19 and 73.7 in the second case. Results are also showed in Graphic 5 and 6.

Water Stress

In contrast with ET, future water stress increased, with a increasing of 20 % (range from 9.89 to – 26.77 %). In fact under baseline climatic condition resulted higher than under future climatic conditions: in CP the average was 59.17 days while in CF was 47.23 days. Also the range changed, so in first situation ET was in the interval 42.93 and 88.29, while from 32.70 to 69.26 day. If consider CV, it is identical for both scenarios. The correlation of Pearsons as result of comparison enter CP and CF was 0.95 (P<0). Results are also showed in Graphic 7 and 8.



Graphic 7 – Relation between Water Stress and crop yields under climatic baseline conditions.



Graphic 8 – Relation between average Water Stress and crop yields under climatic future conditions.

Nitrogen stress

Future nitrogen stress increased, with a increasing of 13.2 % (range from – 5.96 to + 77.6 %). In fact under baseline climatic condition resulted lower than under future climatic conditions: in CP the average was 7 days while in CF was7.32 days. Also the range changed, so in first situation NS was in the interval 2.36 and 12.54 days, while from 4.07 to 11.8 days in the second case. If consider CV passed from 0.40 to 0.30. The correlation of Pearsons as result of comparison enter CP and CF was 0.40 (P<0.001). Results are also showed in Graphic 9 and 10.

Graphic 9– Relation between Nitrogen Stress and crop yields under climatic baseline conditions.

Graphic 10 – Relation between Nitrogen Stress and crop yields under climatic future conditions.

3.1.3 Ancona

Impacts of climate change on yields

The simulated average durum wheat yield for the baseline period was 4.1 t/ha, with a CV of 0.12, and ranged from 3.12 to 5.09 t/ha, while under future climate conditions was 4.27 t/ha, with a CV of 0.11, and ranged from 3.36 to 5.16 t/ha, showing an increase of 4, 2% (ranging from 1.26 % to 7.5 %), respect baseline conditions. Considering the two series of data, the Pearson's correlation coefficient was 0.99 ($p<0$). Results are also showed throught the box plot in Figure 1.

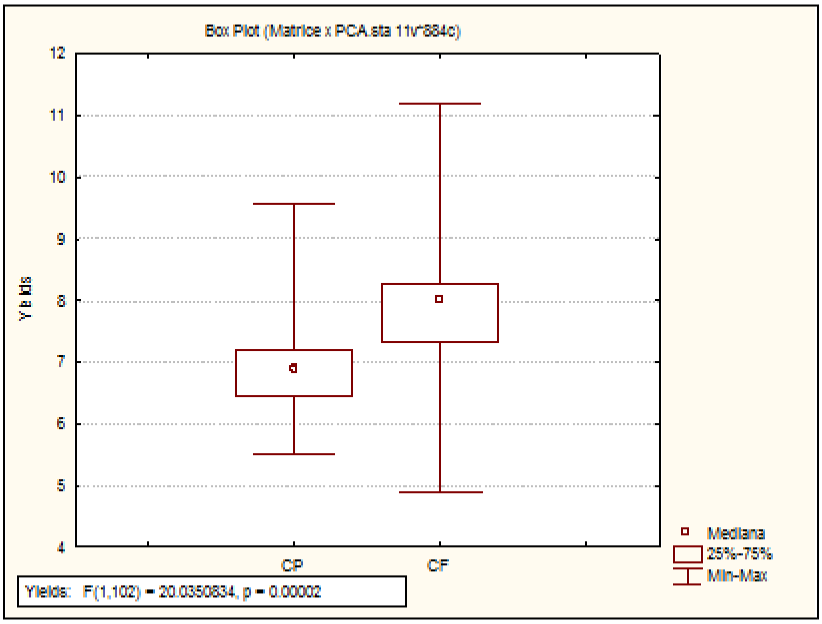
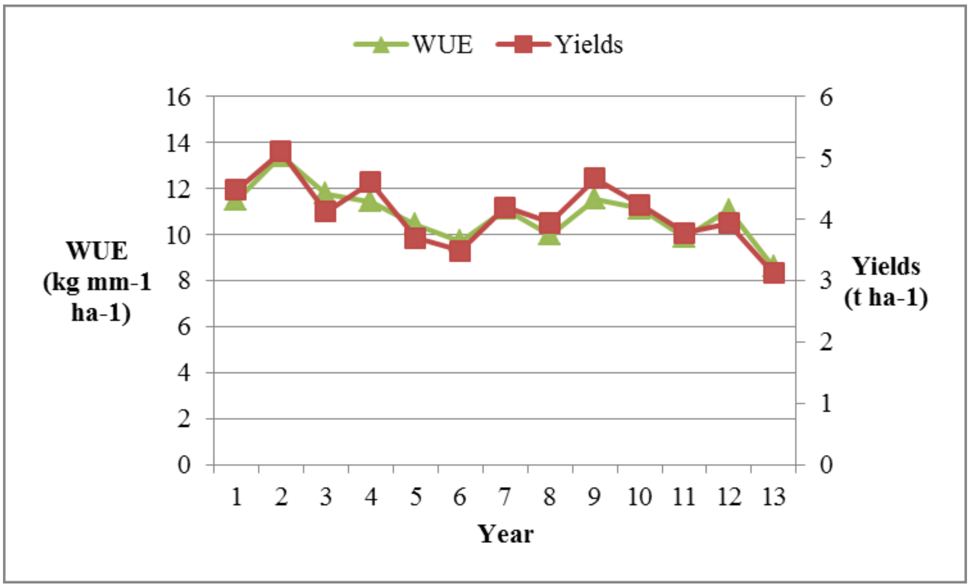


Figure 1– Durum wheat yields under baseline and future climate in Ancona site.

Water Use Efficiency

Considering the Water Use Efficiency, there was an increase in the future of 4.8 % respect to the baseline conditions, with a range from 1.58 to 8.17 %. Analysis of interannual variability under baseline condition indicated an average WUE of 10.89 kg mm^{-1} ha $^{-1}$ and a range from 8.58 to 13.41 kg mm^{-1} ha $^{-1}$. Under future climate, the average WUE was 11.43 kg mm^{-1} ha $^{-1}$, and it ranged from 9.28 to 13.63 kg mm^{-1} ha^{-1} Comparison of values under the two climatic scenarios showed a Pearson's correlation coefficient of 0.98 ($p< 0.001$). Figure 2 and 3 showed the correlation between Yields and WUE in the baseline and future conditions respectively. Results are also showed in Graphic 1 and 2.



Graphic 1 – Relation between average Water Use Efficiency and crop yields under climate baseline conditions.

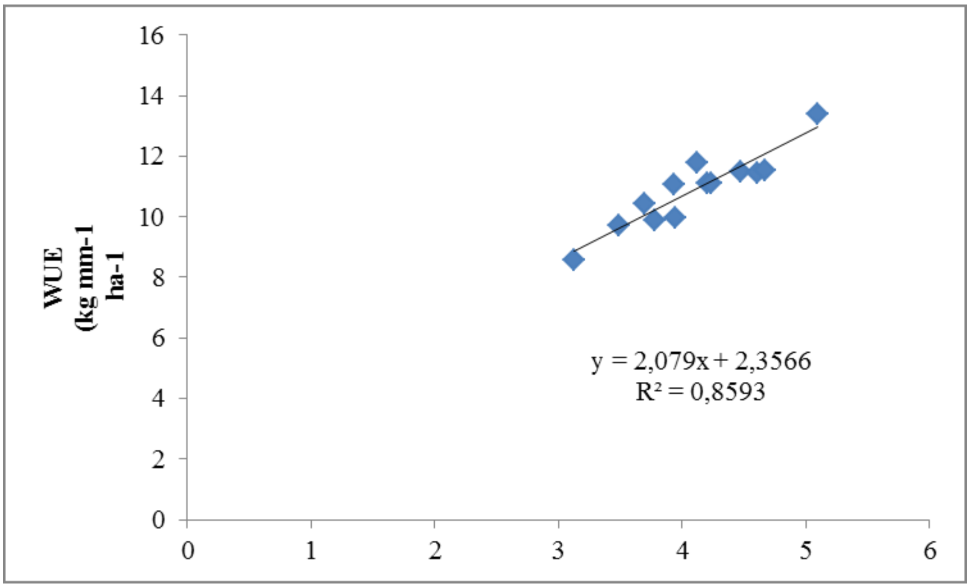
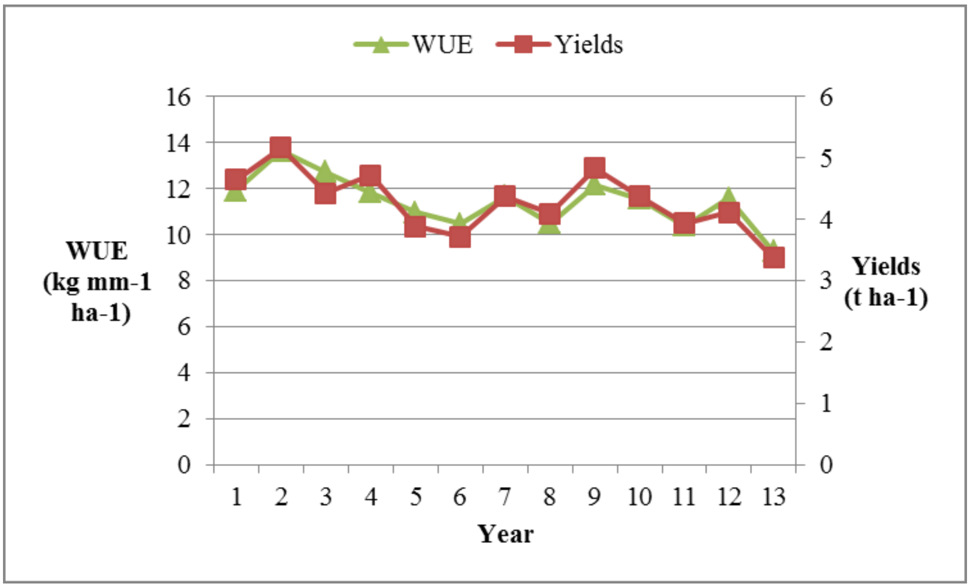


Figure 2 – Correlation between crop yields and WUE under climatic baseline conditions



Graphic 2– Relation between average Water Use Efficiency and crop yields under climate future conditions.

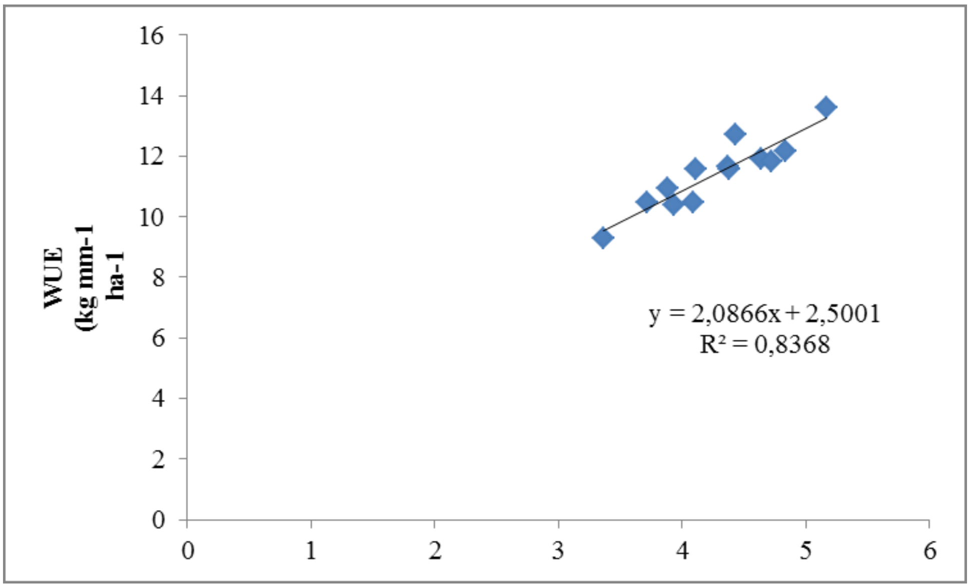
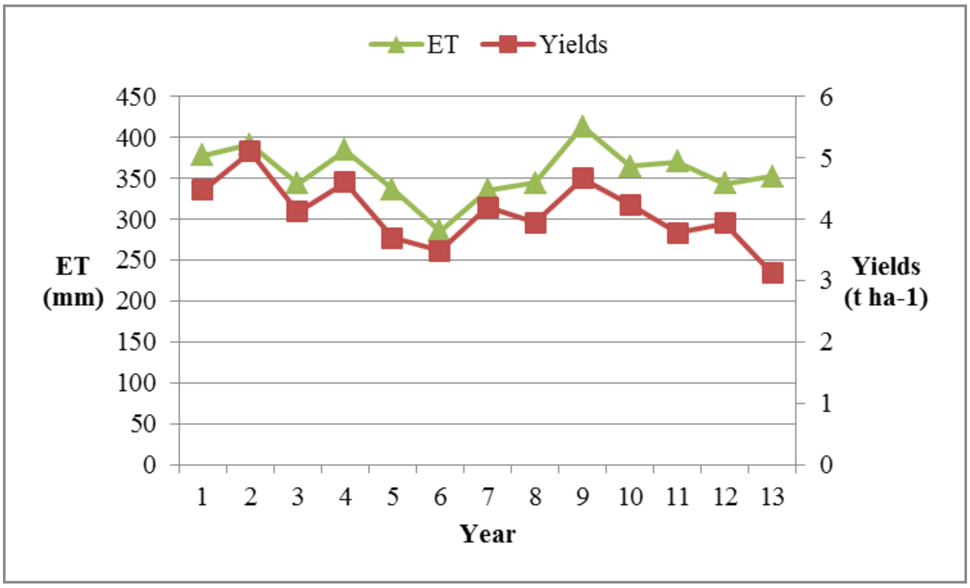


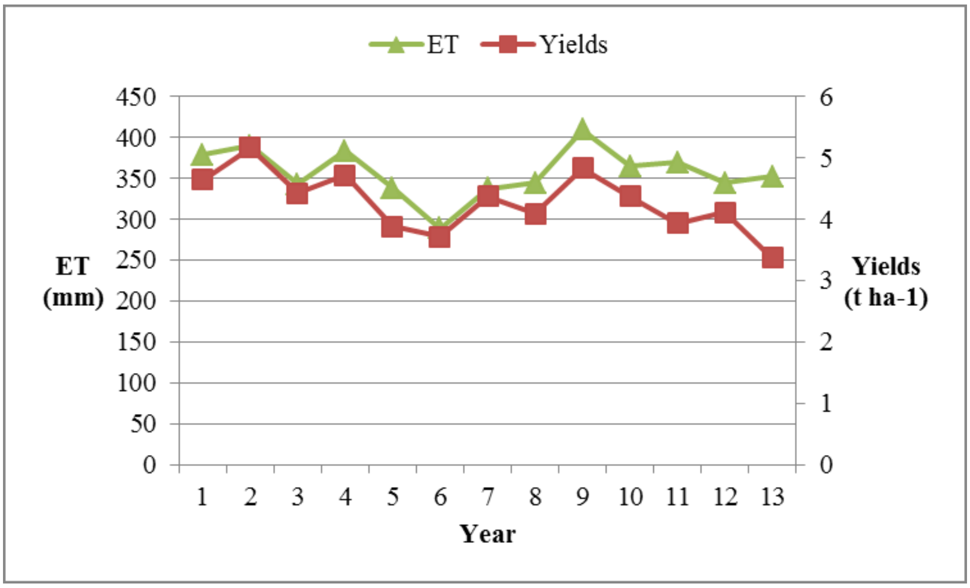
Figure 3 – Correlation between crop yields and wue under climatic future conditions

Evapotranspiration

Deviations between baseline climate and future have been observed also for Evapotranspiration. Under baseline climatic conditions average ET was 357,28 mm, and a range from 285.5 to 413.5 mm. Respect to the previous conditions, future ET, with an average of 357.22 mm, increased of 1 % and ranged from 288,8 to 409.35 mm, with a CV of 0.08, egual for the baseline condition. Comparison of values under the two climatic scenarios showed a Pearson's correlation coefficient of 0.98 ($p< 0.001$). Analysis among wheat yields and evapotranspiration show a higher correlation under future climate ($R^2 = 0.83$). Results are also showed in Graphic 3 and 4.

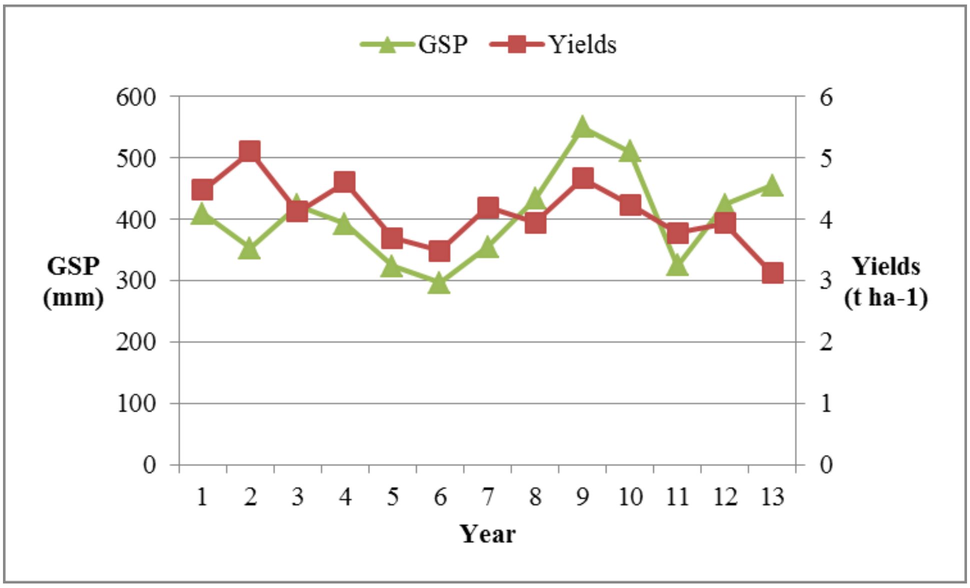


Graphic 3 – Relation between average Evapotranspiration and crop yields under climatic baseline conditions.

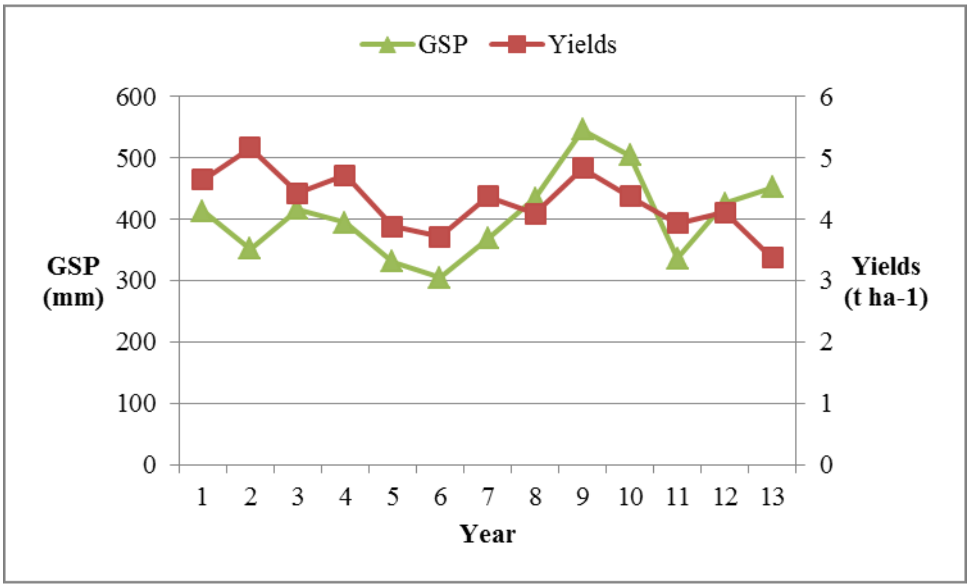


Graphic 4 – Relation between average Evapotranspiration and crop yields under future climatic conditions.

Changes in Growing Season Precipitation



Graphic 5– Relation between average Growing Seasonal Precipitation and crop yields under climatic baseline conditions.

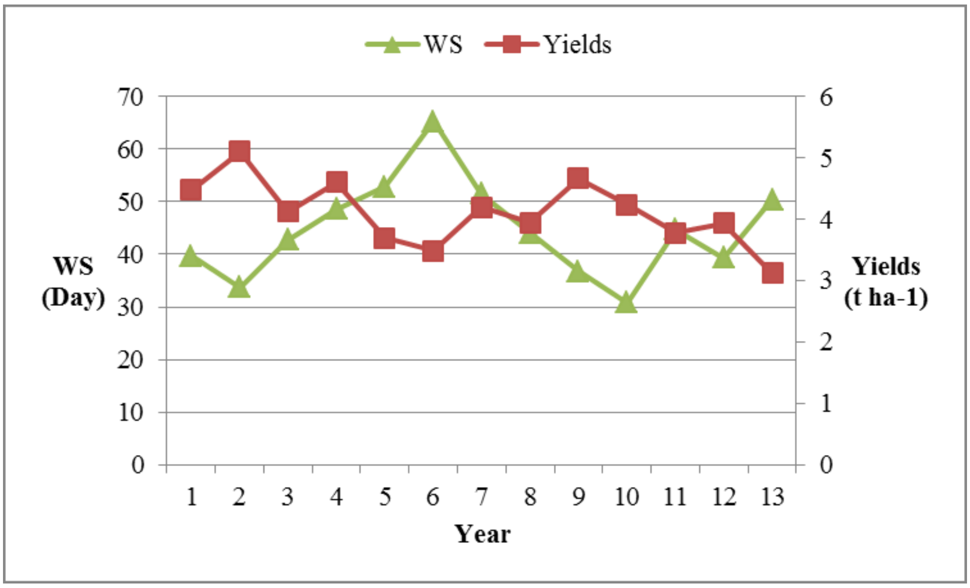


Graphic 6– Relation between average Growing Seasonal Precipitation and crop yields under future climatic conditions.

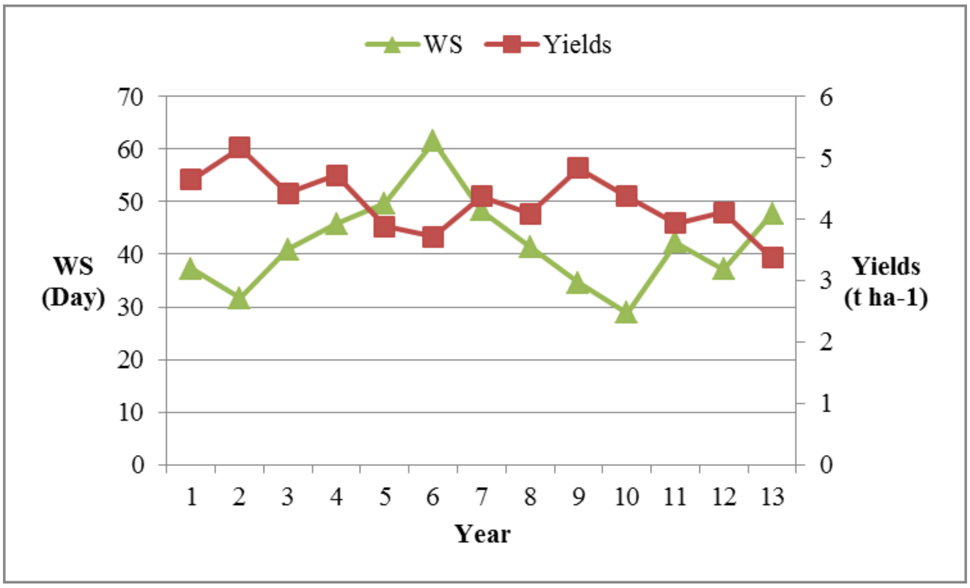
Considering GSP, baseline scenario showed an average of 403.7 mm, almost similar to future scenario, with 406 mm observed. GSP ranged from 296.5 to 549.5 mm in CP, while from 305.2 to 545.8 mm in CF. In % values, the small increase of 1 % was observed in the CF, ranging from 1.5 to 3.7 %. Also CV and dev.st. were higher in the CP respect to CF: 0.18 and 71.3 respectively in the fist case, and 0.16 and 66.7 in the second case. Results are also showed in Graphic 5 and 6.

Water Stress

In contrast with ET, future water stress increased, with a increasing of 5,8 % (range from 4.48 to – 6.15 %). In fact under baseline climatic condition resulted higher than under future climatic conditions: in CP the average was 44.6 day while in CF was 42.08 day. Also the range changed, so in first situation ET was in the interval 30.8 and 65.2, while in the future from 28.9 to 61.47 day. The CV is egual in the same conditions. The correlation of Pearsons as result of comparison enter CP and CF was 0.99 (P<0.001). Results are also showed in Graphic 7 and 8.



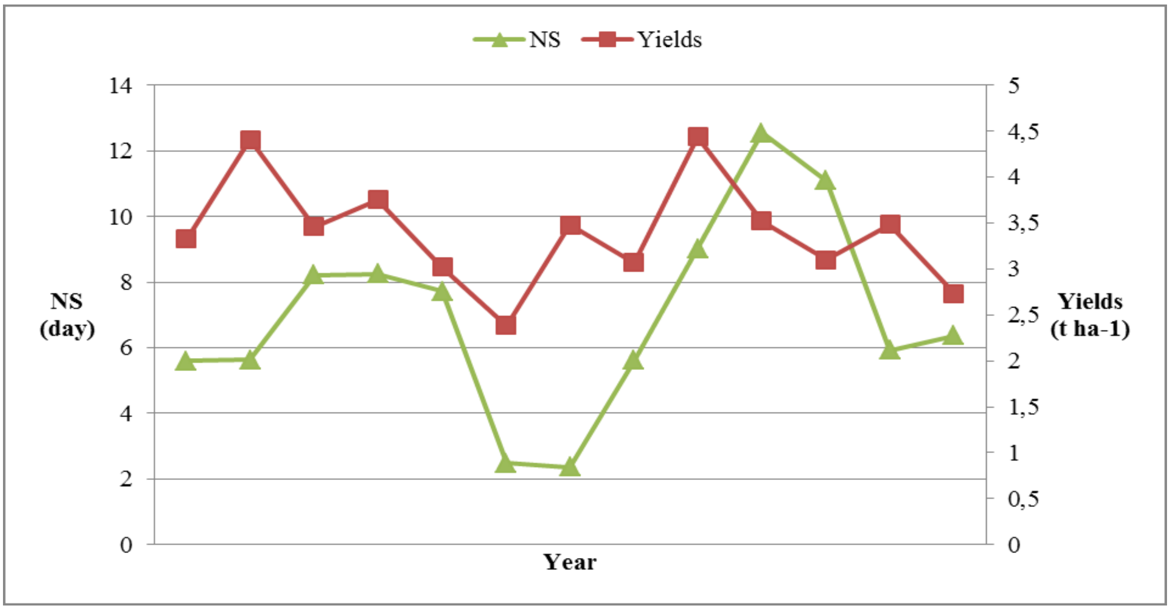
Graphic 7 – Relation between average Growing Seasonal Precipitation and crop yields under climatic baseline conditions.



Graphic 8 – Relation between average Water Stress and crop yields under future climatic conditions.

Nitrogen stress

Future nitrogen stress increased, with a increasing of 1.35 % (range from -5.7 to + 9.6 %). In fact under baseline climatic condition resulted slightly lower than under future climatic conditions: in CP the average was 7,05 days while in CF was7.11 days. Also the range changed, so in first situation NS was in the interval 4.03 and 11.09 days, while from 4.25 to 11.4 days in the second case. If consider CV, it was very similar and passed from 0.30 to 0.29. The correlation of Pearsons as result of comparison enter CP and CF was 0.40 (P<0.001). Results are also showed in Graphic 9 and 10.



Graphic 9– Relation between Nitrogen Stress and crop yields under climatic baseline conditions.

Graphic 10– Relation between Nitrogen Stress and crop yields under climatic future conditions.

3.2 Climate change effects with different CO_2 concentrations and any crop stress

The second set of results was obtained considering:

- climatic baseline condition with a concentration of CO_2 in the amount of 378 ppm;
- climatic future condition with a concentration of CO_2 in the amount of 408 ppm;
- water and nitrogen stress imposed (autoirrigation and autofertlization with one value).

3.2.1 Oristano

Impacts of climate change on yield

The simulated average durum wheat yield for the baseline period was 3.47 t/ha, with a CV of 0.33, and ranged from 2.18 to 5.3 t/ha, while under future climate conditions was 2.76 t/ha, with a CV of 0.29, and ranged from 1.22 to 4.25 t/ha, showing a decrease of - 18% (ranging from -46.8 % to + 27.1 %), respect baseline conditions. Considering the two series of data, the Pearson's correlation coefficient was 0.70 ($p<0.001$). Results are also showed throught the box plot in Figure 1.

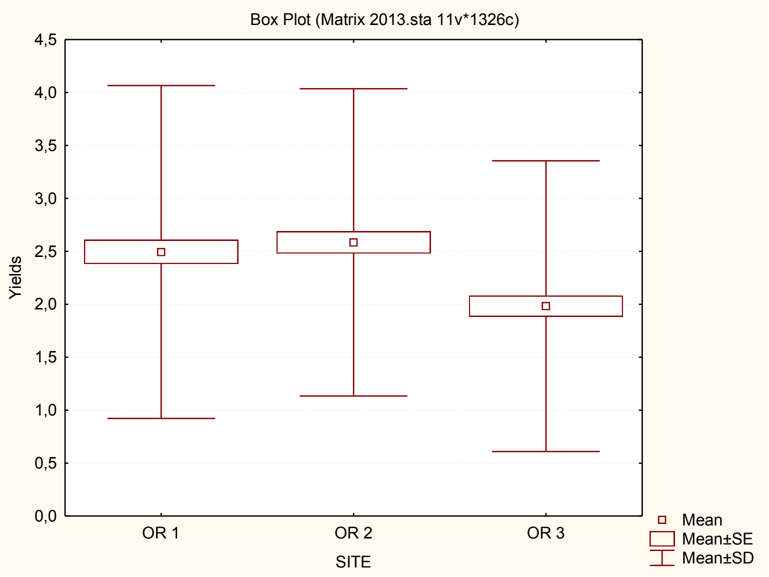


Figure 1– Durum wheat yields under baseline and future climate in Oristano site.

Water Use Efficiency

Considering the Water Use Efficiency, there was a decrease in the future of 23.2 % respect to the baseline conditions, with a range from – 44.13 to – 4.4 %. Analysis of interannual variability under baseline condition indicated an average WUE of 19.9 kg biom/mm H_2O and a range from 7.13 to 17.45 kg biom/mm H_2O. Under future climate, the average WUE was 9.30 kg mm^{-1} ha $^{-1}$, and it ranged from 5.64 to 17.3 kg biom/mm H_2O. Comparison of values under the two climatic scenarios showed a Pearson's correlation coefficient of 0.78 ($p < 0.001$). Figure 2 and 3 showed the correlation between Yields and WUE in the baseline and future conditions respectively. Results are also showed in Graphic 1 and 2.

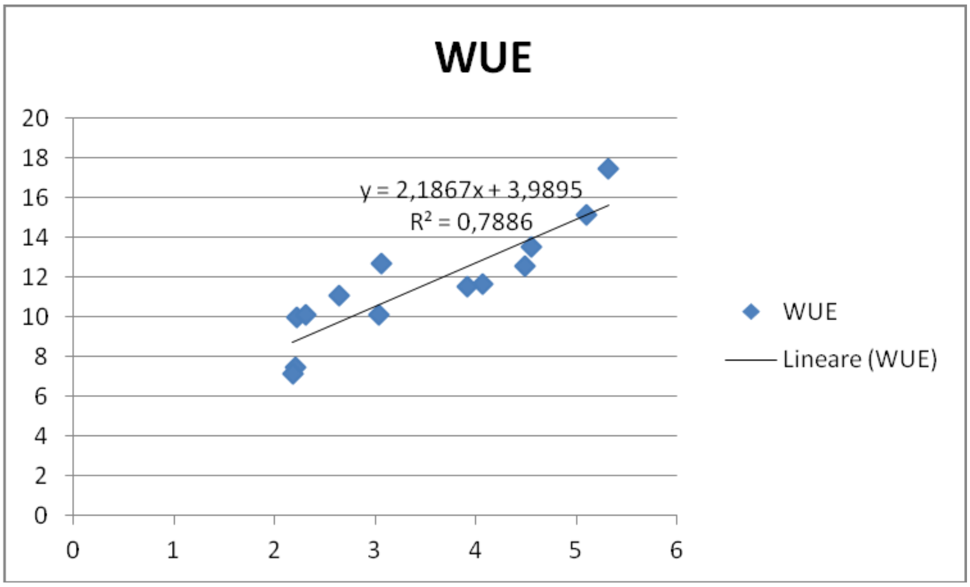


Figure 2– Correlation between crop and WUE under climatic baseline conditions

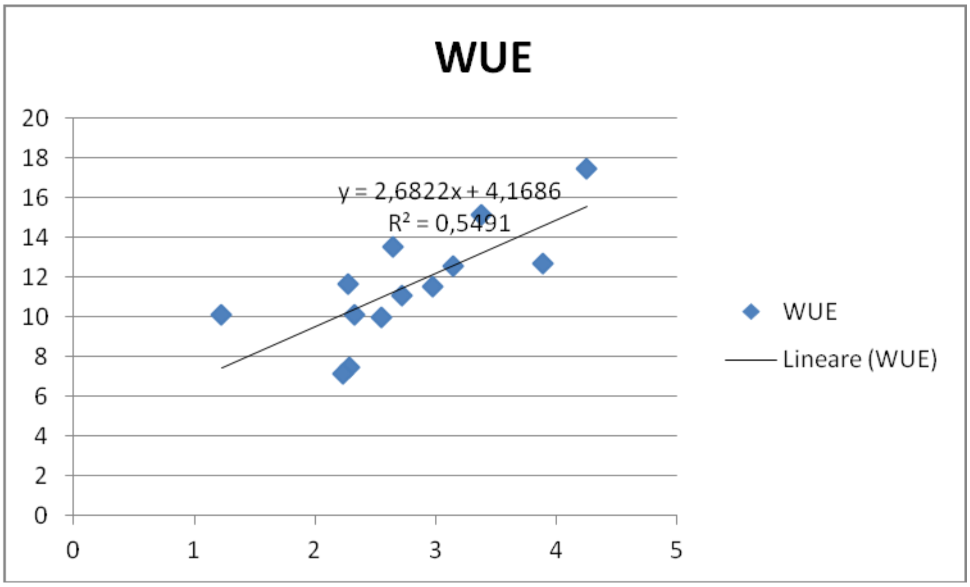
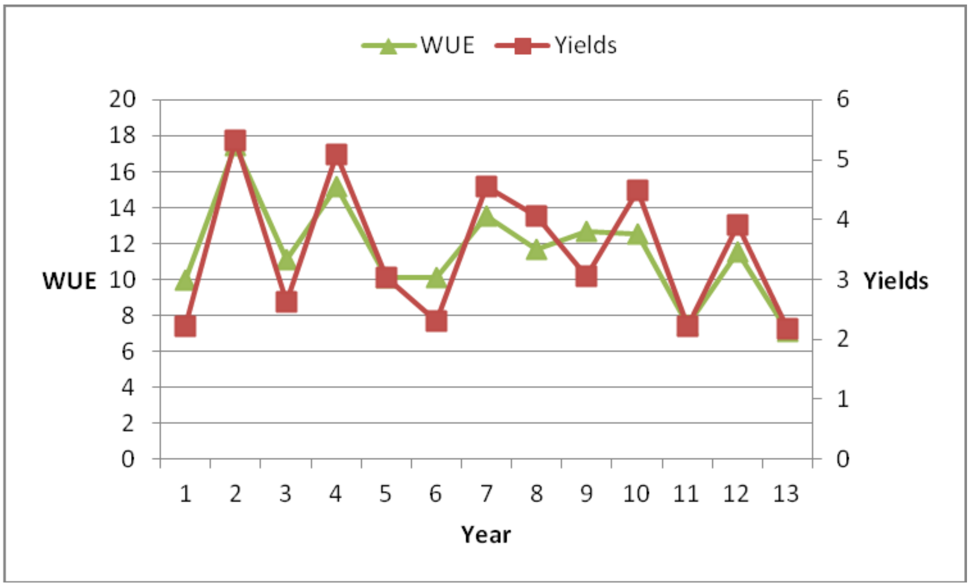
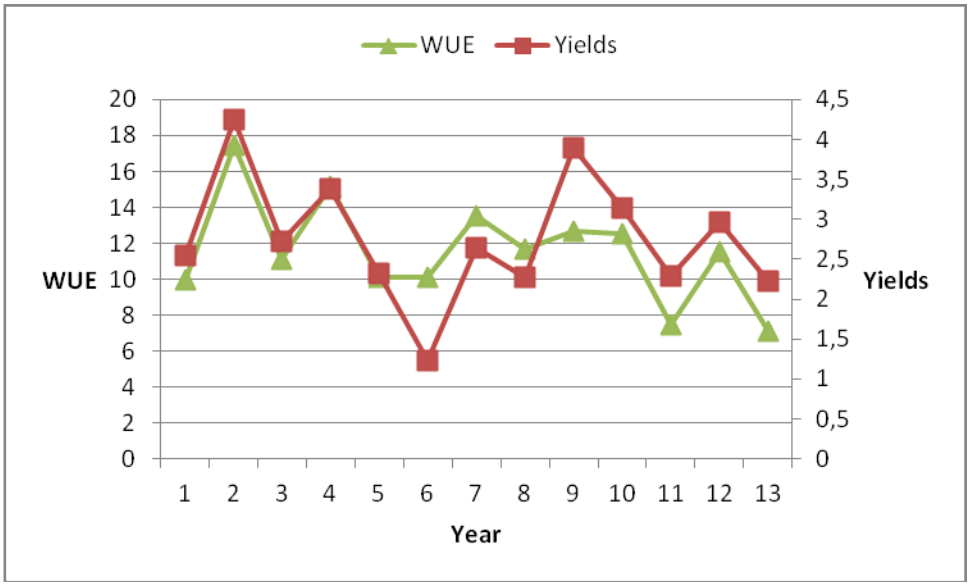


Figure 3– Correlation between crop yields and wue under climatic future conditions



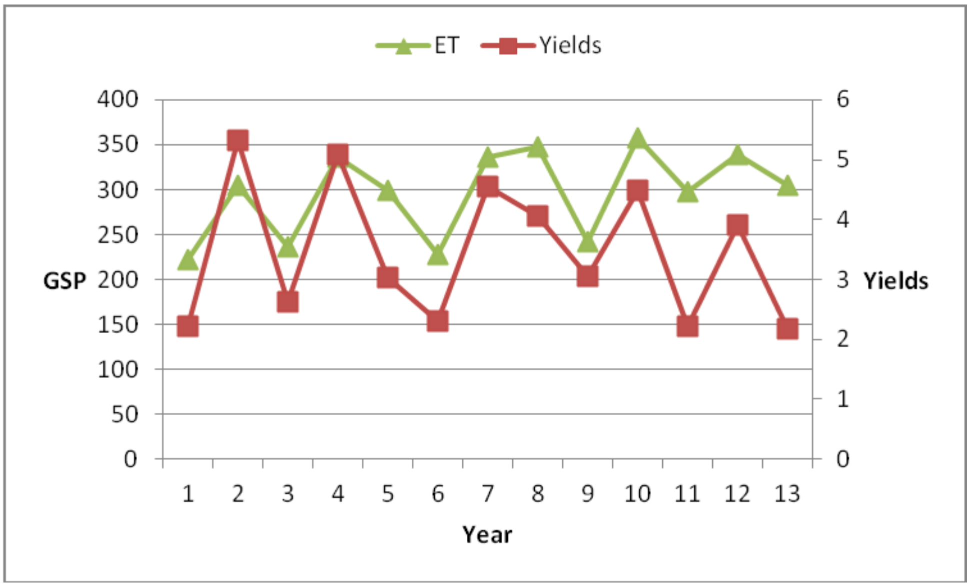
Graphic 1– Relation between average Water Use Efficiency and crop yields under climate baseline conditions.



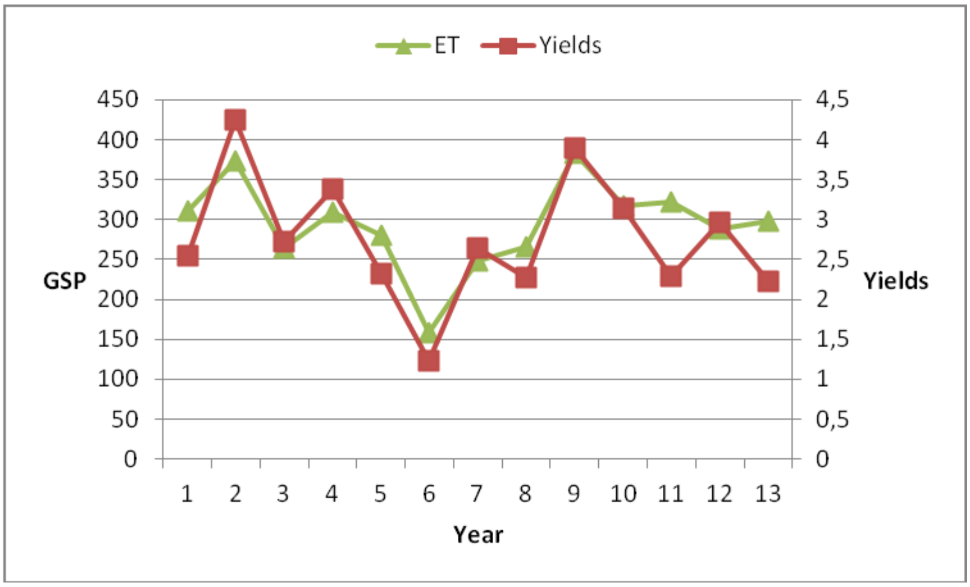
Graphic 2 – Relation between average Water Use Efficiency and crop yields under climate future conditions.

Evapotranspiration

Deviations between baseline climate and future have been observed also for Evapotranspiration. Under baseline climatic conditions average ET was 296 mm, with a CV of 0.16 , and a range from 222.5 to 357.6 mm. Respect to the previous conditions, future ET, with an average of 293 mm, increased of 1.5 % (- 30.5 to + 58.9) and ranged from 158.5 to 383.8 mm, with a CV of 0.19. Comparison of values under the two climatic scenarios showed a Pearson's correlation coefficient of 0.20 ($p < 0.44$). Analysis among wheat yields and evapotranspiration showed a higher correlation under future climate ($R^2 = 0.67$). Results are also showed in Graphic 3 and 4.

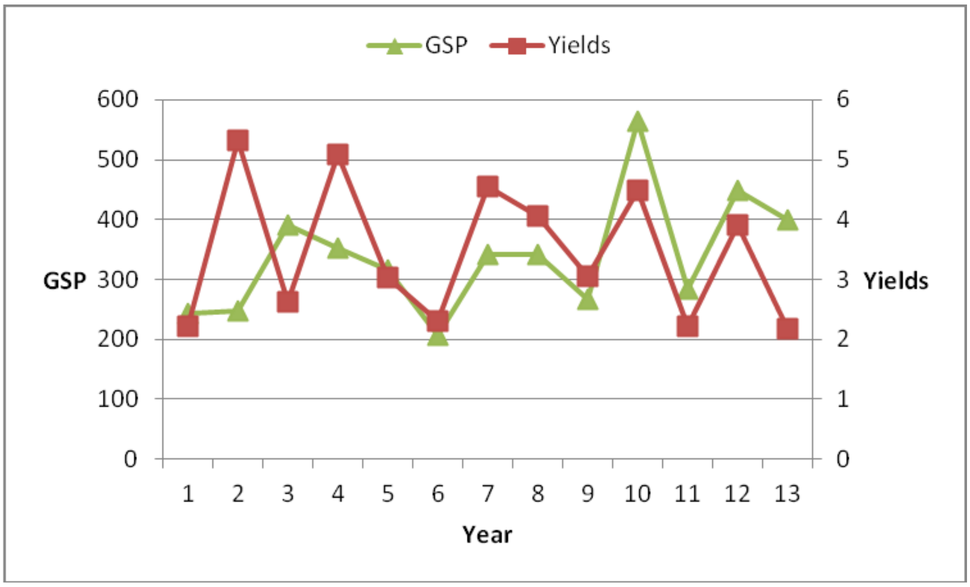


Graphic 3 – Relation between average Evapotranspiration and crop yields under climate baseline conditions.

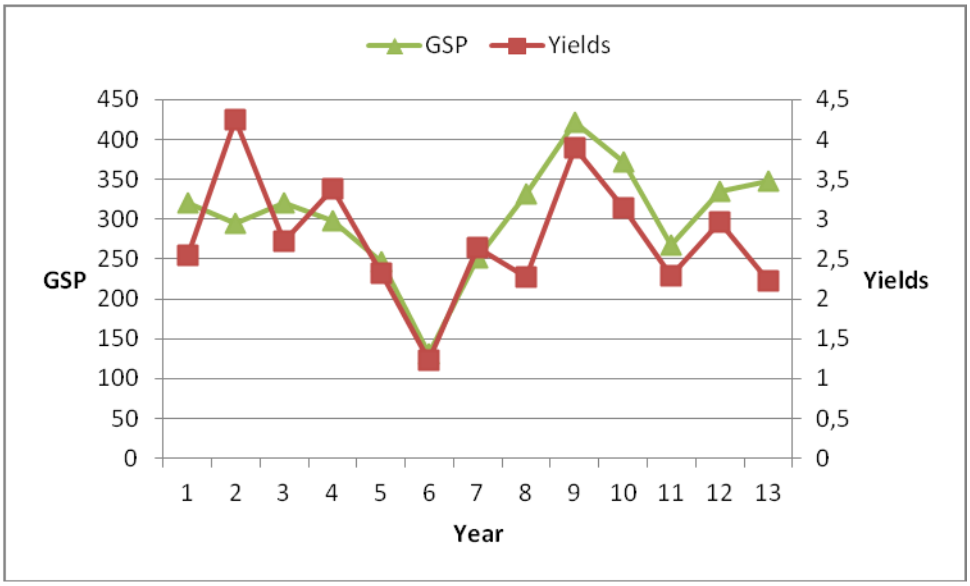


Graphic 4 – Relation between average Evapotranspiration and crop yields under climate future conditions.

Changes in Growing Season Precipitation



Graphic 5 – Relation between average Water Use Efficiency and crop yields under climate baseline conditions.

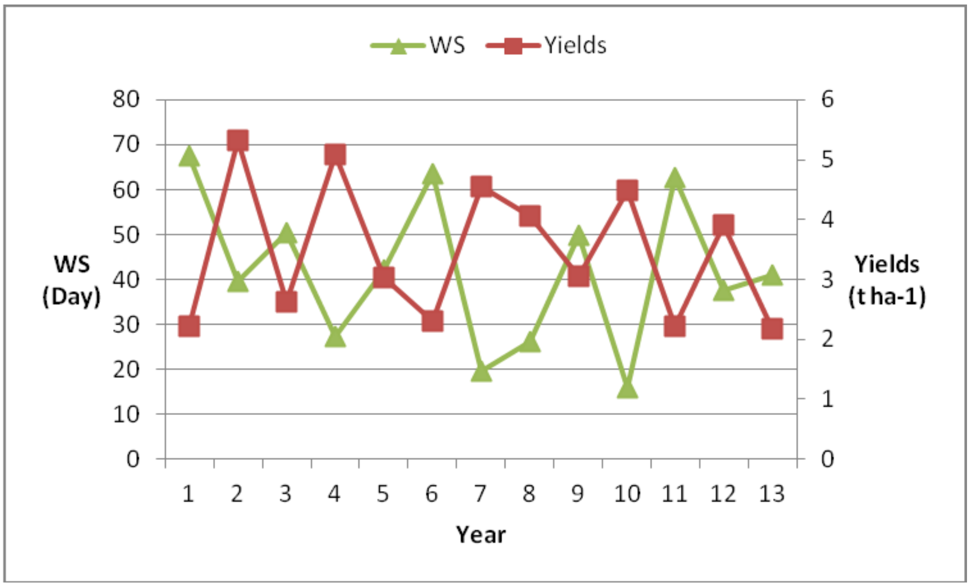


Graphic 6 – Relation between average Water Use Efficiency and crop yields under climate future conditions.

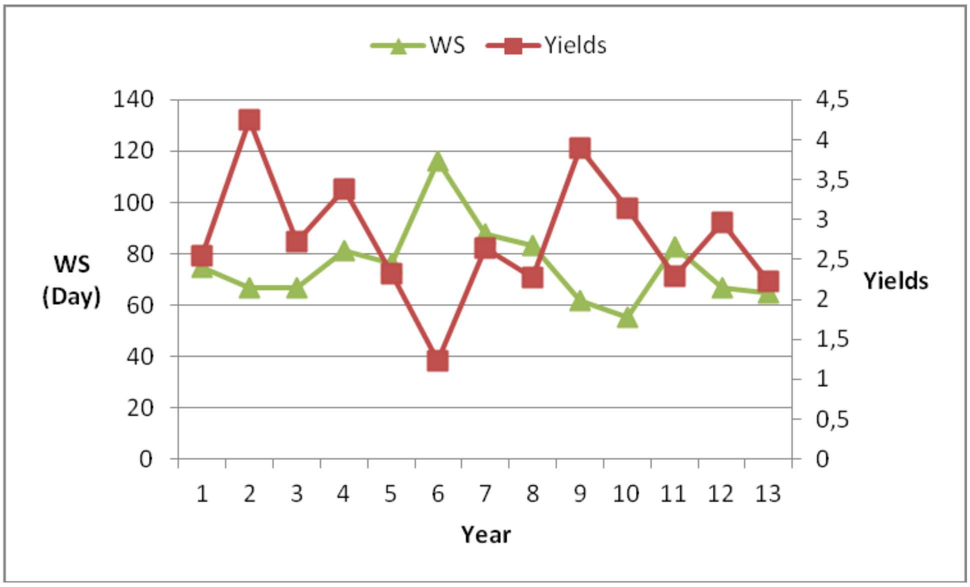
Considering GSP, baseline scenario showed an average of 338.5 mm, slightly higher respect to future scenario, when 309 mm were observed. GSP ranged from 206.2 to 563.8 mm in CP, while from 130.34 to 421.9 mm in CF, as showed in first step of results for the same site. In % values, a decrease of about 0.06 % was observed in the CF, ranging from – 0.37 to + 0.58 %. Also CV and dev.st. were higher in the CP respect to CF: 0.29 and 97.3 respectively in the first case, and 0.23 and 71 in the second case. Results are also showed in Graphic 5 and 6.

Water Stress

According to ET, future water stress increased, with an average increasing of 118 % (range from 10.3 to 348 %). In fact under baseline climatic condition resulted lower than under future climatic conditions: in CP the average was 41.8 days while in CF was 75.7 days. Also the range changed, so in first situation WS was in the interval 16 and 67.6 days, while from 55.45 to 116.3 days. If consider CV passed from 0.41 to 0.21. The correlation of Pearsons as result of comparison enter CP and CF was 0.40 (P<0.001). Also in this case, the results were the same showed in the first set of results. Results are also showed in Graphic 7 and 8.



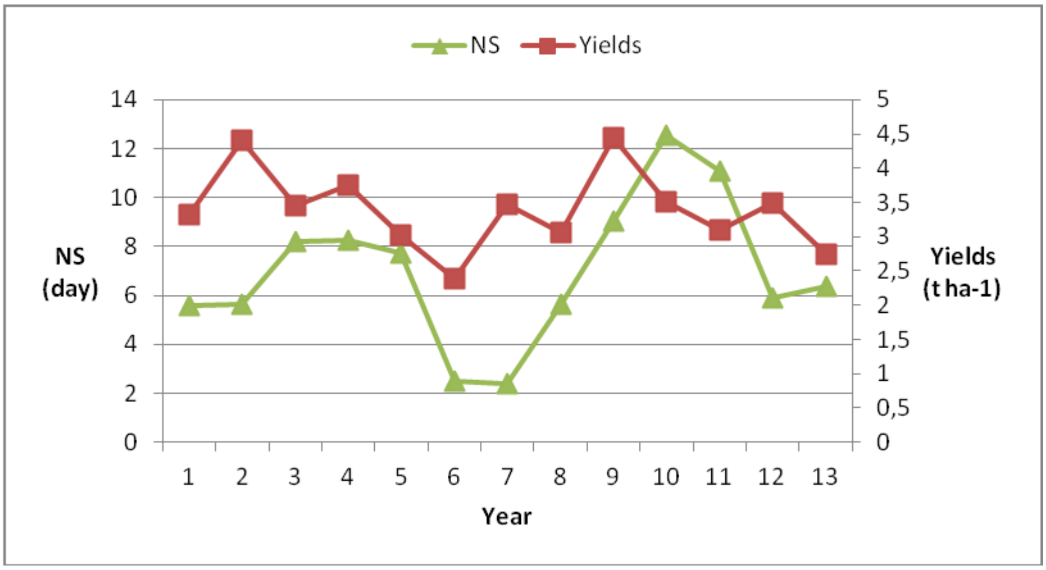
Graphic 7– Relation between average Water Stress Day and crop yields under climate baseline conditions.



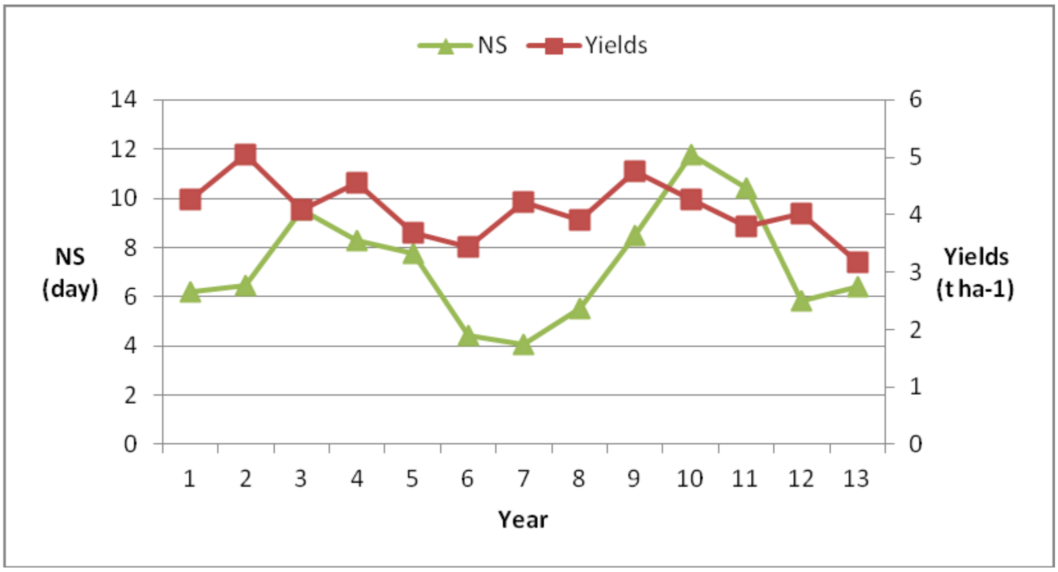
Graphic 8– Relation between average Water Stress Day and crop yields under climate future conditions.

Nitrogen stress

Future nitrogen stress decreased, with a decreasing of 6 % (range from -52 to + 146 %). In fact under baseline climatic condition resulted slightly higher than under future climatic conditions: in CP the average was 11.2 days while in CF was 9.18 days. Also the range changed, so in first situation NS was in the interval 2.83 and 19.8 days, while from 2.5 to 16.5 days in the second case. If consider CV, it decreased from 0.49 to 0.43. The correlation of Pearsons as result of comparison enter CP and CF was 0.40 (P<0.001). Results are also showed in Graphic 9 and 10.



Graphic 9 – Relation between Nitrogen Stress and crop yields under climatic baseline conditions.



Graphic 10 – Relation between Nitrogen Stress and crop yields under climatic future conditions.

3.2.2 Benevento

Impacts of climate change on yields

The simulated average durum wheat yield for the baseline period was 3.4 t/ha, with a CV of 0.16, and ranged from 2.5 to 4.4 t/ha, while under future climate conditions was 4 t/ha, with a CV of 0.13, and ranged from 3.1 to 5 t/ha, showing an increase of 18% (ranging from 6 % to + 33 %), respect baseline conditions. Considering the two series of data, the Pearson's correlation coefficient was 0.94 ($p<0$). Results are also showed throught the box plot in Figure and were similar with the first set of results for the same site. Results are also showed in Graphic 1 and 2. Results are also showed throught the box plot in Figure 1.

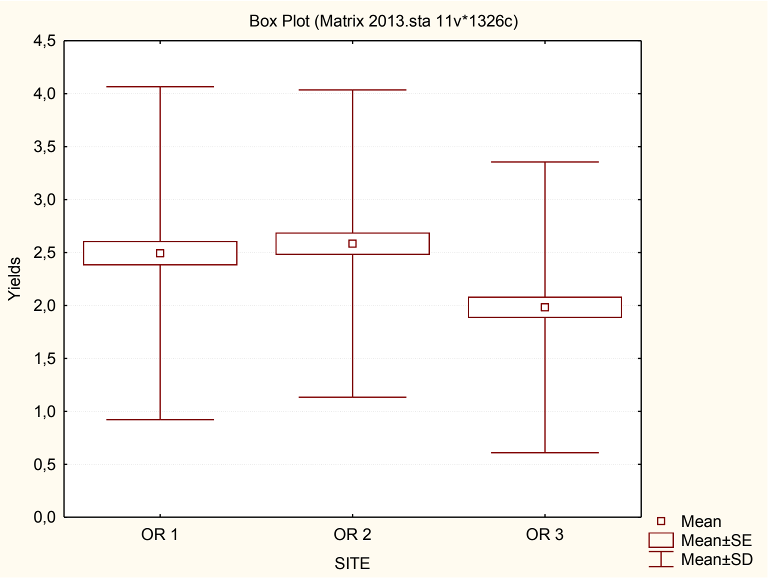
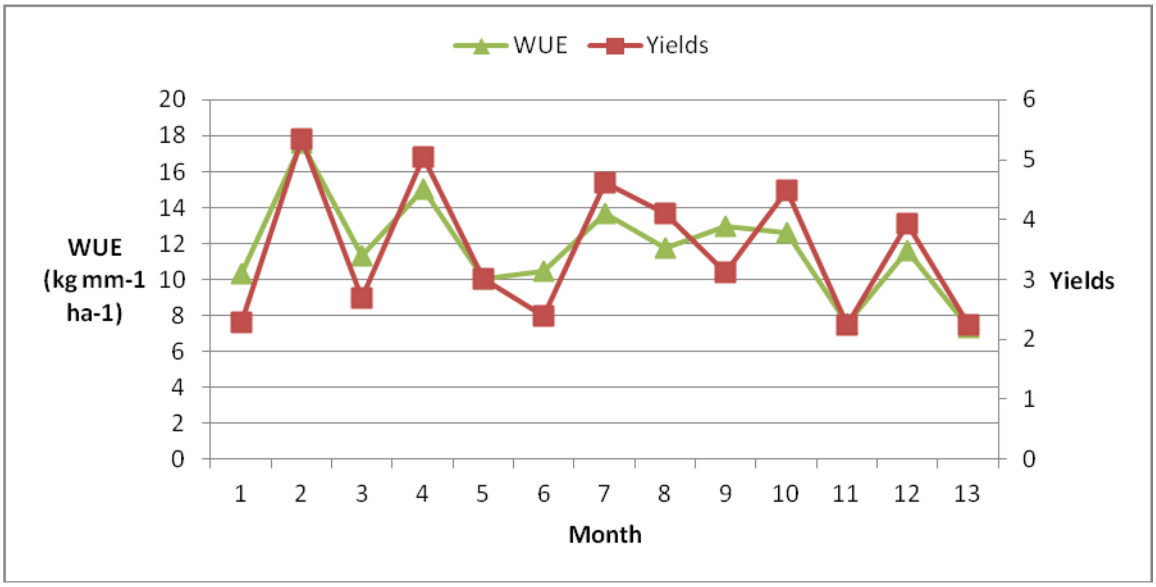


Figure – Durum wheat yields under baseline and future climate in Benevento site.

Water Use Efficiency

Considering the Water Use Efficiency, there was an increase in the future of 6.3 % respect to the baseline conditions, with a range from – 0.15 to 13.1 %. Analysis of interannual variability under baseline condition indicated an average WUE of 10.14 kg biom/mm H_2O and a range from 8.2 to 12.4 kg biom/mm H_2O. Under future climate, the average WUE was 10.73 kg biom/mm H_2O , and it ranged from 8.4 to 13.25 kg biom/mm H_2O. Comparison of values under the two climatic scenarios showed a Pearson's correlation coefficient of 0.98 ($p< 0.001$). The same results were showed in the first set of results. Figure 2 and 3 showed the correlation between Yields and WUE in the baseline and future conditions respectively. Results are also showed in Graphic 1 and 2.



Graphic 1– Relation between average Water Use Efficiency and crop yields under climate baseline conditions.

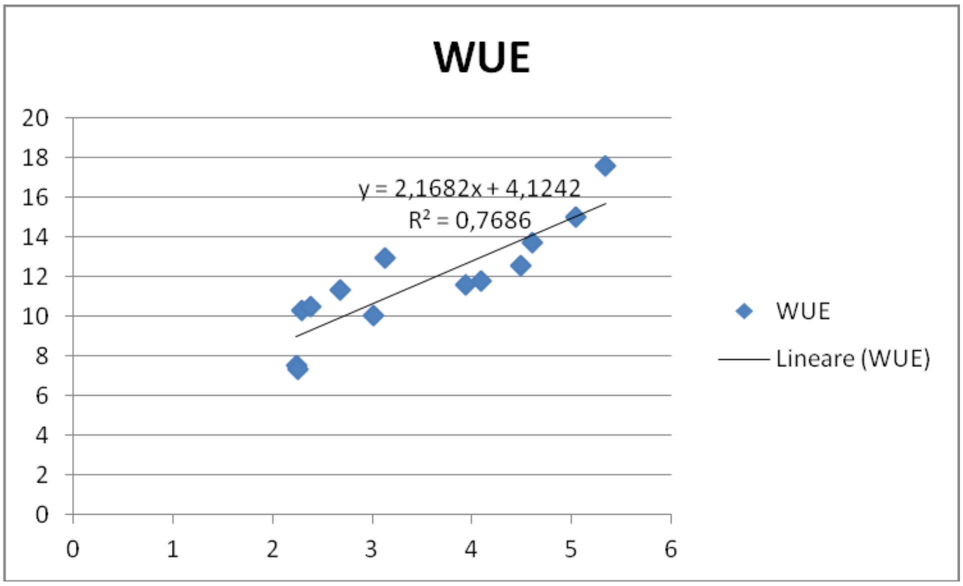


Figure 2– Correlation between crop yields and WUE under climatic baseline conditions

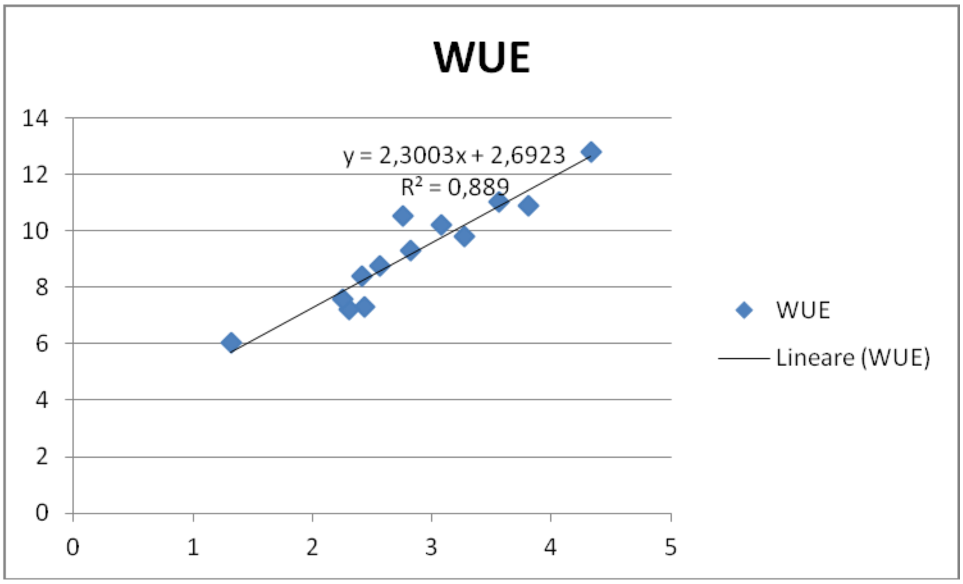
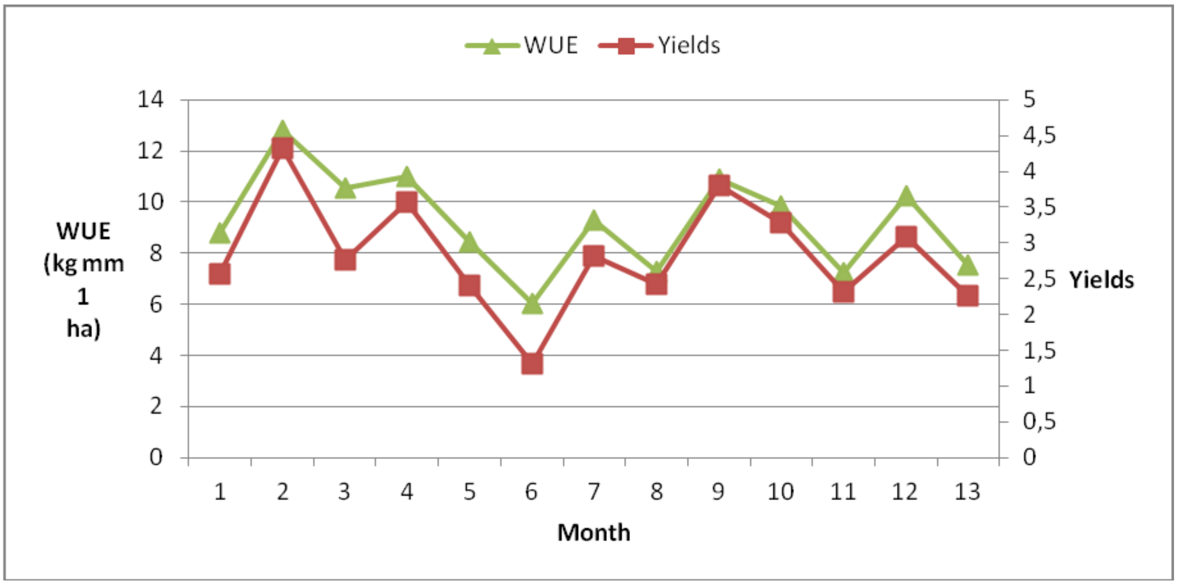


Figure 3– Correlation between crop yields and wue under climatic future conditions



Graphic 2 – Relation between average Water Use Efficiency and crop yields under climate future conditions.

Evapotranspiration

Deviations between baseline climate and future have been observed also for Evapotranspiration. Under baseline climatic conditions average ET was 318,8 mm, with a CV of 0.13, and a range from 219.7 to 396.6 mm. Respect to the previous conditions, future ET, with an average of 354.4 mm, increased of 12 % (3.3-27.5 %) and ranged from 280,3 to 414.2 mm, with a CV of 0.09. Comparison of values under the two climatic scenarios showed a Pearson's correlation coefficient of 0.98 ($p< 0$). Analysis among wheat yields and evapotranspiration show a normal correlation under future climate ($R^2 = 0.46$). this results were very similar with these showed in the first set of results for the same site. Results are also showed in Graphic 3 and 4

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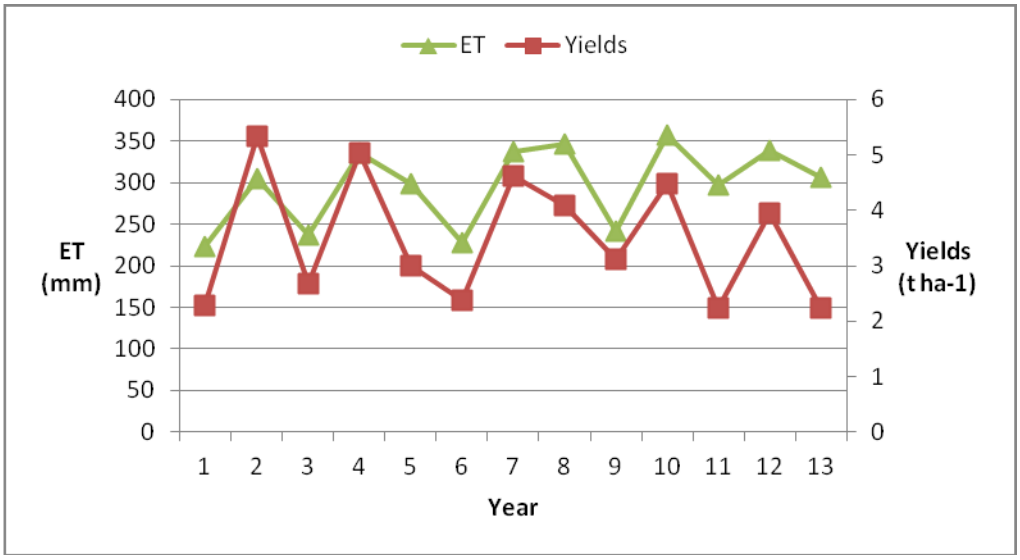
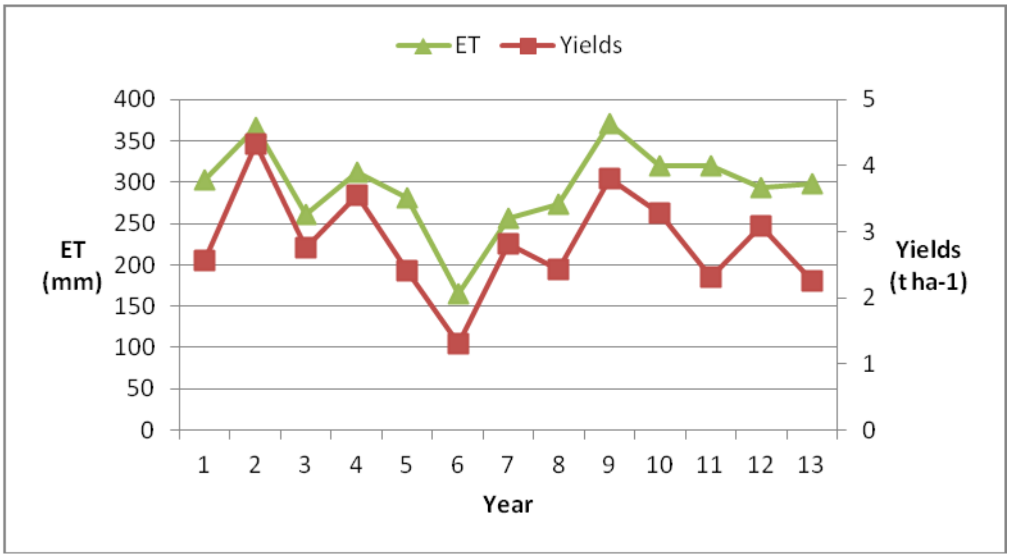
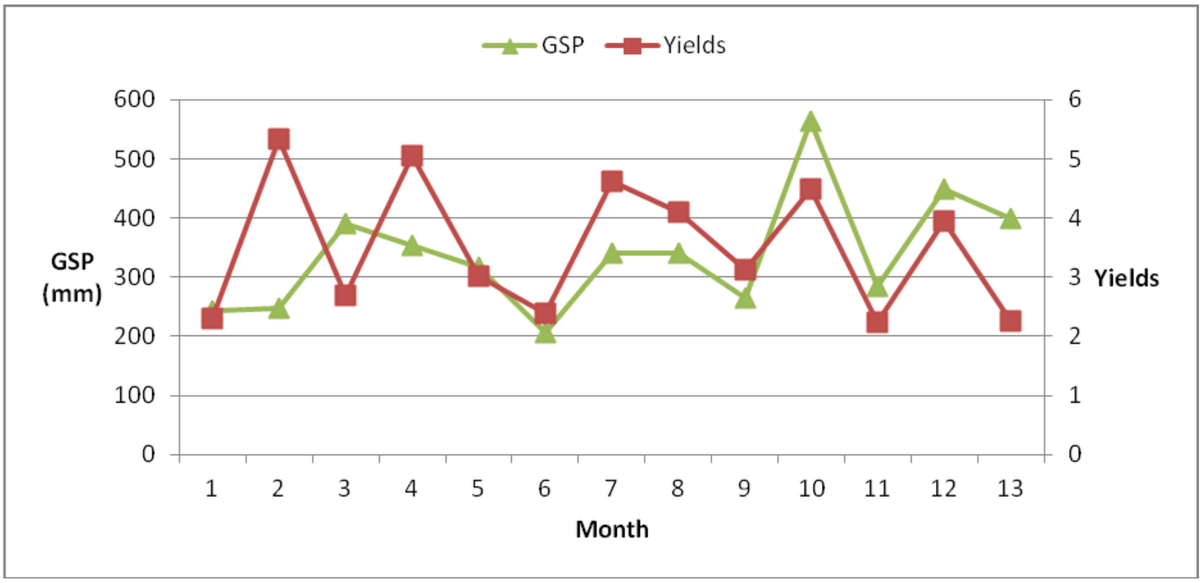


Graphic 3– Relation between average Evapotranspiration and crop yields under climatic baseline conditions.

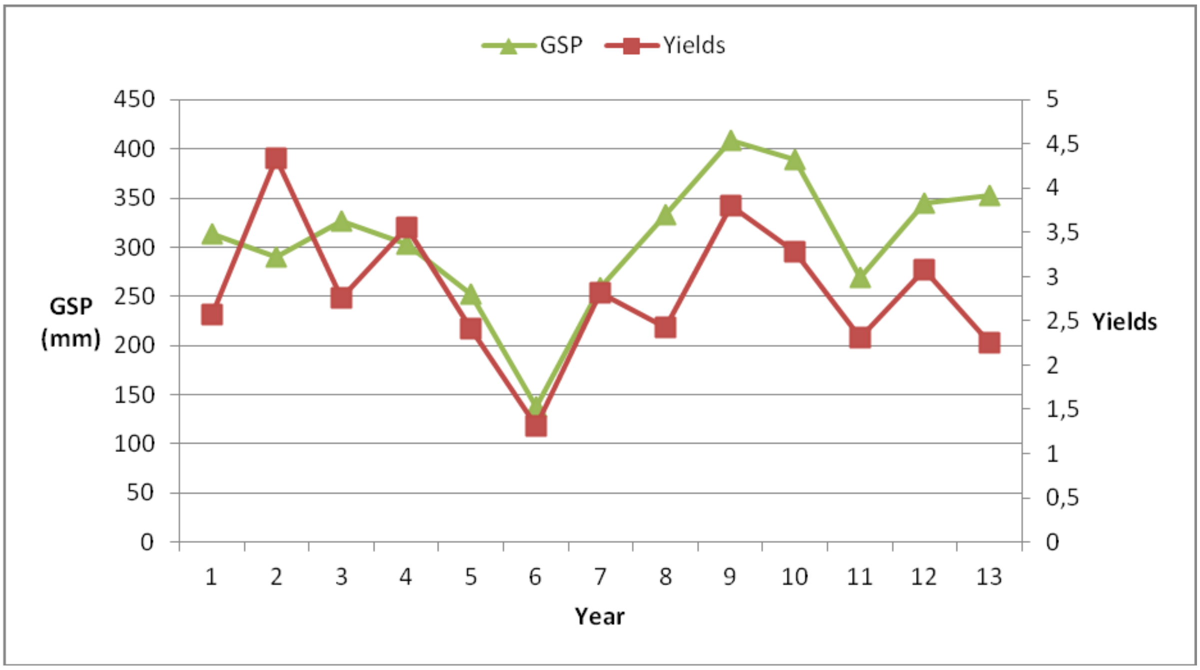


Graphic 4– Relation between average Evapotranspiration and crop yields under climatic future conditions.

Changes in Growing Season Precipitation



Graphic 5– Relation between average Growing Seasonal Precipitation and crop yields under climatic baseline conditions.

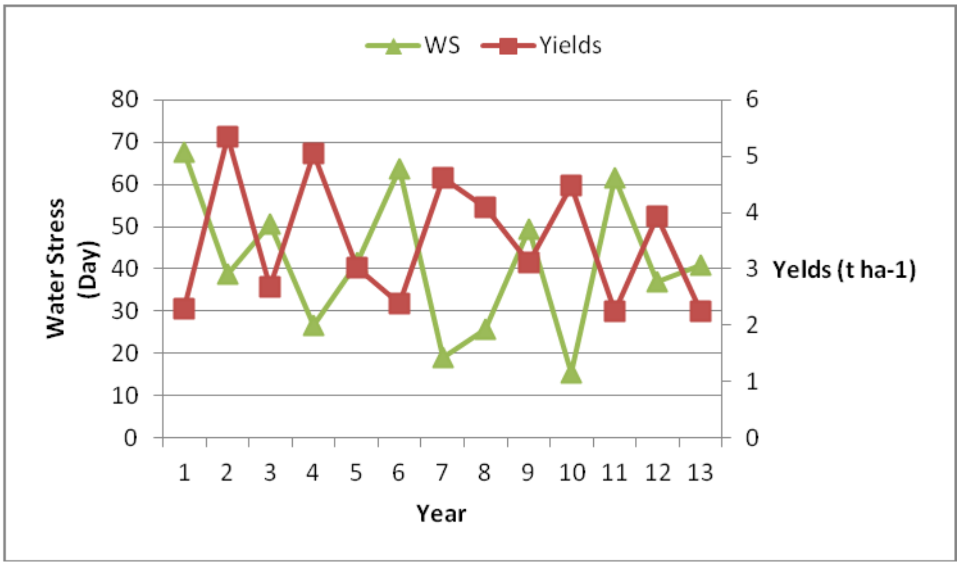


Graphic 6– Relation between average Growing Seasonal Precipitation and crop yields under climatic future conditions.

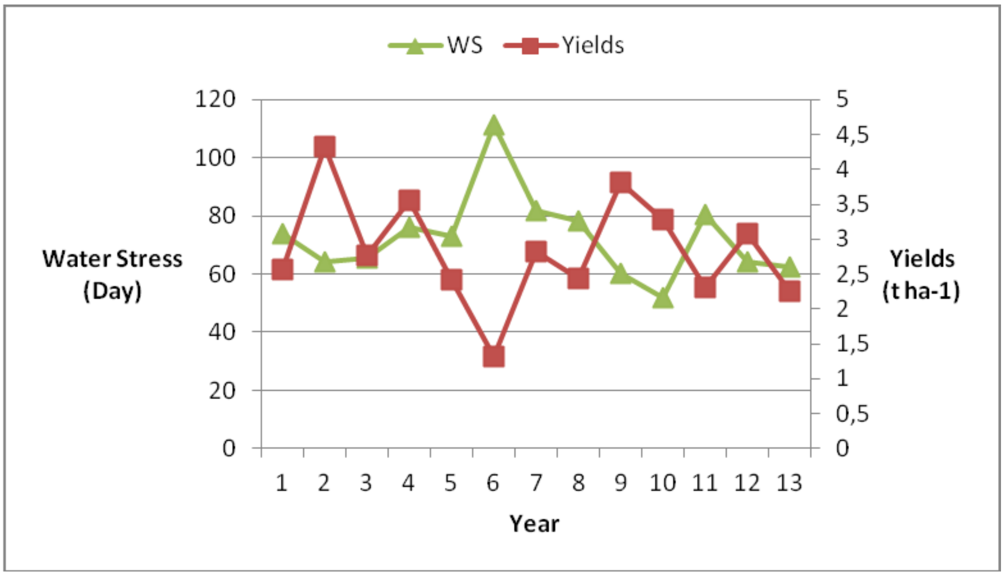
Considering GSP, baseline scenario showed an average of 358 mm, slower respect to future scenario, when 399 mm were observed. GSP ranged from 203.4 to 503.6 mm in CP, while from 286 to 547 mm in CF. In % values, an increase of about 12.6 % was observed in the CF, ranging from + 6 to + 41 %. Instead CV and dev.st. were higher in the CP respect to CF: 0.21 and 76.7 respectively in the fist case, and 0.18 and 73.3 in the second case. The same results were observed in the first set of results for the same site. Results are also showed in Graphic 5 and 6.

Water Stress

According to ET, future water stress decreased, with a decreasing of - 19.5 % (range from - 26 to – 10 %). In fact under baseline climatic condition resulted lower than under future climatic conditions: in CP the average was 57 days while in CF was 46 days. Also the range changed, so in first situation ET was in the interval 41 and 84.5, while from 31.7 to 67.6 day. If consider CV, it is similar for both scenarios (0.20 and 0.19). The correlation of Pearsons as result of comparison enter CP and CF was 0.95 (P<0). Results are also showed in Graphic 7 and 8.



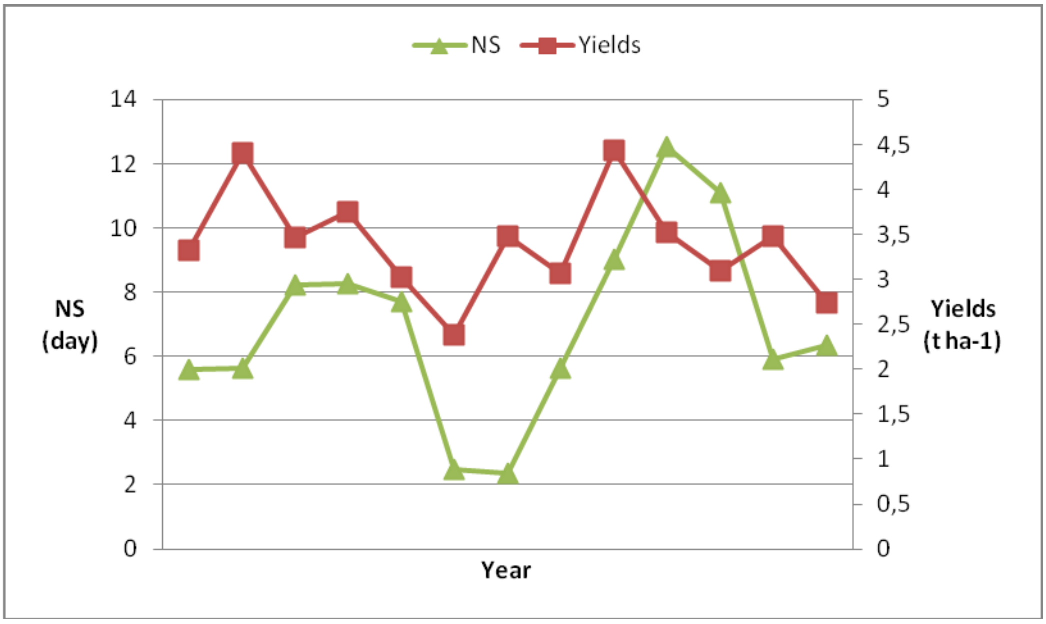
Graphic 7– Relation between Water Stress and crop yields under climatic baseline conditions.



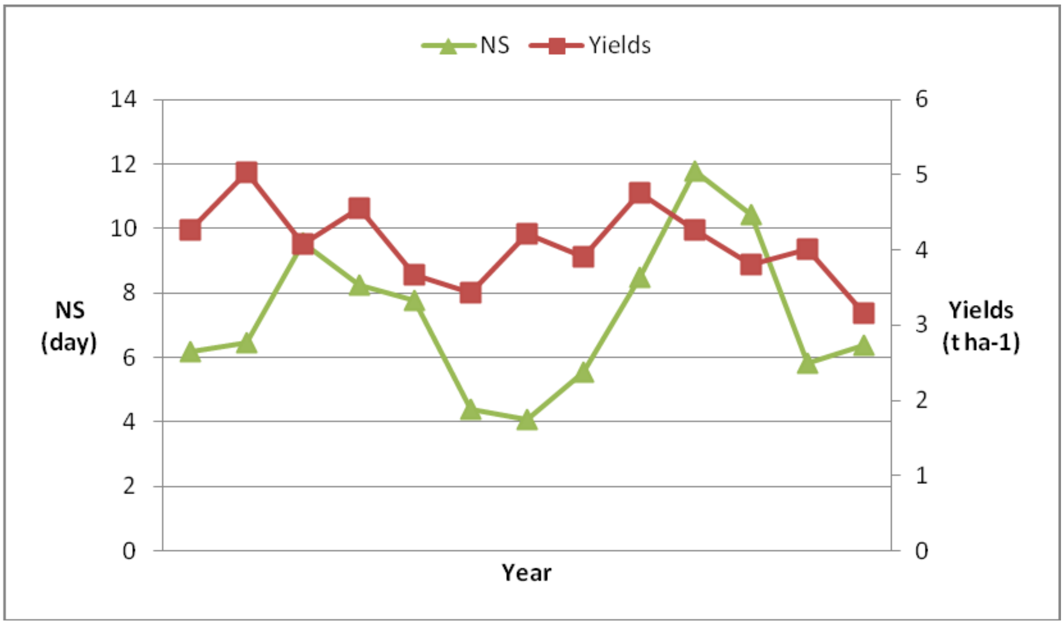
Graphic 8– Relation between average Growing Seasonal Precipitation and crop yields under climatic future conditions.

Nitrogen stress

Future nitrogen stress increased, with a increasing of 16 % (range from – 4.76 to + 79.9 %). In fact under baseline climatic condition resulted slightly higher than under future climatic conditions: in CP the average was 6.6 days while in CF was 7 days. Also the range changed, so in first situation NS was in the interval 2.26 and 12 days, while from 3.9 to 11.4 days in the second case. If consider CV, it decreased from 0.40 to 0.30. The correlation of Pearsons as result of comparison enter CP and CF was 0.40 (P<0.001). Results are also showed in Graphic 9 and 10.



Graphic 9– Relation between Nitrogen Stress and crop yields under climatic baseline conditions.



Graphic 10– Relation between Nitrogen Stress and crop yields under climatic future conditions.

3.2.3 Ancona

Impacts of climate change on yield

The simulated average durum wheat yield for the baseline period was 3.5 t/ha, with a CV of 0.32, and ranged from 2.2 to 5.3 t/ha. while under future climate conditions was 2.84 t/ha, with a CV of 0.28, and ranged from 1.31 to 4.33 t/ha, showing a decrease of 15% (ranging from -21.8% to + 44.9 %), respect to baseline conditions. Considering the two series of data, the Pearson's correlation coefficient was 0.70 ($p<0.001$). Results are also showed throught the box plot in Figure 1.

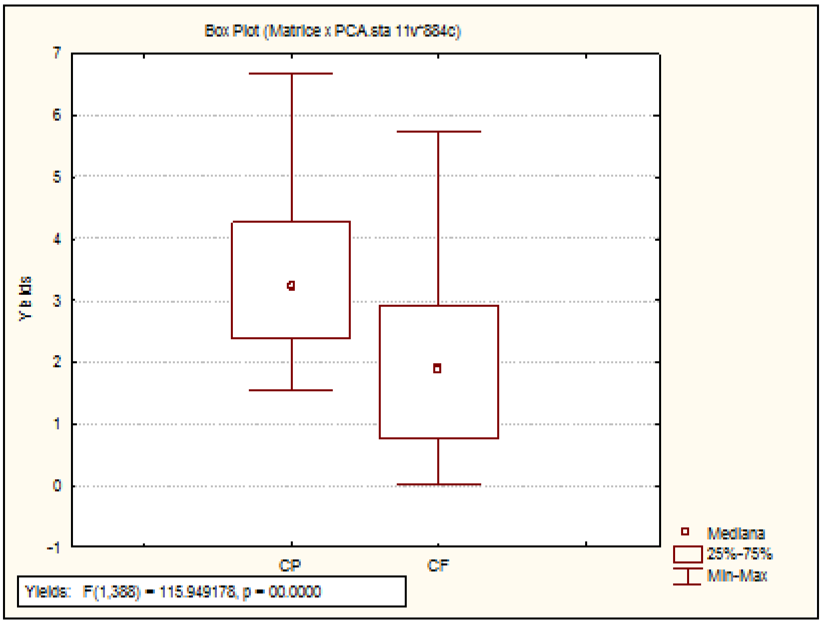


Figure 1 – Durum wheat yields under baseline and future climate in Oristano site.

Water Use Efficiency

Considering the Water Use Efficiency, there was a decrease in the future of 19 % respect to the baseline conditions, with a range from – 42.4 to 2.78%. Analysis of interannual variability under baseline condition indicated an average WUE of 11.71 kg biom/mm H_2O and a range from 7.35 to 17.59 kg biom/mm H_2O. Under future climate, the average WUE was 9.22 kg mm^{-1} ha $^{-1}$, and it ranged from 6.03 to 12.8 kg biom/mm H_2O. Respect to CP, in the CF was registered a minor variation for WUE, that maybe found a stabilization. Comparison of values under the two climatic scenarios showed a Pearson's correlation coefficient of 0.78 ($p< 0.001$). Figure 2 and 3 showed the correlation between Yields and WUE in the baseline and future conditions respectively. Results are also showed in Graphic 4 and 5.

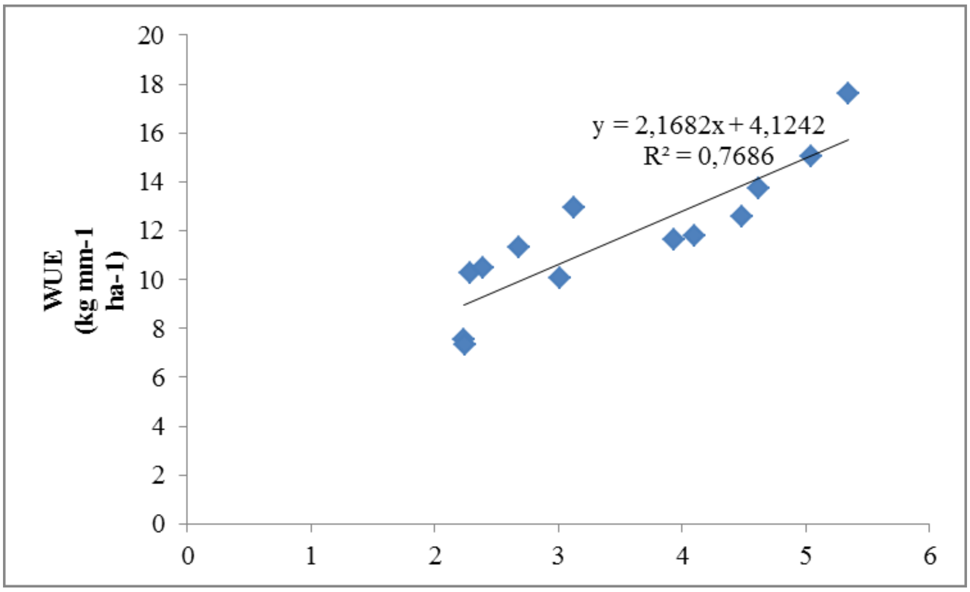


Figure 2 – Correlation between crop and WUE under climatic baseline conditions

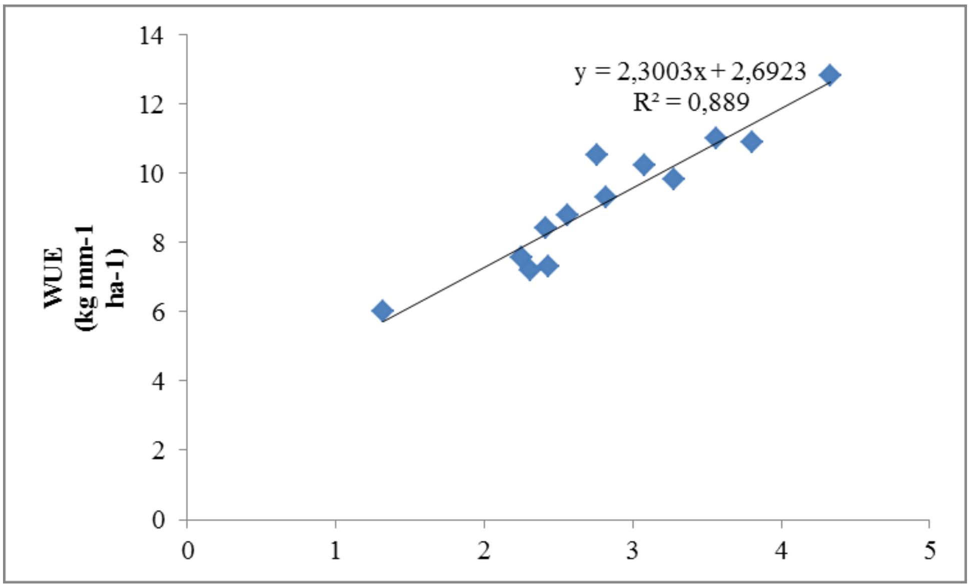
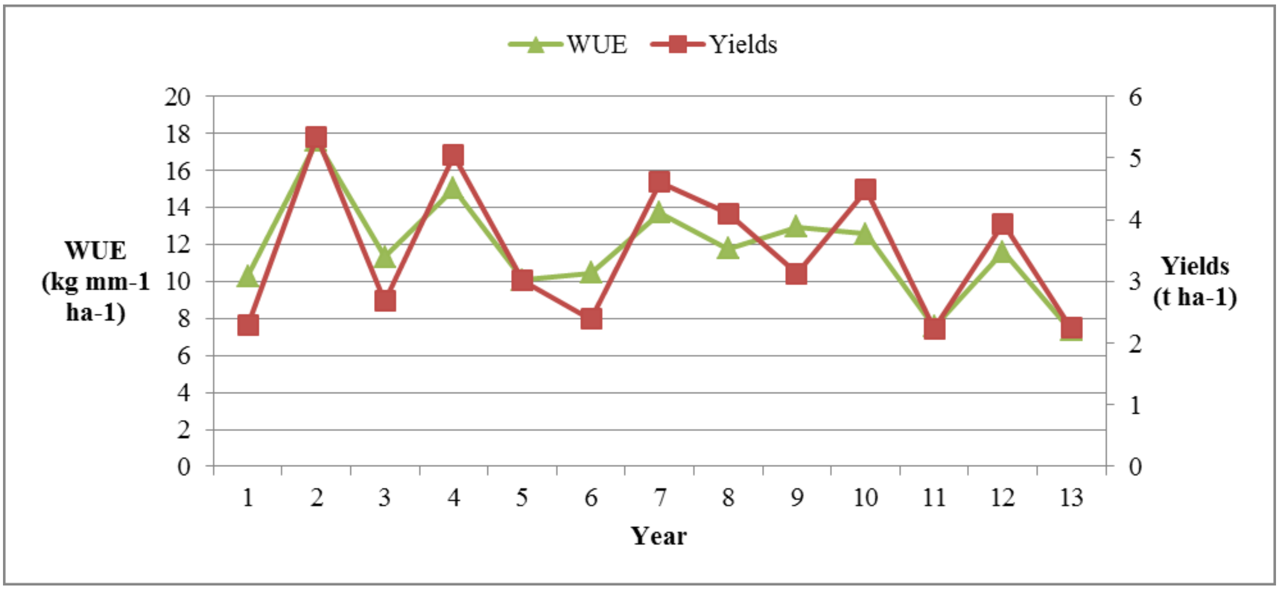
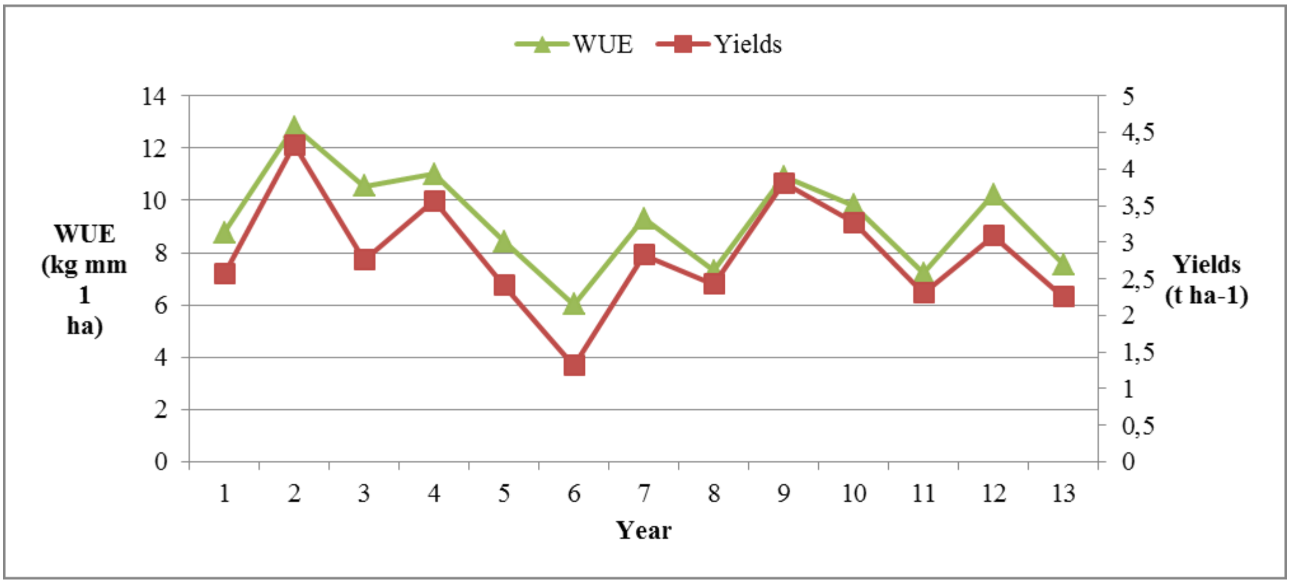


Figure 3 – Correlation between crop yields and wue under climatic future conditions



Graphic 1 – Relation between average Water Use Efficiency and crop yields under climate baseline conditions.



Graphic 2 – Relation between average Water Use Efficiency and crop yields under climate future conditions.

Evapotranspiration

Deviations between baseline climate and future have been observed also for Evapotranspiration. Under baseline climatic conditions average ET was 296,44 mm, with a CV of 0.24 , and a range from 222.47 to 357.17 mm. Respect to the previous conditions, future ET, with an average of 293.8 mm, increased of 1.21 % (-27.7 - + 53.7) and ranged from 164,66 to 371.28 mm, with a CV of 0.17. Comparison of values under the two climatic scenarios showed a Pearson's correlation coefficient of 0.20 ($p< 0.44$). Analysis among wheat yields and evapotranspiration show a higher correlation under future climate ($R^2 = 0.67$). Figure 4 and 5 showed the correlation between Yields and ET in the baseline and future conditions respectively. Results are also showed in Graphic 3 and 4.

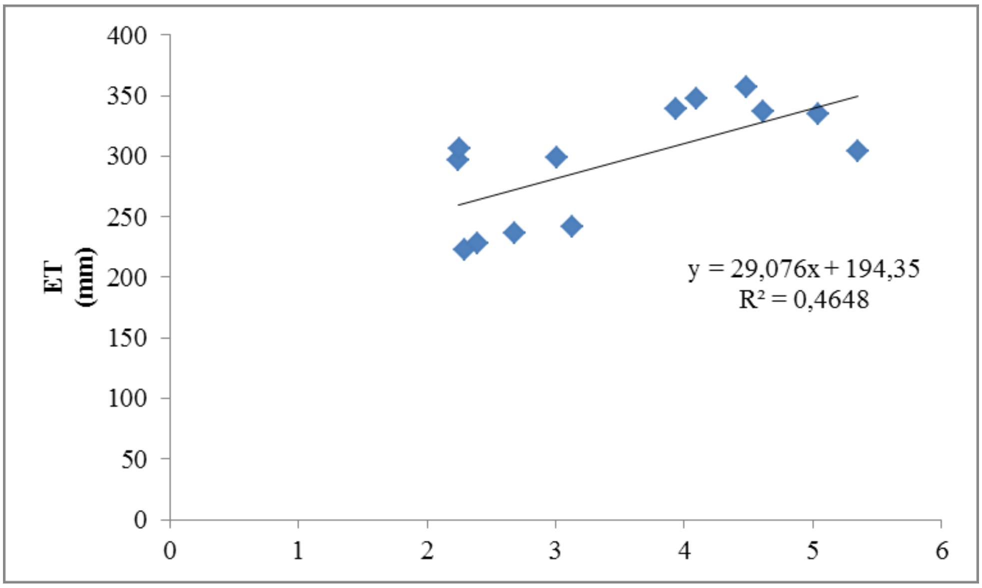


Figure 4 – Correlation between crop and ET under climatic baseline conditions

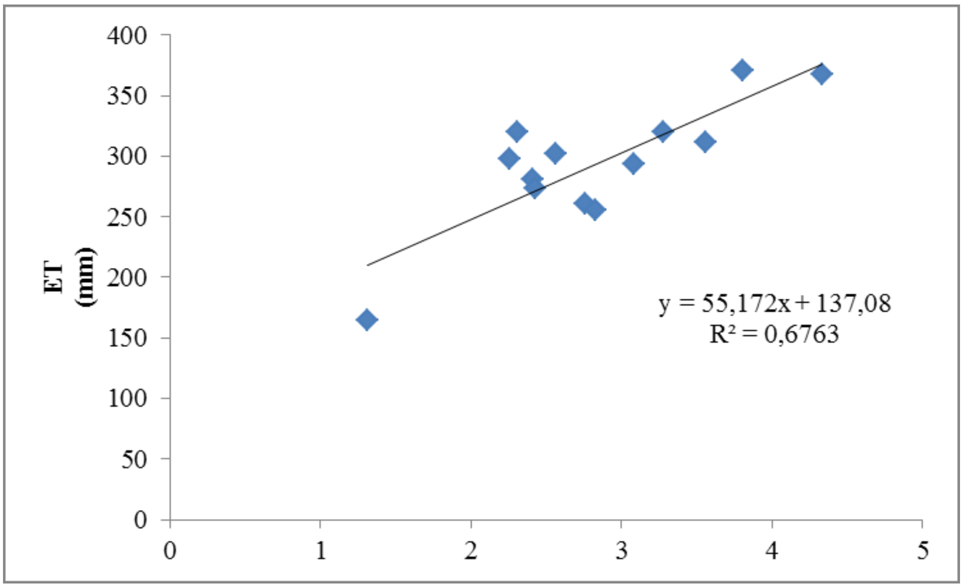
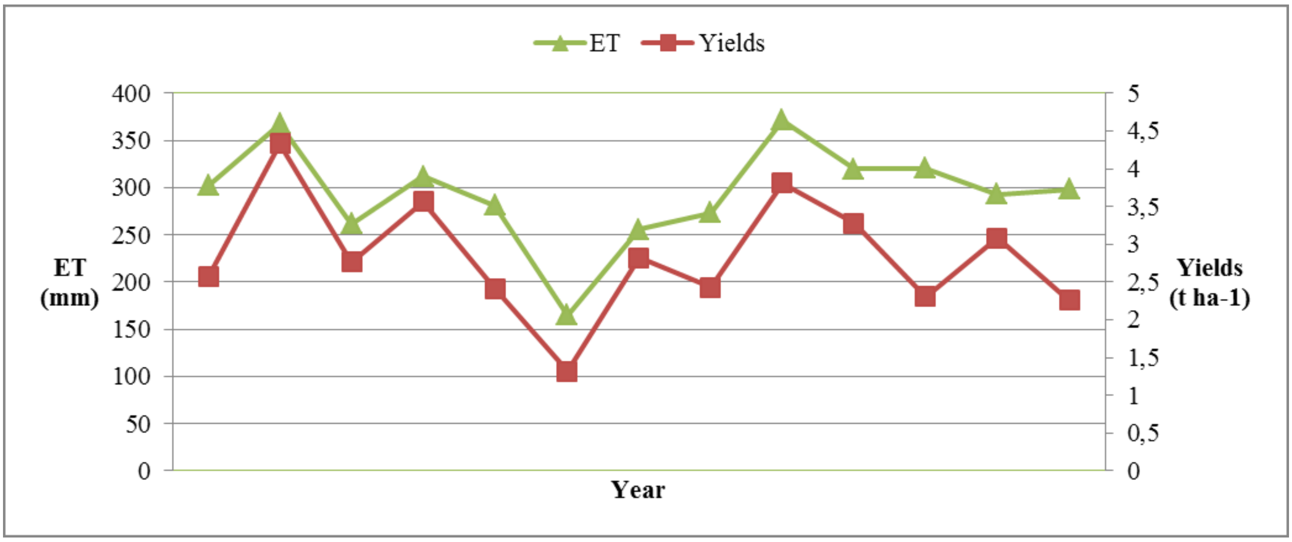


Figure 5 – Correlation between crop and ET under climatic future conditions

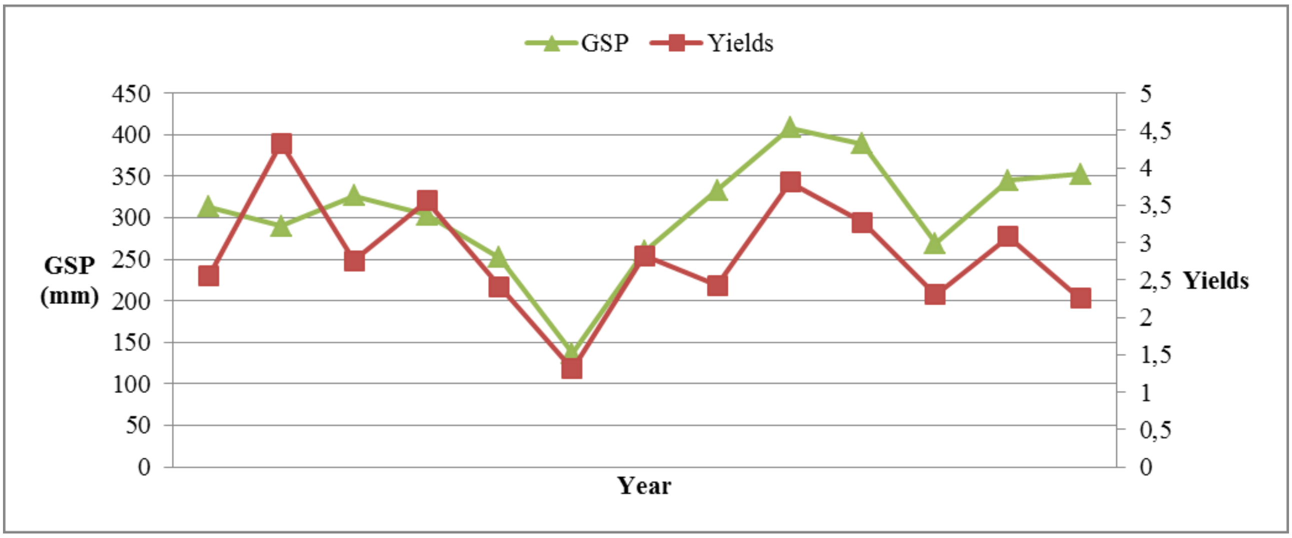
Graphic 3 – Relation between average Evapotranspiration and crop yields under climate baseline conditions.



Graphic 4 – Relation between average Evapotranspiration and crop yields under climate future conditions.

Changes in Growing Season Precipitation

Graphic 5 – Relation between average GSP and crop yields under climate baseline conditions.



Graphic 6 – Relation between average GSP and crop yields under climate future conditions.

Considering GSP, baseline scenario showed an average of 338.5 mm, slightly higher respect to future scenario, when 306 mm were observed. GSP ranged from 206.2 to 506.8 mm in CP, while from 137 to 408 mm in CF. In % values, a decrease of about 6 % was observed in the CF, ranging from – 33.3 to + 53.3 %. Also CV and dev.st. were higher in the CP respect to CF: 0.27 and 93.5 respectively in the fist case, and 0.22 and 66.4 in the second case. Results are also showed in Graphic 5 and 6.

Water Stress

In contrast with ET, future water stress decreased, with a increasing of 107 % (range from 9.16 to 330 %). In fact under baseline climatic condition resulted higher than under future climatic conditions: in CP the average was 41.32 days while in CF was 72.6 days. Also the range changed, so in first situation ET was in the interval 15.32 and 67.67 days, while from 51.70 to 11.46 days. If consider CV passed from 41.32 to 72.56. The correlation of Pearsons as result of comparison enter CP and CF was 0.40 (P<0.001). Figure 6 and 7 showed the correlation between Yields and ET in the baseline and future conditions respectively. Results are also showed in Graphic 7 and 8.

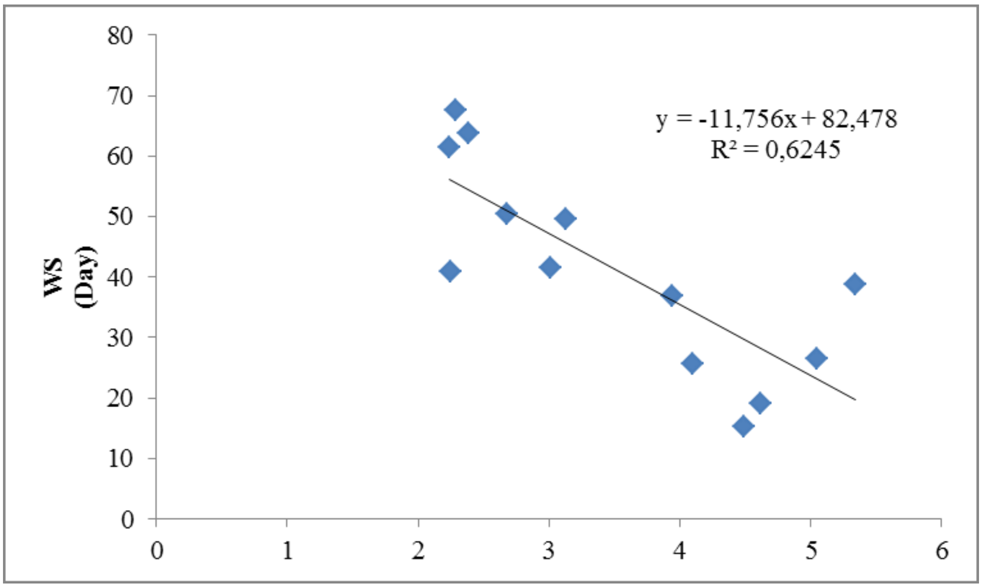


Figure 6 – Correlation between crop and WS under climatic baseline conditions

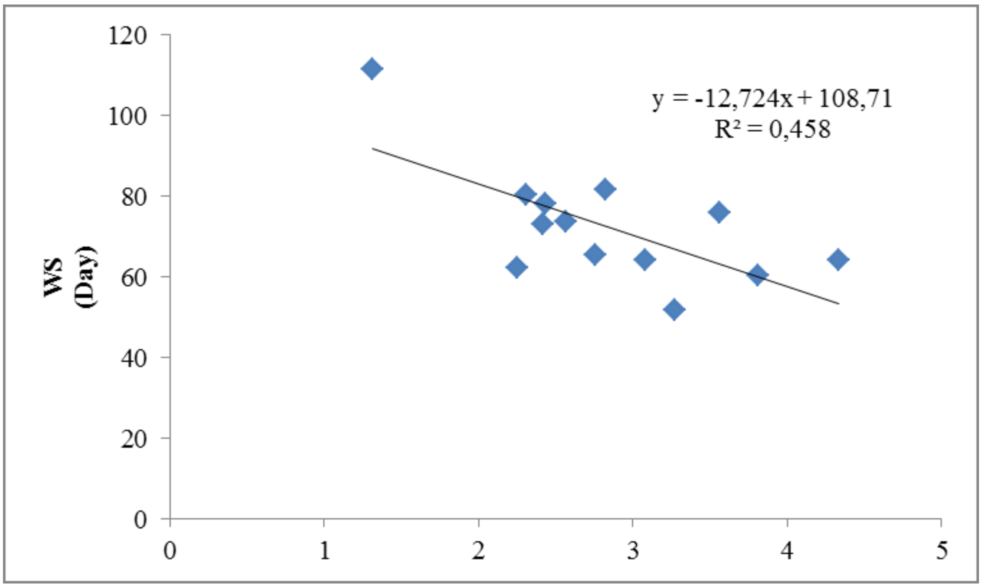
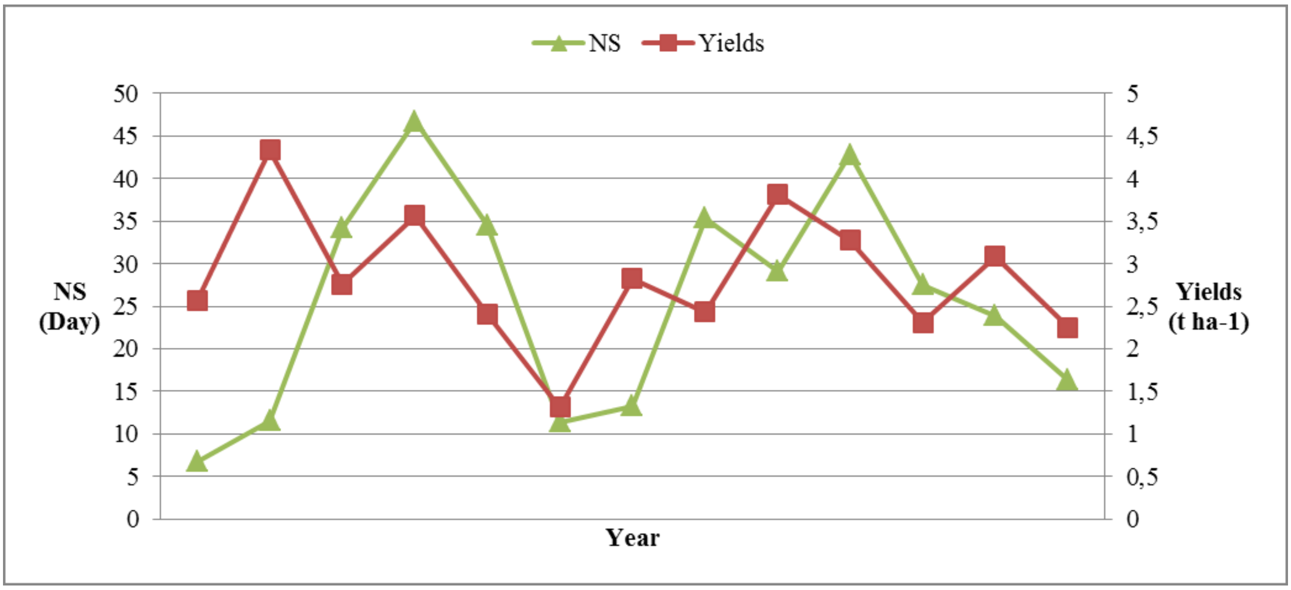


Figure 7 – Correlation between crop and WS under climatic future conditions

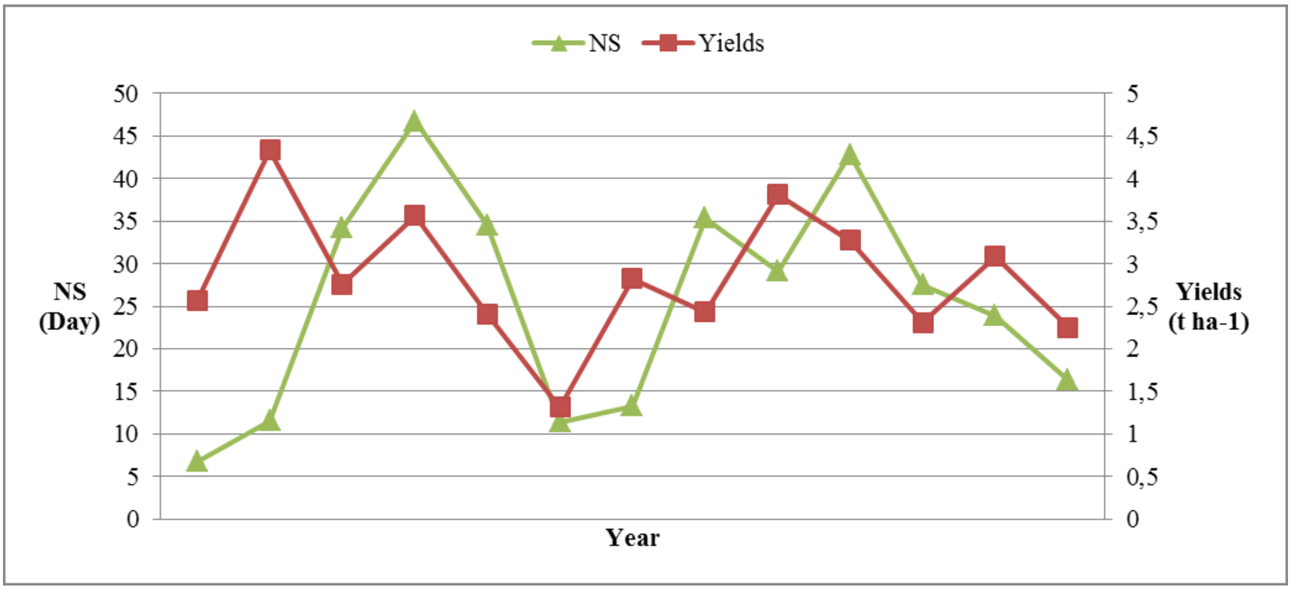
Graphic 7 – Relation between average Water Stress Day and crop yields under climate baseline conditions.

Graphic 8 – Relation between average Water Stress Day and crop yields under climate future conditions.

Nitrogen stress



Graphic 9 – Relation between average Nitrogen stress and crop yields under climate baseline conditions.



Graphic 10 – Relation between average Nitrogen stress and crop yields under climate future conditions.

Future nitrogen stress decreased, with a decreasing of 13.2 % (range from -56 to + 125 %). In fact under baseline climatic condition resulted higher than under future climatic conditions: in CP the average was 10.51 days while in CF was 9 days. Also the range changed, so in first situation NS was in the interval 3.3 and 23.26 days, while from 2.65 to 17.77 days in the second case. If consider CV passed from 0.59 to 0.46. The correlation of Pearsons as result of comparison enter CP and CF was 0.40 (P<0.001). Results are also showed in Graphic 9 and 10.

3.3 Climatic change effects with same CO_2 concentration and water crop stress

The third set of results was obtained considering:

- climatic baseline condition with a concentration of CO_2 in the amount of 378 ppm;
- climatic future condition with a concentration of CO_2 in the amount of 378 ppm;
- water and nitrogen stress imposed (autoirrigation and autofertlization with zero value).

3.3.1 Oristano

Impacts of climate change on yield

The simulated average durum wheat yield for the baseline period was 3.5 t/ha, with a CV of 0.32, and ranged from 2.2 to 5.3 t/ha. while under future climate conditions was 2.84 t/ha, with a CV of 0.28, and ranged from 1.31 to 4.33 t/ha, showing a decrease of 15% (ranging from -21.8% to + 44.9 %), respect to baseline conditions. Considering the two series of data, the Pearson’s correlation coefficient was 0.70 ($p<0.001$). Results are also showed throught the box plot in Figure 1.

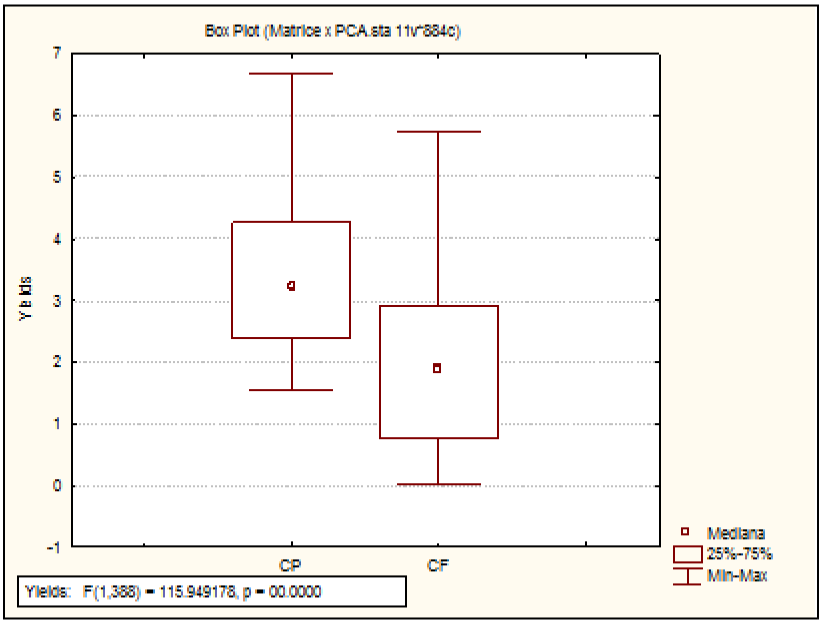


Figure 1 – Durum wheat yields under baseline and future climate in Oristano site.

Water Use Efficiency

Considering the Water Use Efficiency, there was a decrease in the future of 19 % respect to the baseline conditions, with a range from – 42.4 to 2.78%. Analysis of interannual variability under baseline condition indicated an average WUE of 11.71 kg biom/mm H_2O and a range from 7.35 to

17.59 kg biom/mm H_2O. Under future climate, the average WUE was 9.22 kg mm^{-1} ha $^{-1}$, and it ranged from 6.03 to 12.8 kg biom/mm H_2O. Respect to CP, in the CF was registered a minor variation for WUE, that maybe found a stabilization. Comparison of values under the two climatic scenarios showed a Pearson's correlation coefficient of 0.78 ($p< 0.001$). Figure 2 and 3 showed the correlation between Yields and WUE in the baseline and future conditions respectively. Results are also showed in Graphic 4 and 5.

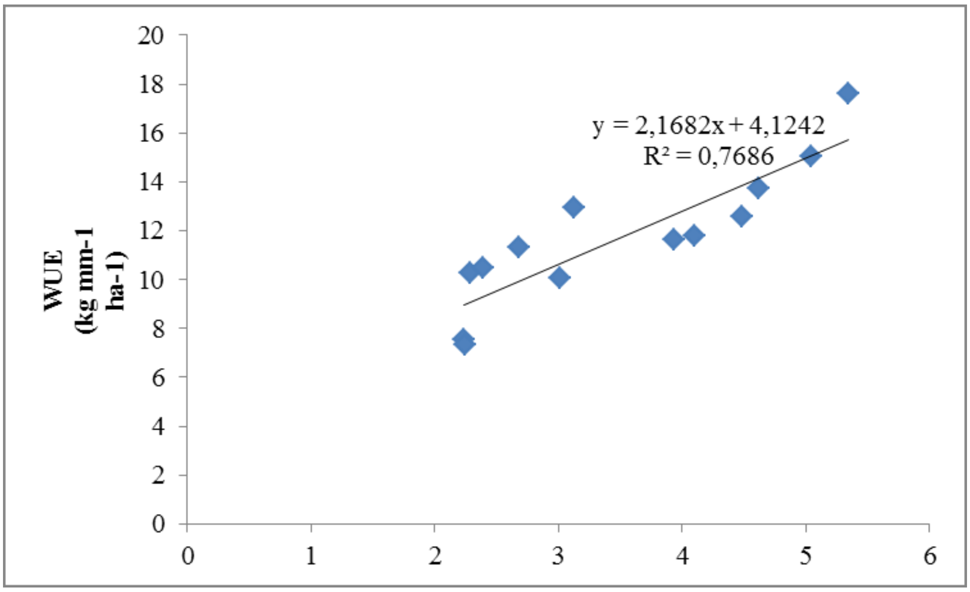


Figure 2 – Correlation between crop and WUE under climatic baseline conditions

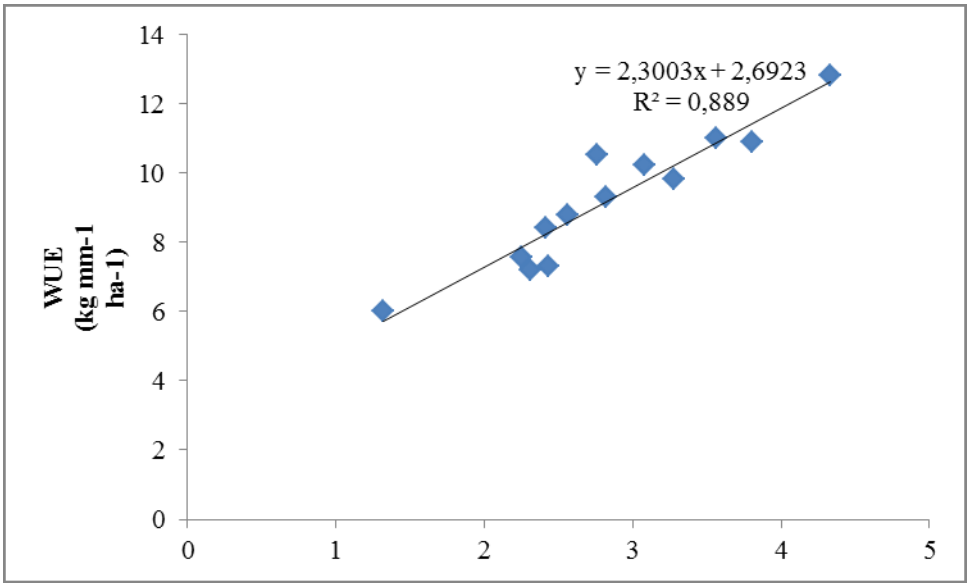
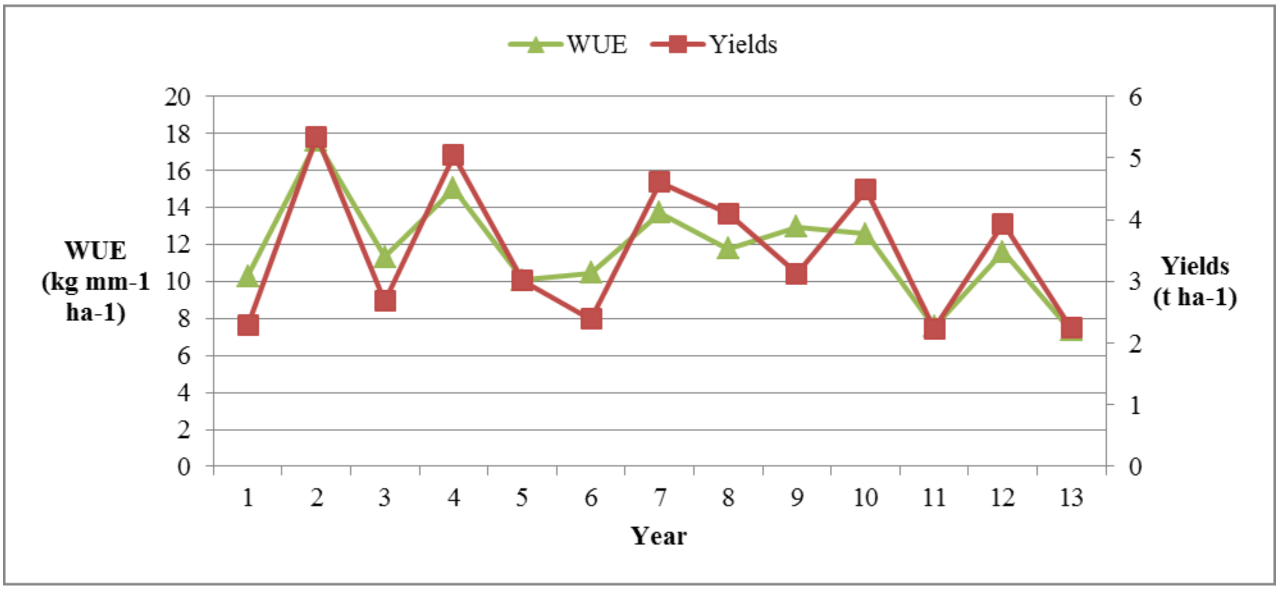
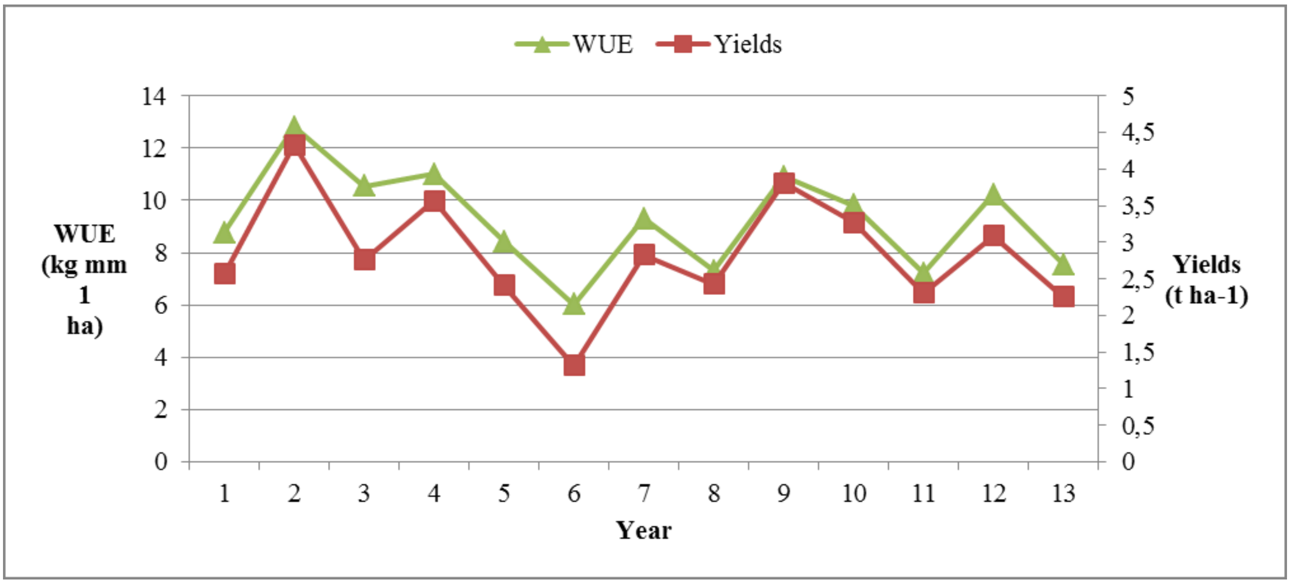


Figure 3 – Correlation between crop yields and wue under climatic future conditions



Graphic 1 – Relation between average Water Use Efficiency and crop yields under climate baseline conditions.



Graphic 2 – Relation between average Water Use Efficiency and crop yields under climate future conditions.

Evapotranspiration

Deviations between baseline climate and future have been observed also for Evapotranspiration. Under baseline climatic conditions average ET was 296,44 mm, with a CV of 0.24 , and a range from 222.47 to 357.17 mm. Respect to the previous conditions, future ET, with an average of 293.8 mm, increased of 1.21 % (-27.7 - + 53.7) and ranged from 164,66 to 371.28 mm, with a CV of 0.17. Comparison of values under the two climatic scenarios showed a Pearson's correlation coefficient of 0.20 ($p < 0.44$). Analysis among wheat yields and evapotranspiration show a higher correlation under future climate ($R^2 = 0.67$). Figure 4 and 5 showed the correlation between Yields and ET in the baseline and future conditions respectively. Results are also showed in Graphic 3 and 4.

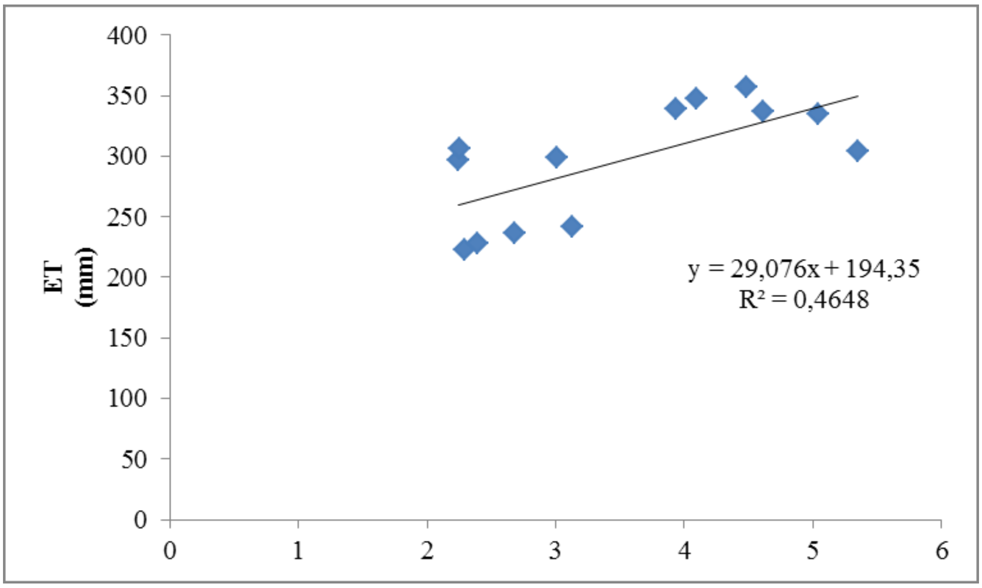


Figure 4 – Correlation between crop and ET under climatic baseline conditions

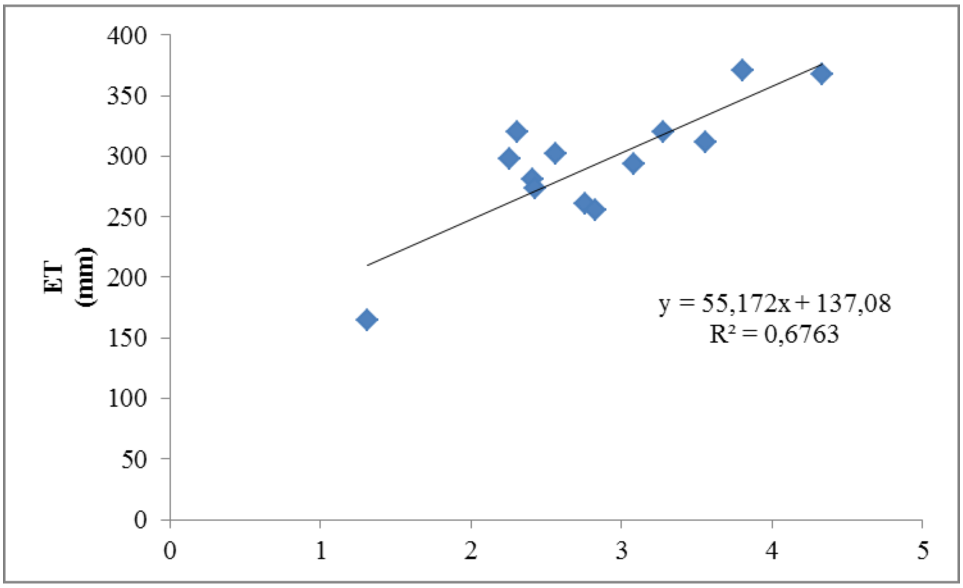
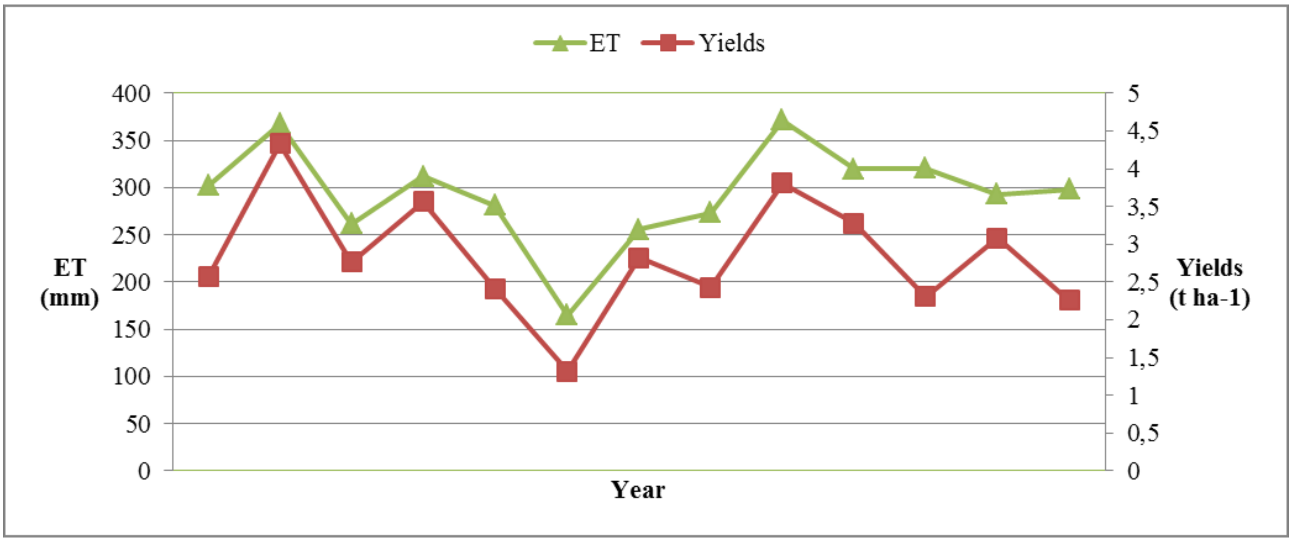


Figure 5 – Correlation between crop and ET under climatic future conditions

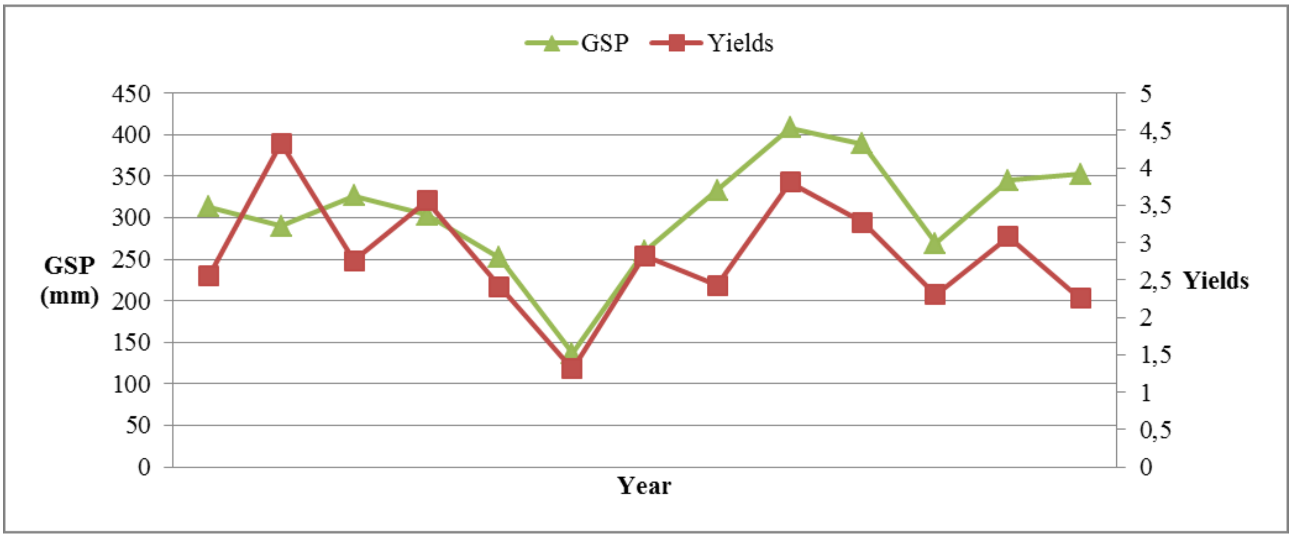
Graphic 3 – Relation between average Evapotranspiration and crop yields under climate baseline conditions.



Graphic 4 – Relation between average Evapotranspiration and crop yields under climate future conditions.

Changes in Growing Season Precipitation

Graphic 5 – Relation between average GSP and crop yields under climate baseline conditions.



Graphic 6 – Relation between average GSP and crop yields under climate future conditions.

Considering GSP, baseline scenario showed an average of 338.5 mm, slightly higher respect to future scenario, when 306 mm were observed. GSP ranged from 206.2 to 506.8 mm in CP, while from 137 to 408 mm in CF. In % values, a decrease of about 6 % was observed in the CF, ranging from – 33.3 to + 53.3 %. Also CV and dev.st. were higher in the CP respect to CF: 0.27 and 93.5 respectively in the fist case, and 0.22 and 66.4 in the second case. Results are also showed in Graphic 5 and 6.

Water Stress

In contrast with ET, future water stress decreased, with a increasing of 107 % (range from 9.16 to 330 %). In fact under baseline climatic condition resulted higher than under future climatic conditions: in CP the average was 41.32 days while in CF was 72.6 days. Also the range changed, so in first situation ET was in the interval 15.32 and 67.67 days, while from 51.70 to 11.46 days. If consider CV passed from 41.32 to 72.56. The correlation of Pearsons as result of comparison enter CP and CF was 0.40 (P<0.001). Figure 6 and 7 showed the correlation between Yields and ET in the baseline and future conditions respectively. Results are also showed in Graphic 7 and 8.

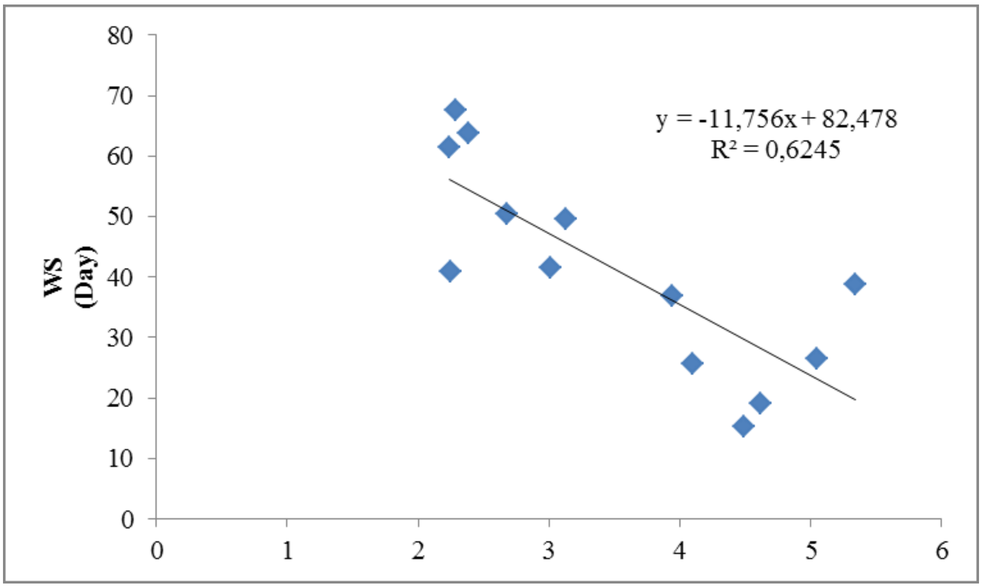


Figure 6 – Correlation between crop and WS under climatic baseline conditions

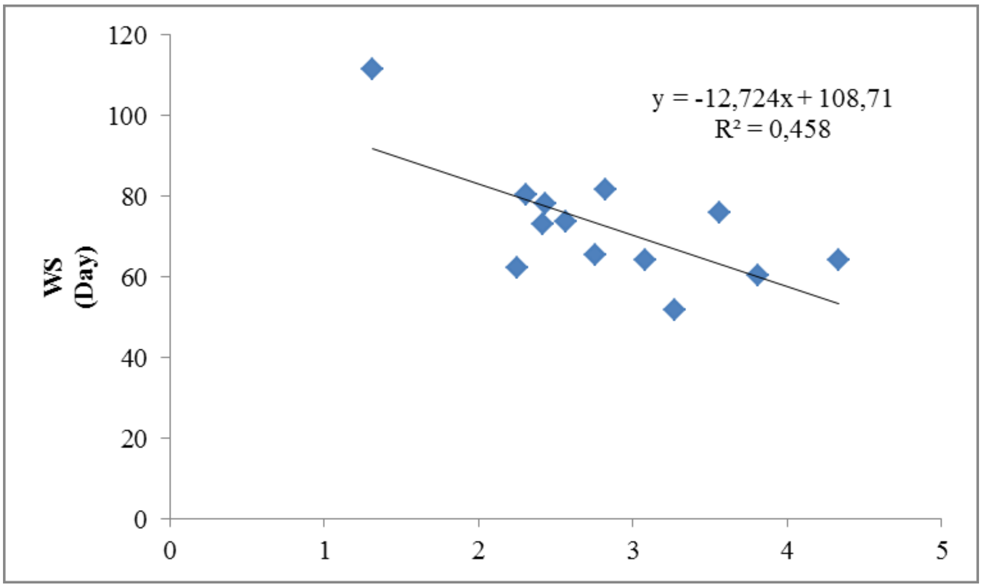
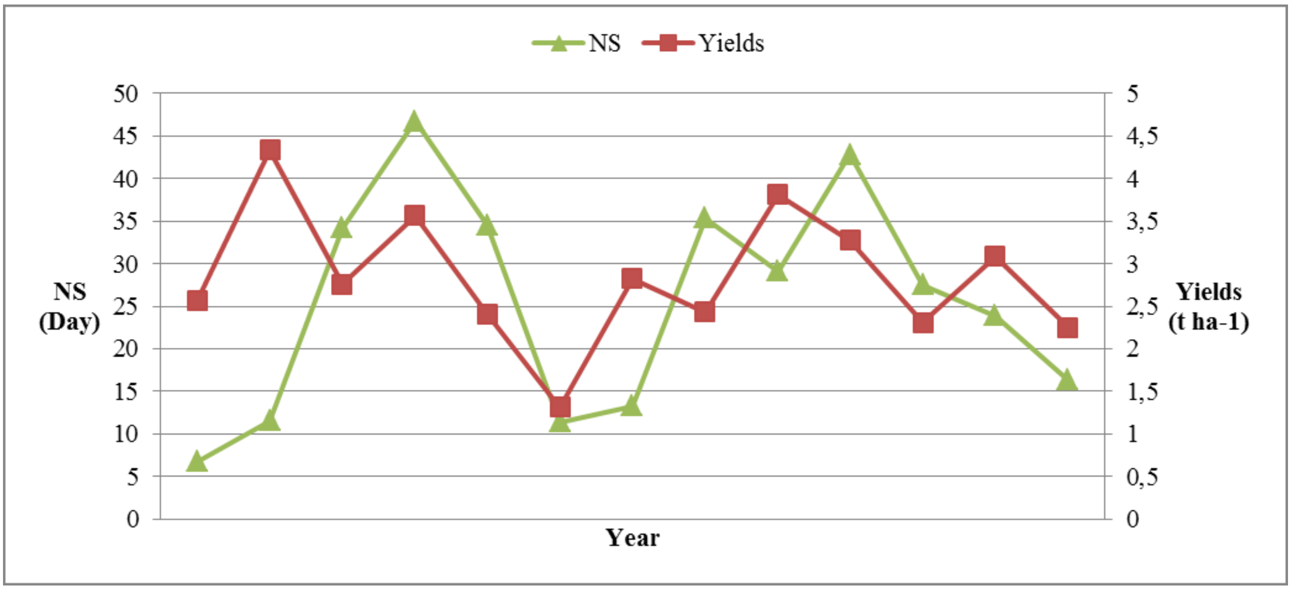


Figure 7 – Correlation between crop and WS under climatic future conditions

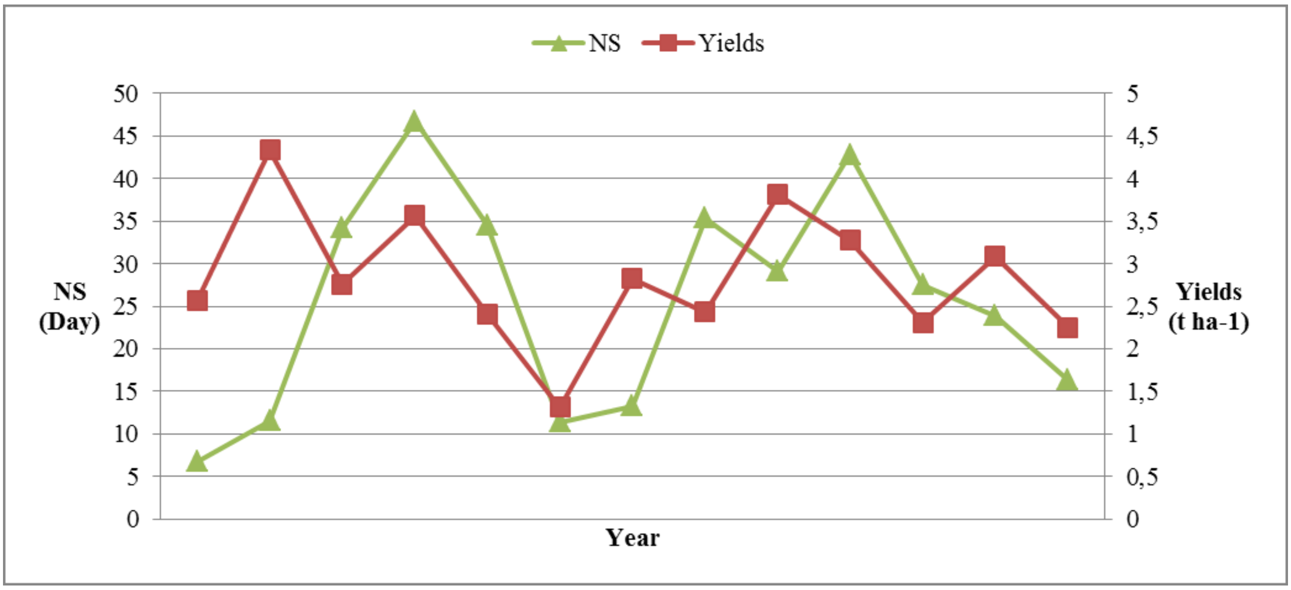
Graphic 7 – Relation between average Water Stress Day and crop yields under climate baseline conditions.

Graphic 8 – Relation between average Water Stress Day and crop yields under climate future conditions.

Nitrogen stress



Graphic 9 – Relation between average Nitrogen stress and crop yields under climate baseline conditions.



Graphic 10 – Relation between average Nitrogen stress and crop yields under climate future conditions.

Future nitrogen stress decreased, with a decreasing of 13.2 % (range from -56 to + 125 %). In fact under baseline climatic condition resulted higher than under future climatic conditions: in CP the average was 10.51 days while in CF was 9 days. Also the range changed, so in first situation NS was in the interval 3.3 and 23.26 days, while from 2.65 to 17.77 days in the second case. If consider CV passed from 0.59 to 0.46. The correlation of Pearsons as result of comparison enter CP and CF was 0.40 (P<0.001). Results are also showed in Graphic 9 and 10.

3.3.2 Benevento

Impacts of climate change on yield

The simulated average durum wheat yield for the baseline period was 3.5 t/ha, with a CV of 0.32, and ranged from 2.2 to 5.3 t/ha. while under future climate conditions was 2.84 t/ha, with a CV of 0.28, and ranged from 1.31 to 4.33 t/ha, showing a decrease of 15% (ranging from -21.8% to + 44.9 %), respect to baseline conditions. Considering the two series of data, the Pearson's correlation coefficient was 0.70 ($p<0.001$). Results are also showed throught the box plot in Figure 1.

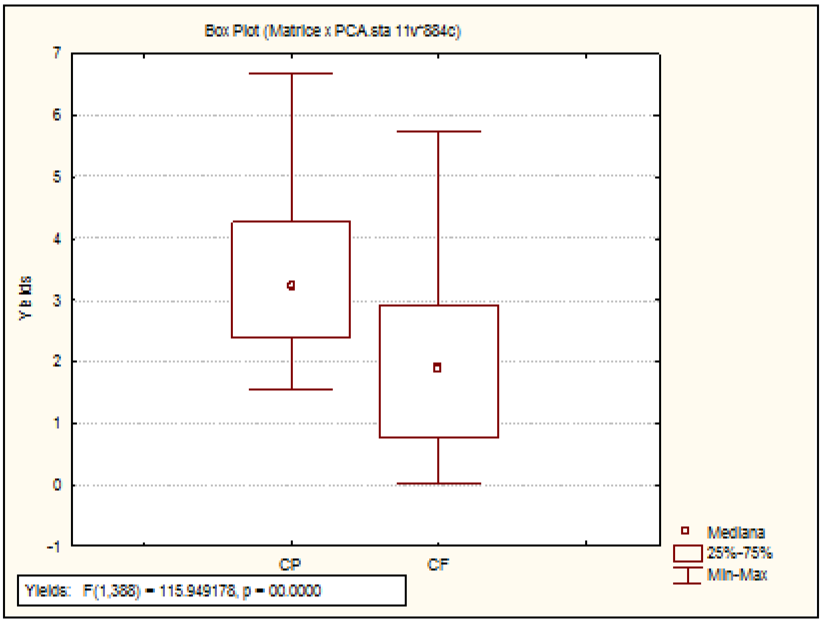


Figure 1 – Durum wheat yields under baseline and future climate in Oristano site.

Water Use Efficiency

Considering the Water Use Efficiency, there was a decrease in the future of 19 % respect to the baseline conditions, with a range from – 42.4 to 2.78%. Analysis of interannual variability under baseline condition indicated an average WUE of 11.71 kg biom/mm H_2O and a range from 7.35 to 17.59 kg biom/mm H_2O. Under future climate, the average WUE was 9.22 kg mm^{-1} ha^{-1}, and it ranged from 6.03 to 12.8 kg biom/mm H_2O. Respect to CP, in the CF was registered a minor variation for WUE, that maybe found a stabilization. Comparison of values under the two climatic scenarios showed a Pearson's correlation coefficient of 0.78 ($p< 0.001$). Figure 2 and 3 showed the correlation between Yields and WUE in the baseline and future conditions respectively. Results are also showed in Graphic 4 and 5.

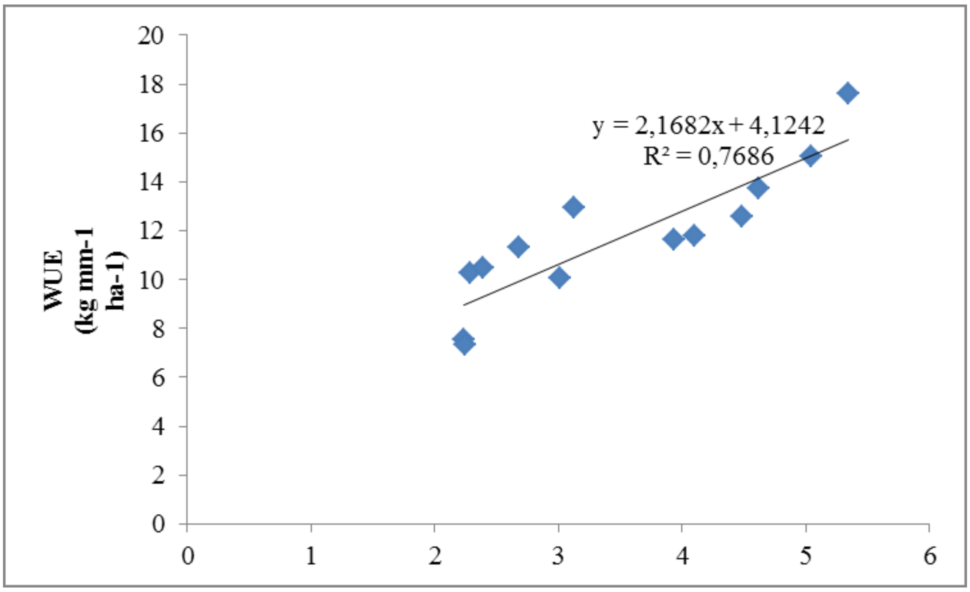


Figure 2 – Correlation between crop and WUE under climatic baseline conditions

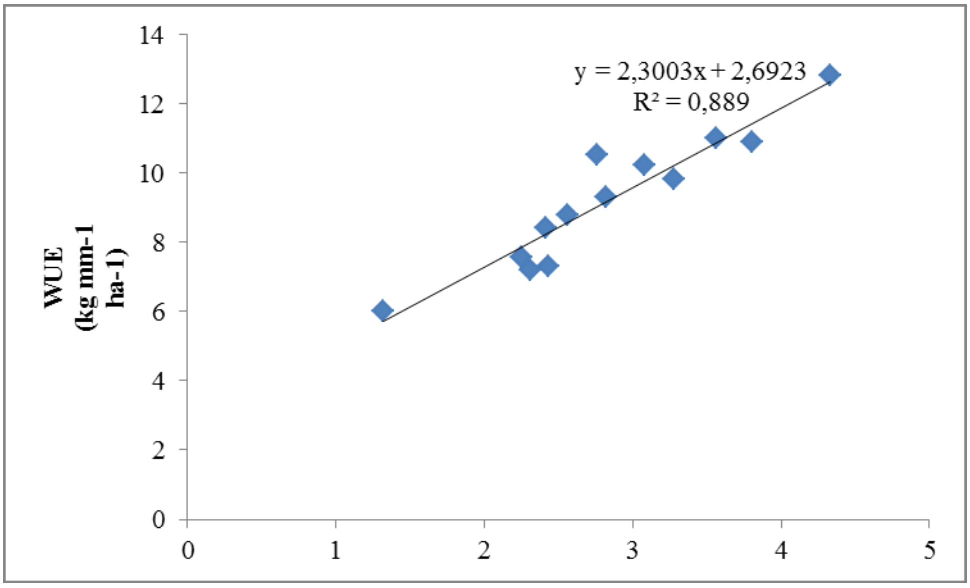
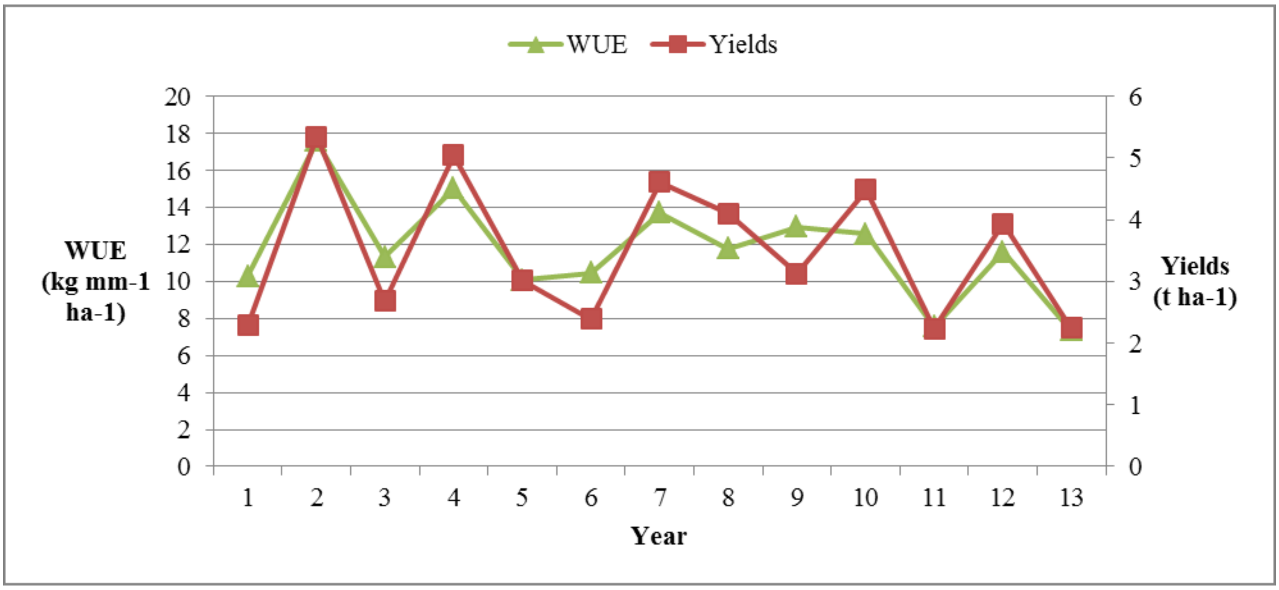
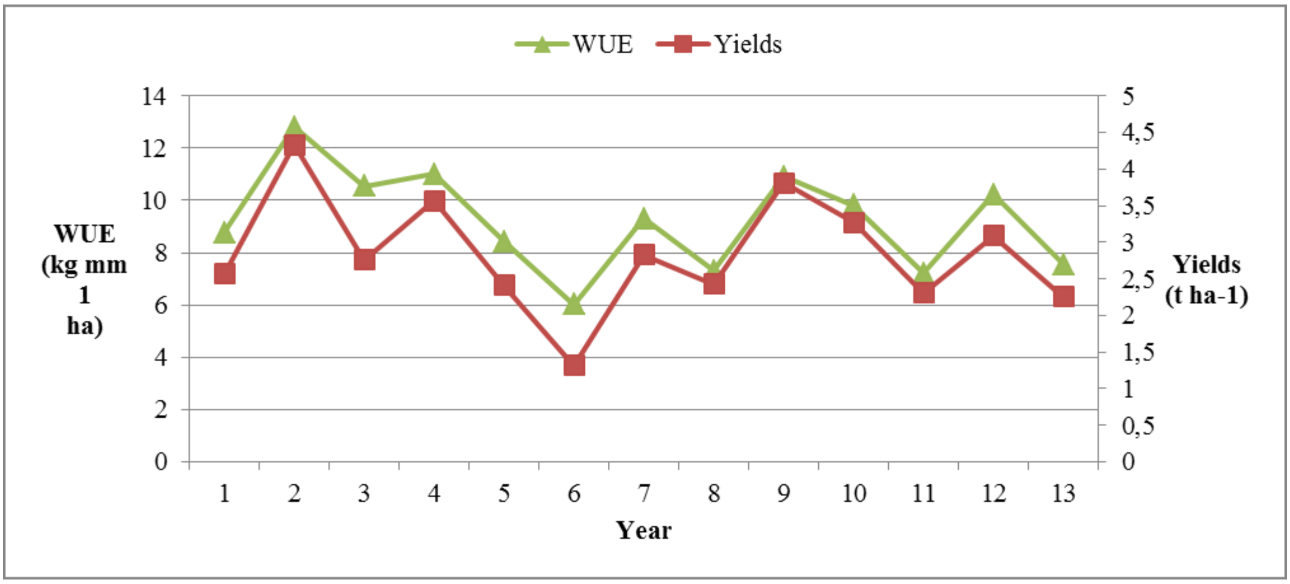


Figure 3 – Correlation between crop yields and wue under climatic future conditions



Graphic 1 – Relation between average Water Use Efficiency and crop yields under climate baseline conditions.



Graphic 2 – Relation between average Water Use Efficiency and crop yields under climate future conditions.

Evapotranspiration

Deviations between baseline climate and future have been observed also for Evapotranspiration. Under baseline climatic conditions average ET was 296,44 mm, with a CV of 0.24 , and a range from 222.47 to 357.17 mm. Respect to the previous conditions, future ET, with an average of 293.8 mm, increased of 1.21 % (-27.7 - + 53.7) and ranged from 164,66 to 371.28 mm, with a CV of 0.17. Comparison of values under the two climatic scenarios showed a Pearson's correlation coefficient of 0.20 ($p < 0.44$). Analysis among wheat yields and evapotranspiration show a higher correlation under future climate ($R^2 = 0.67$). Figure 4 and 5 showed the correlation between Yields and ET in the baseline and future conditions respectively. Results are also showed in Graphic 3 and 4.

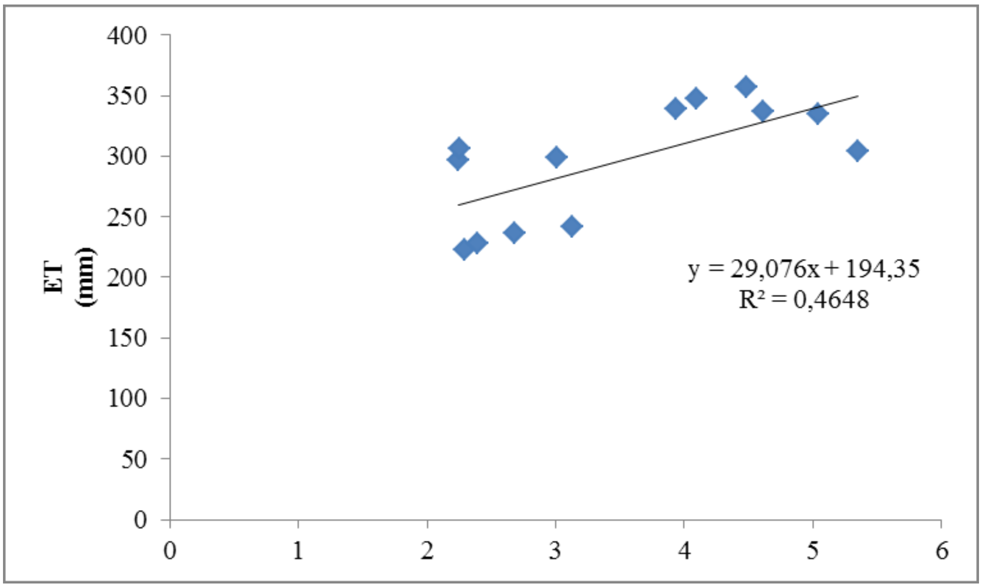


Figure 4 – Correlation between crop and ET under climatic baseline conditions

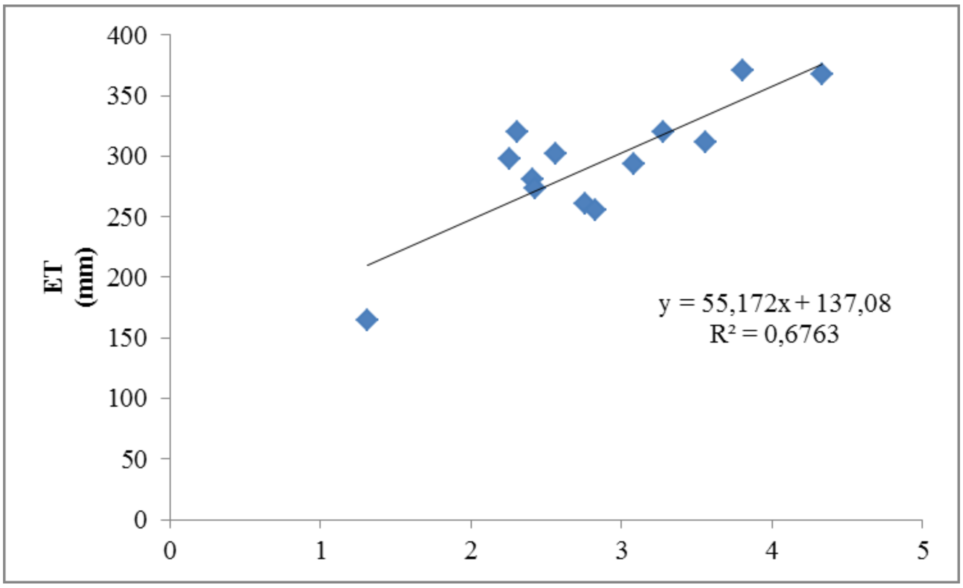
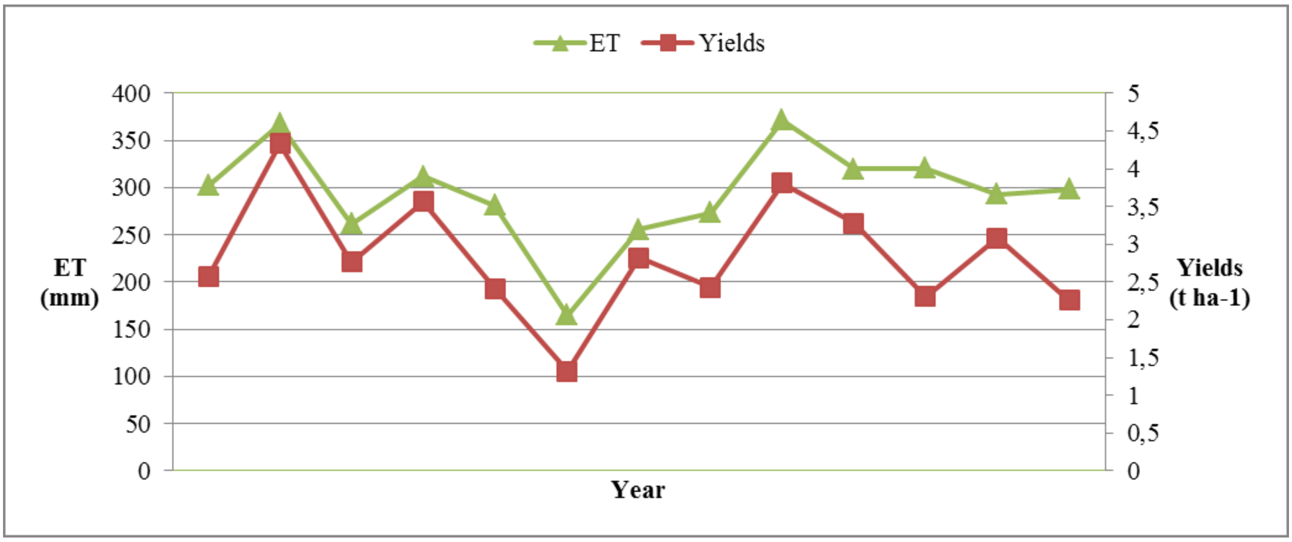


Figure 5 – Correlation between crop and ET under climatic future conditions

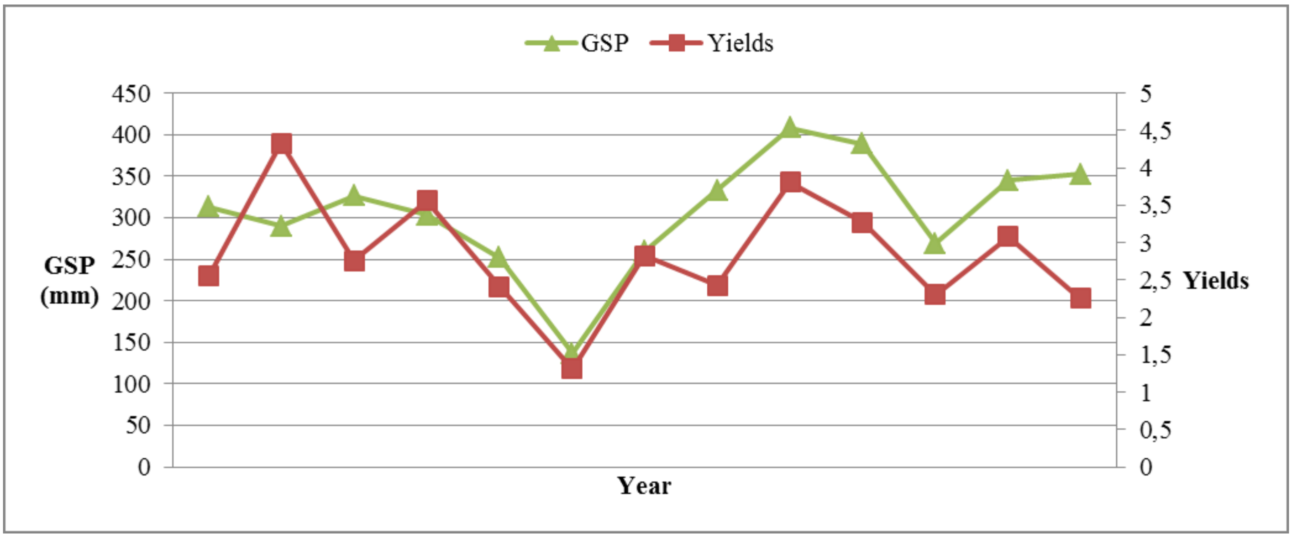
Graphic 3 – Relation between average Evapotranspiration and crop yields under climate baseline conditions.



Graphic 4 – Relation between average Evapotranspiration and crop yields under climate future conditions.

Changes in Growing Season Precipitation

Graphic 5 – Relation between average GSP and crop yields under climate baseline conditions.



Graphic 6 – Relation between average GSP and crop yields under climate future conditions.

Considering GSP, baseline scenario showed an average of 338.5 mm, slightly higher respect to future scenario, when 306 mm were observed. GSP ranged from 206.2 to 506.8 mm in CP, while from 137 to 408 mm in CF. In % values, a decrease of about 6 % was observed in the CF, ranging from – 33.3 to + 53.3 %. Also CV and dev.st. were higher in the CP respect to CF: 0.27 and 93.5 respectively in the fist case, and 0.22 and 66.4 in the second case. Results are also showed in Graphic 5 and 6.

Water Stress

In contrast with ET, future water stress decreased, with a increasing of 107 % (range from 9.16 to 330 %). In fact under baseline climatic condition resulted higher than under future climatic conditions: in CP the average was 41.32 days while in CF was 72.6 days. Also the range changed, so in first situation ET was in the interval 15.32 and 67.67 days, while from 51.70 to 11.46 days. If consider CV passed from 41.32 to 72.56. The correlation of Pearsons as result of comparison enter CP and CF was 0.40 (P<0.001). Figure 6 and 7 showed the correlation between Yields and ET in the baseline and future conditions respectively. Results are also showed in Graphic 7 and 8.

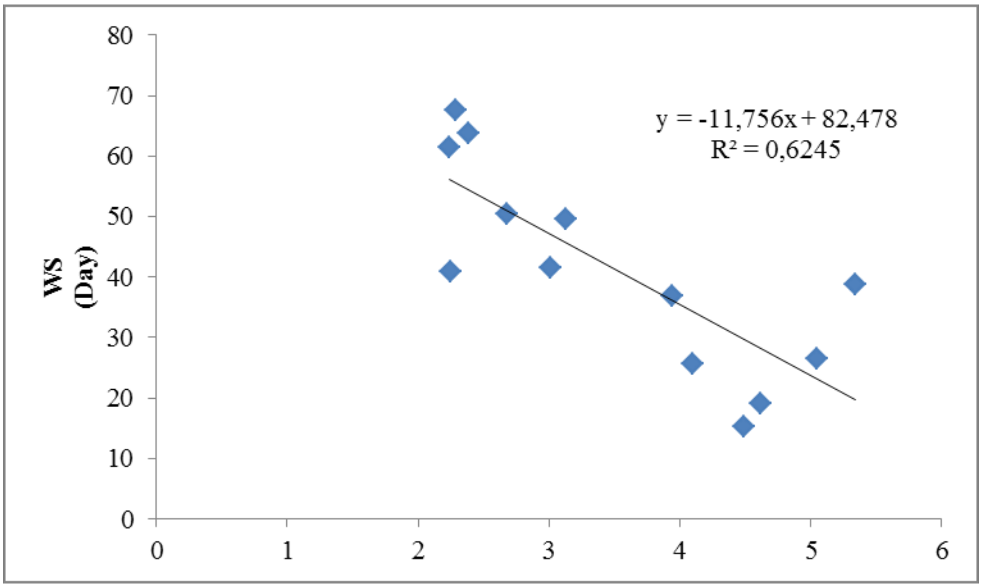
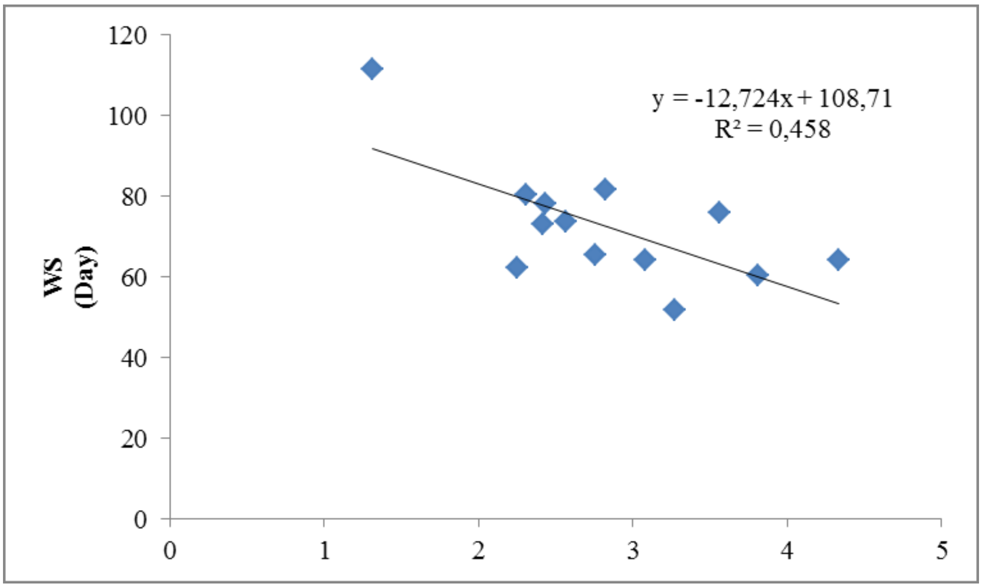


Figure 6 – Correlation between crop and WS under climatic baseline conditions



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Graphic 7 – Relation between average Water Stress Day and crop yields under climate baseline conditions.

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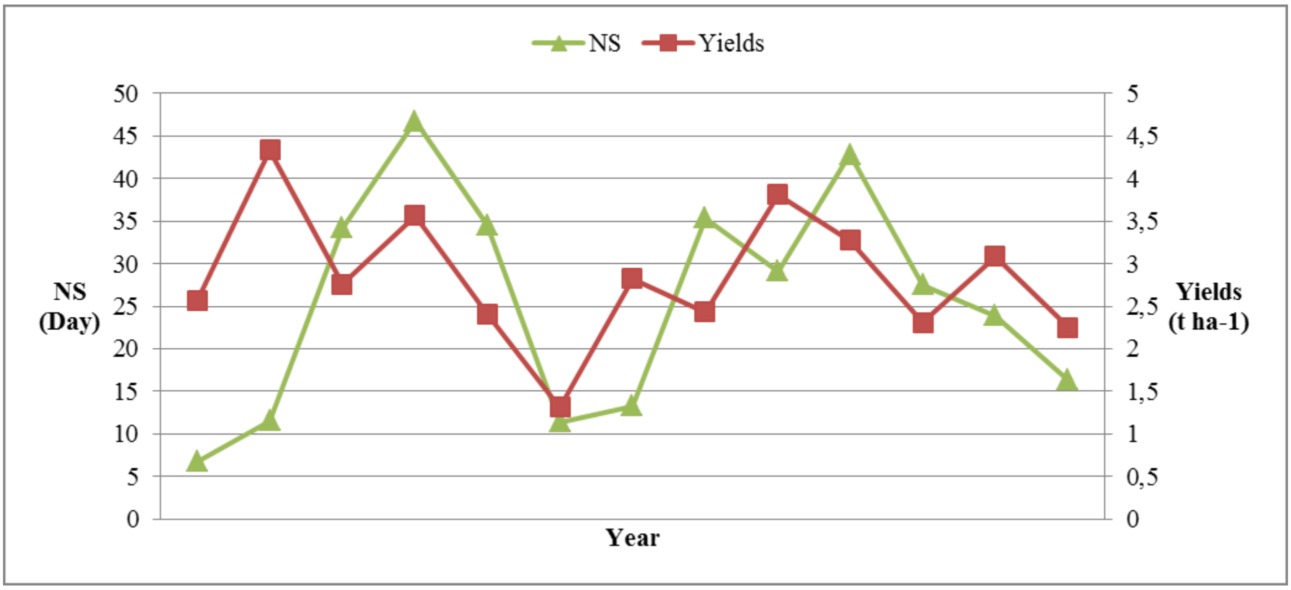
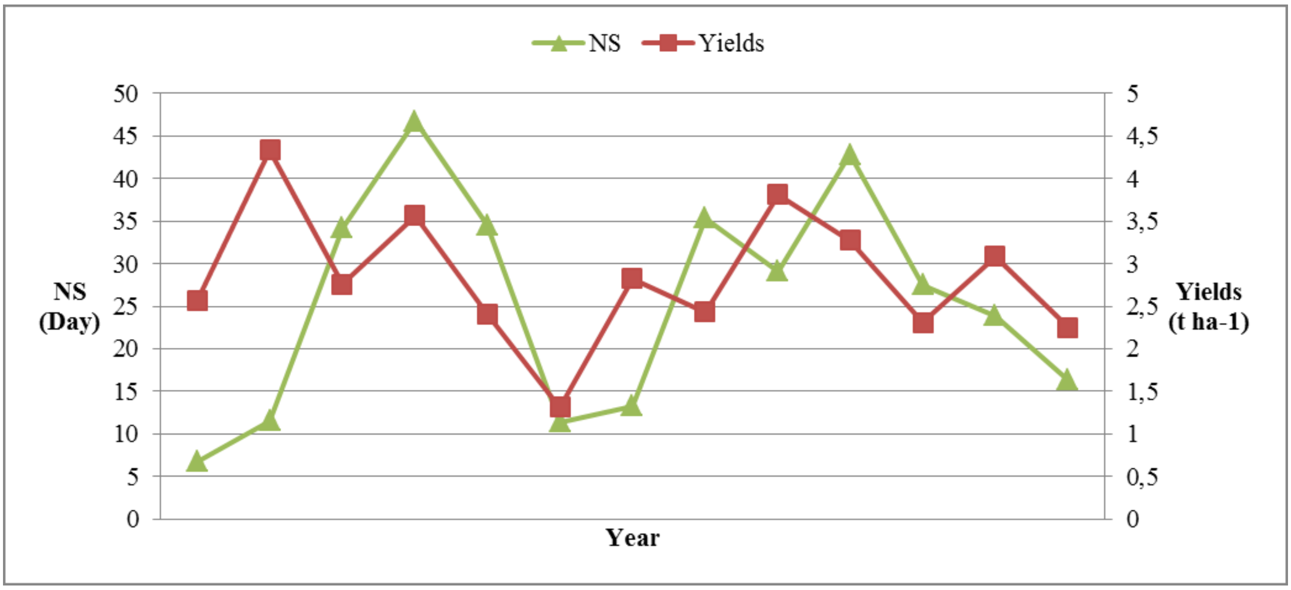
Nitrogen stress



Graphic 9 – Relation between average Nitrogen stress and crop yields under climate baseline conditions.



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3.3.3 Ancona

Impacts of climate change on yield

The simulated average durum wheat yield for the baseline period was 3.5 t/ha, with a CV of 0.32, and ranged from 2.2 to 5.3 t/ha. while under future climate conditions was 2.84 t/ha, with a CV of 0.28, and ranged from 1.31 to 4.33 t/ha, showing a decrease of 15% (ranging from -21.8% to + 44.9 %), respect to baseline conditions. Considering the two series of data, the Pearson's correlation coefficient was 0.70 ($p<0.001$). Results are also showed throught the box plot in Figure 1.

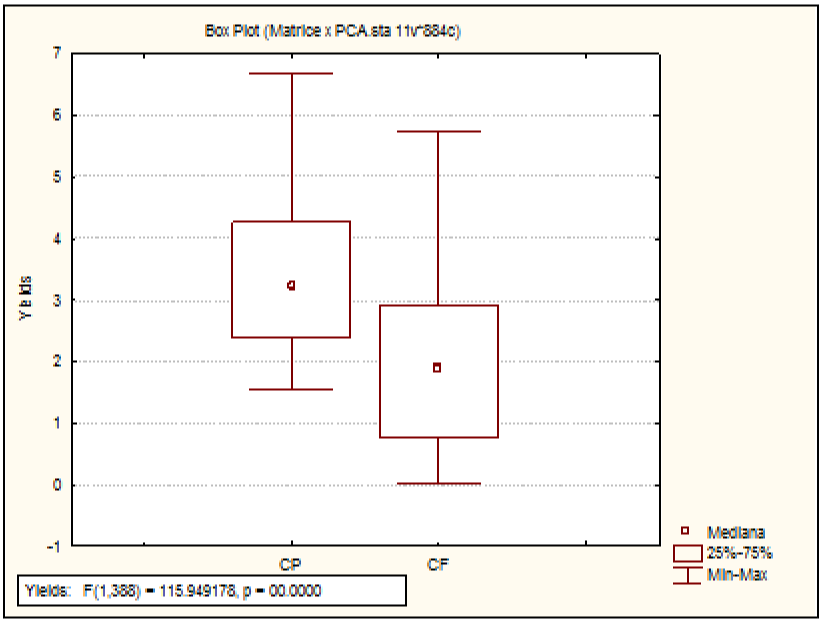


Figure 1 – Durum wheat yields under baseline and future climate in Oristano site.

Water Use Efficiency

Considering the Water Use Efficiency, there was a decrease in the future of 19 % respect to the baseline conditions, with a range from – 42.4 to 2.78%. Analysis of interannual variability under baseline condition indicated an average WUE of 11.71 kg biom/mm H_2O and a range from 7.35 to 17.59 kg biom/mm H_2O. Under future climate, the average WUE was 9.22 kg mm^{-1} ha $^{-1}$, and it ranged from 6.03 to 12.8 kg biom/mm H_2O. Respect to CP, in the CF was registered a minor variation for WUE, that maybe found a stabilization. Comparison of values under the two climatic scenarios showed a Pearson's correlation coefficient of 0.78 ($p< 0.001$). Figure 2 and 3 showed the correlation between Yields and WUE in the baseline and future conditions respectively. Results are also showed in Graphic 4 and 5.

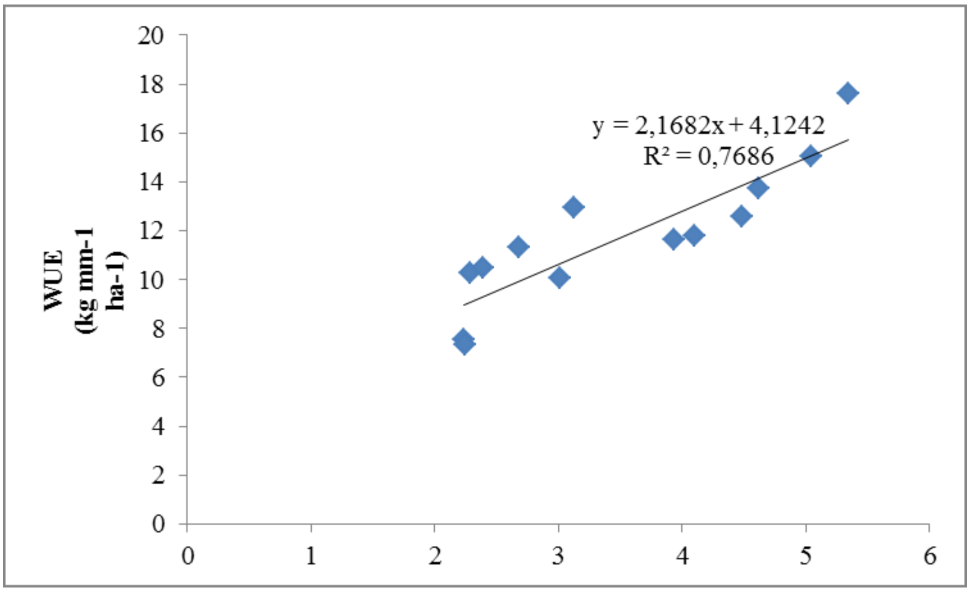


Figure 2 – Correlation between crop and WUE under climatic baseline conditions

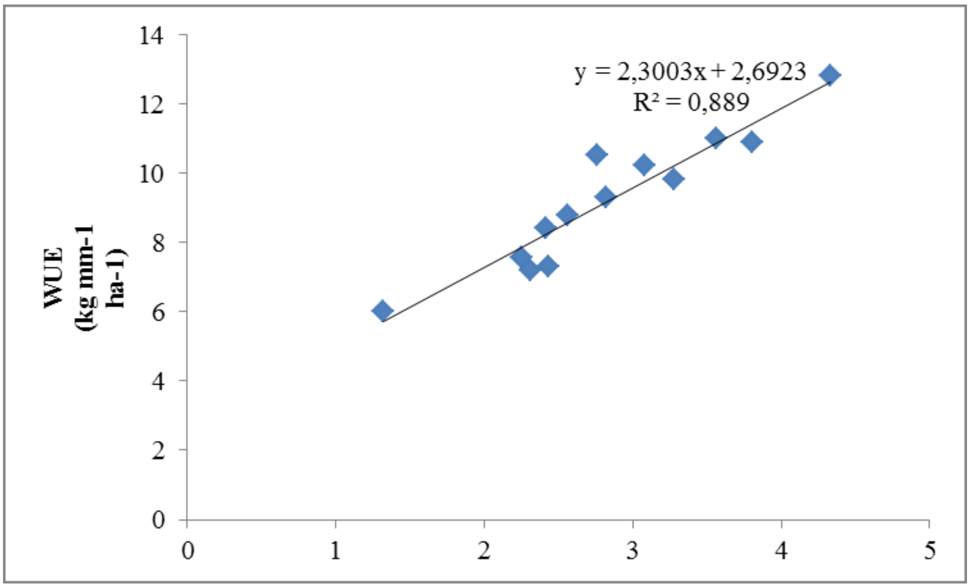
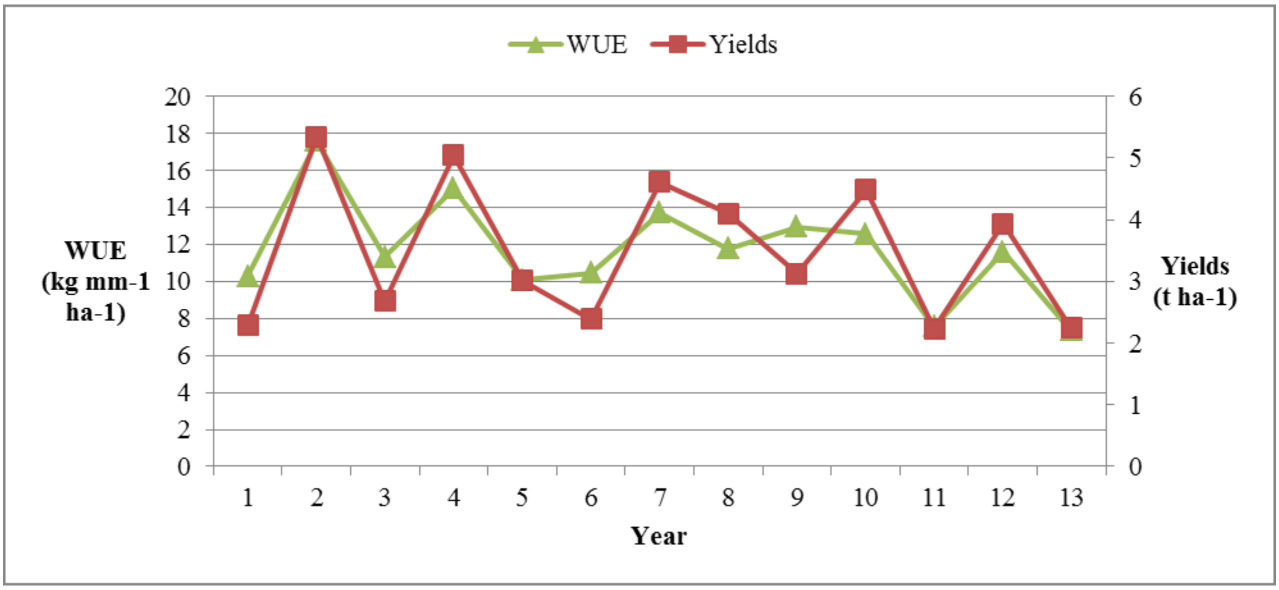
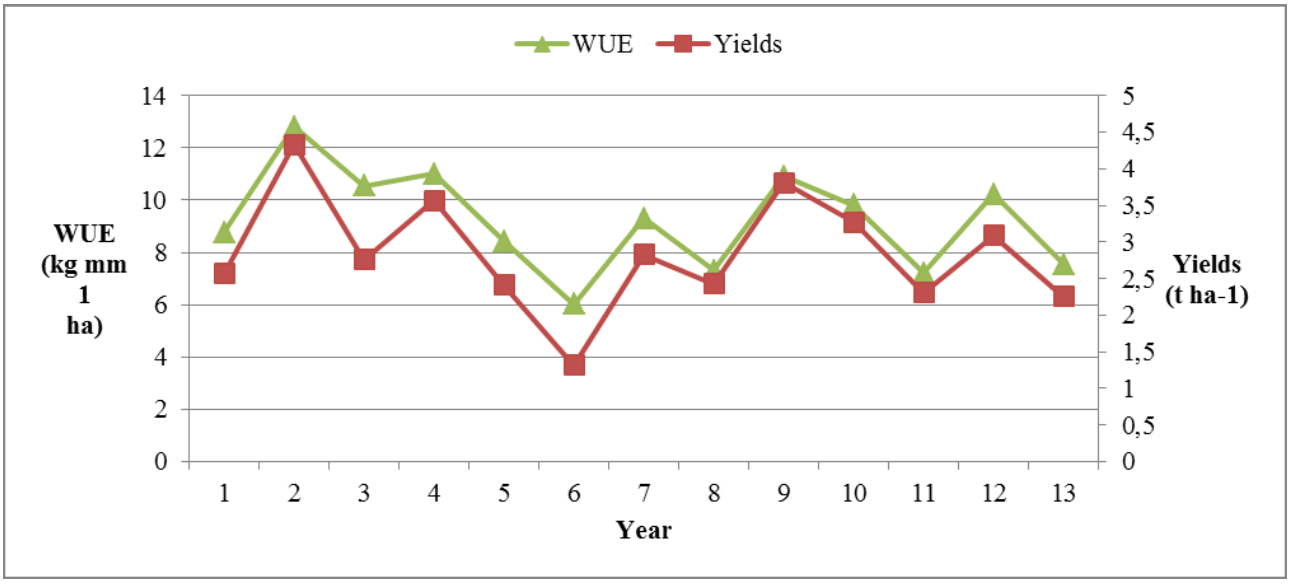


Figure 3 – Correlation between crop yields and wue under climatic future conditions



Graphic 1 – Relation between average Water Use Efficiency and crop yields under climate baseline conditions.



Graphic 2 – Relation between average Water Use Efficiency and crop yields under climate future conditions.

Evapotranspiration

Deviations between baseline climate and future have been observed also for Evapotranspiration. Under baseline climatic conditions average ET was 296,44 mm, with a CV of 0.24 , and a range from 222.47 to 357.17 mm. Respect to the previous conditions, future ET, with an average of 293.8 mm, increased of 1.21 % (-27.7 - + 53.7) and ranged from 164,66 to 371.28 mm, with a CV of 0.17. Comparison of values under the two climatic scenarios showed a Pearson's correlation coefficient of 0.20 ($p < 0.44$). Analysis among wheat yields and evapotranspiration show a higher correlation under future climate ($R^2 = 0.67$). Figure 4 and 5 showed the correlation between Yields and ET in the baseline and future conditions respectively. Results are also showed in Graphic 3 and 4.

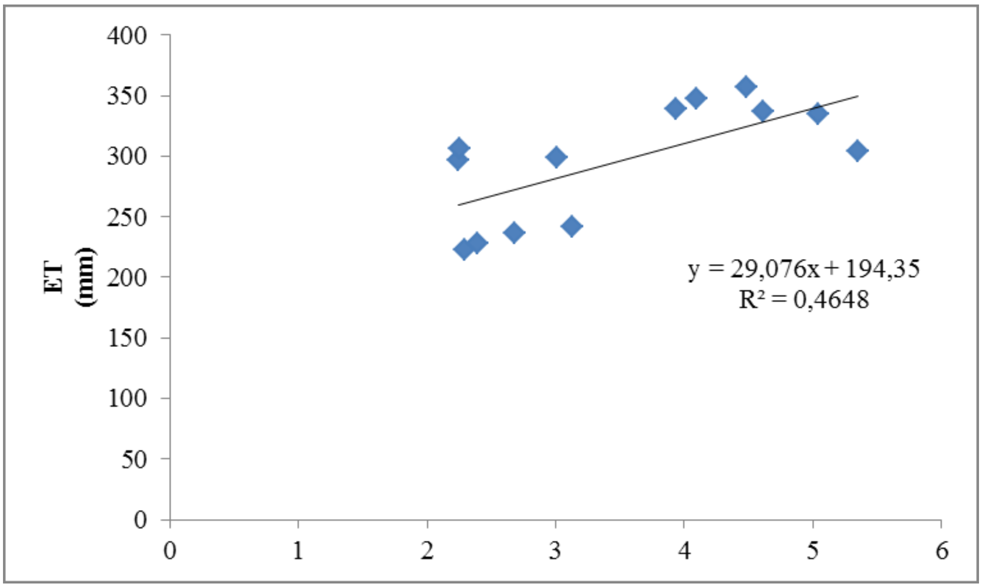
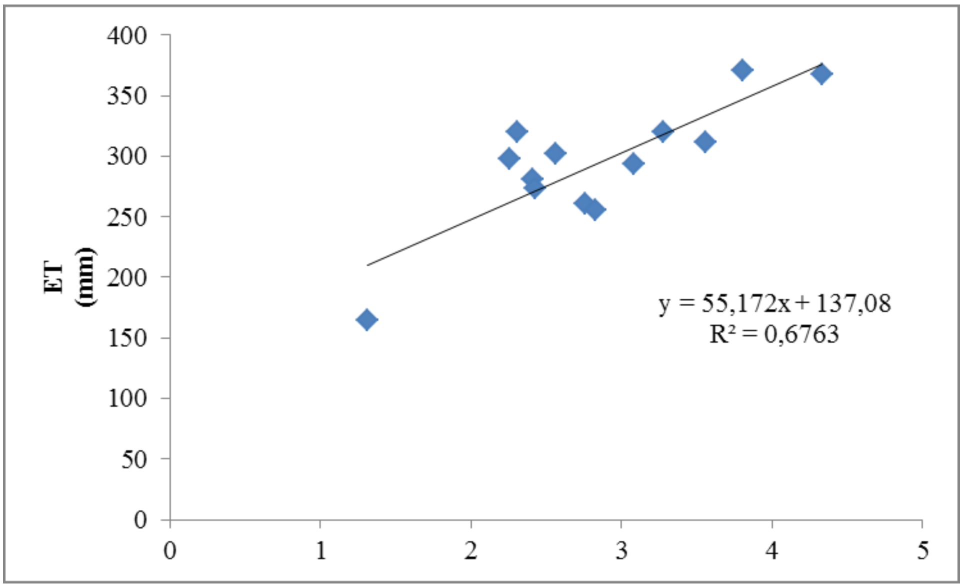


Figure 4 – Correlation between crop and ET under climatic baseline conditions



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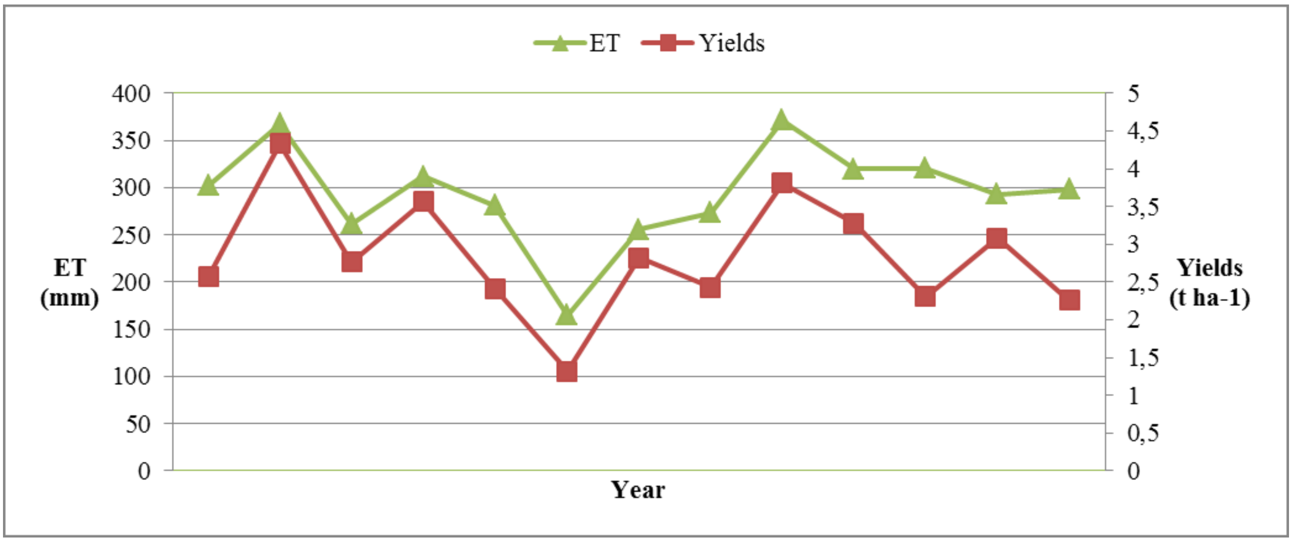
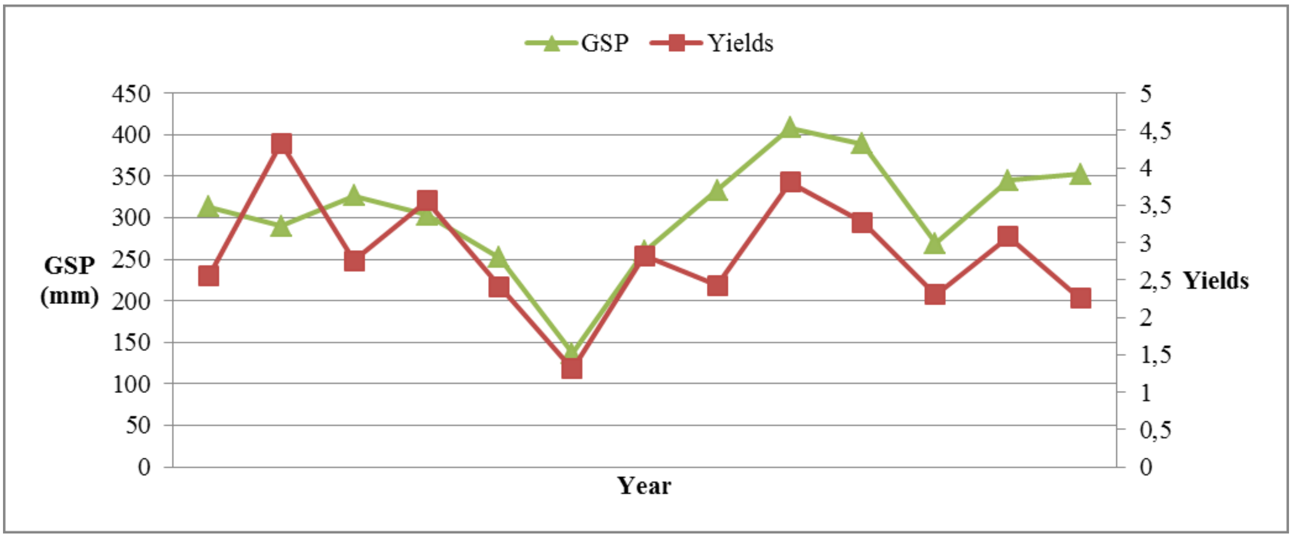
Graphic 3 – Relation between average Evapotranspiration and crop yields under climate baseline conditions.



Graphic 4 – Relation between average Evapotranspiration and crop yields under climate future conditions.

Changes in Growing Season Precipitation

Graphic 5 – Relation between average GSP and crop yields under climate baseline conditions.



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Water Stress

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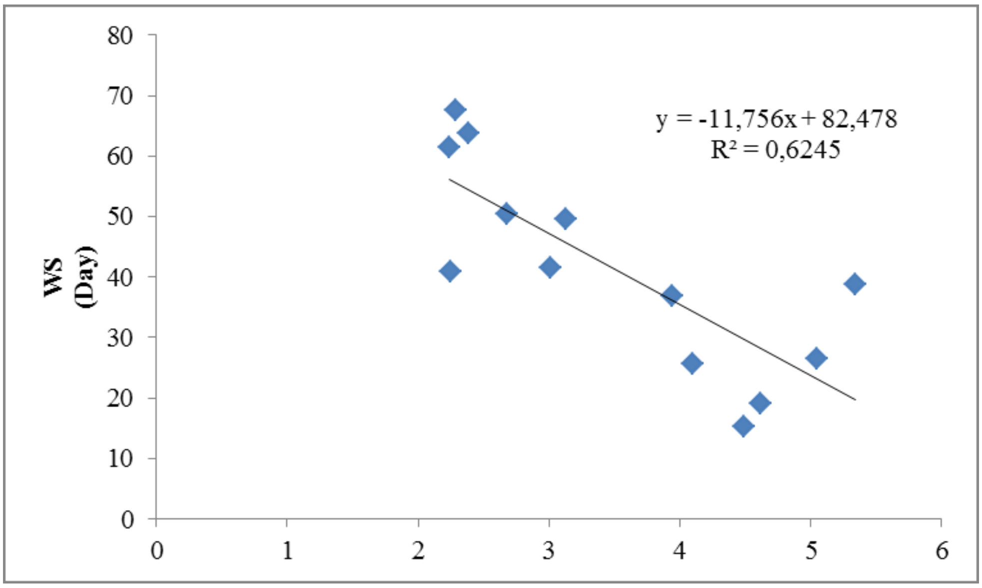

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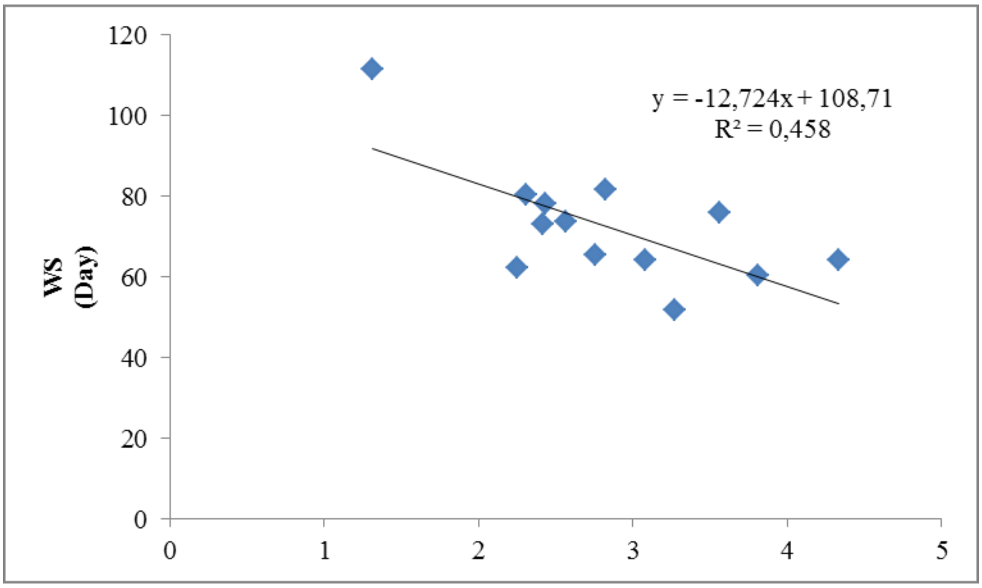

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Graphic 7 – Relation between average Water Stress Day and crop yields under climate baseline conditions.

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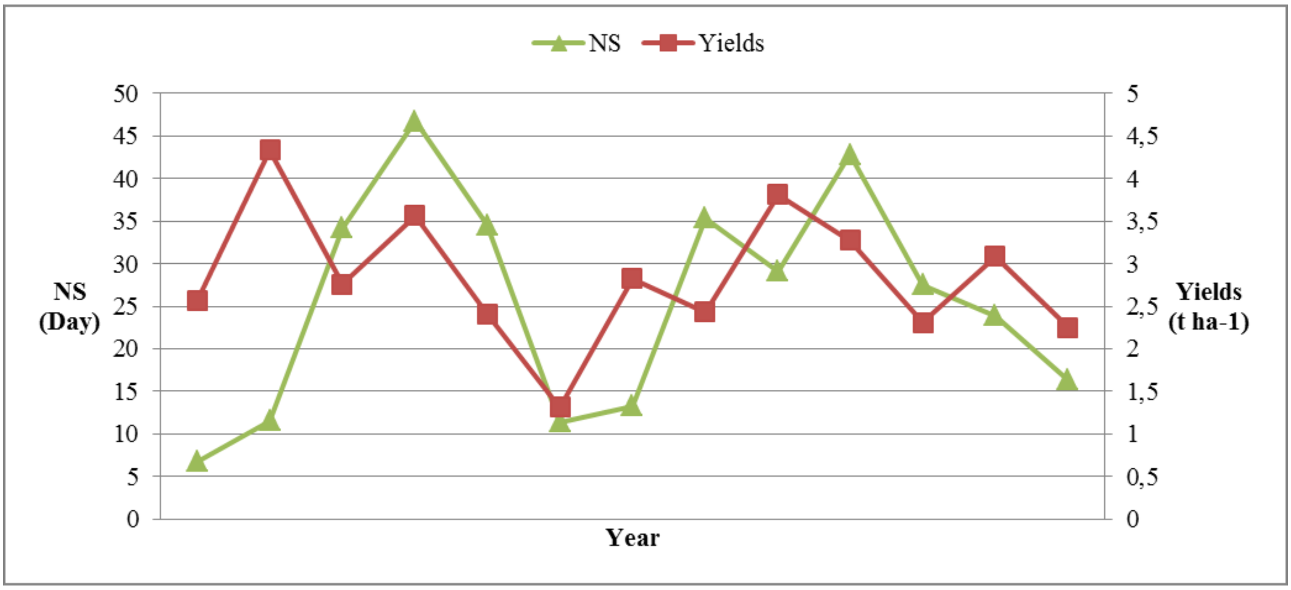
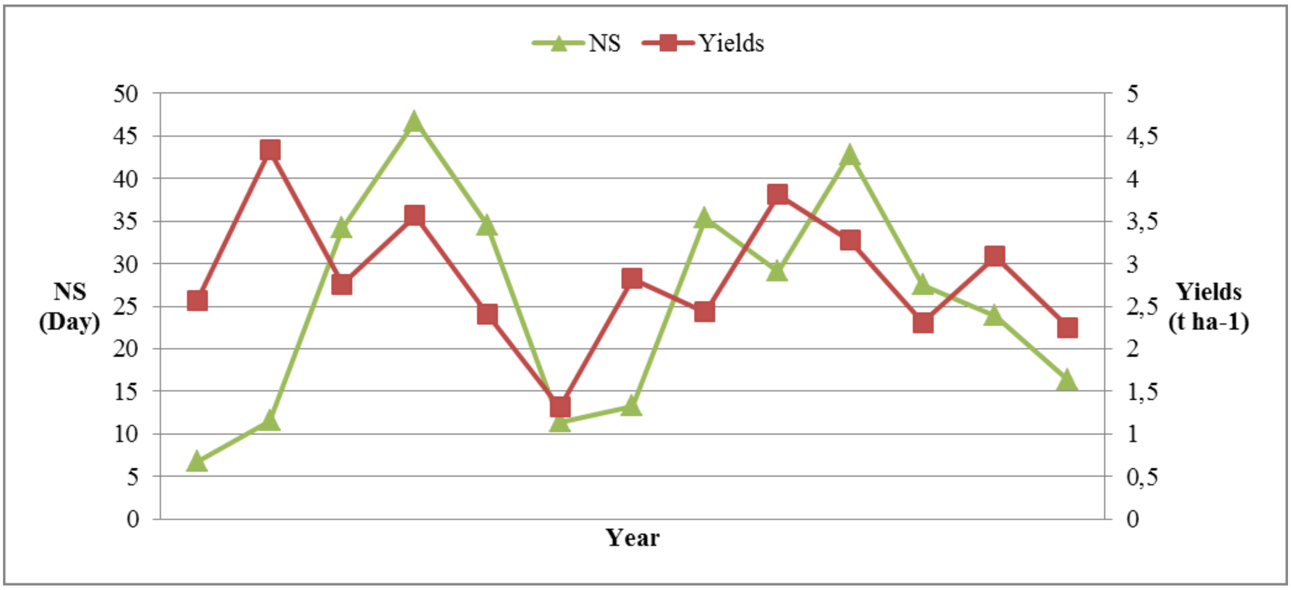
Nitrogen stress



Graphic 9 – Relation between average Nitrogen stress and crop yields under climate baseline conditions.



Graphic 10 – Relation between average Nitrogen stress and crop yields under climate future conditions.

Future nitrogen stress decreased, with a decreasing of 13.2 % (range from -56 to + 125 %). In fact under baseline climatic condition resulted higher than under future climatic conditions: in CP the average was 10.51 days while in CF was 9 days. Also the range changed, so in first situation NS was in the interval 3.3 and 23.26 days, while from 2.65 to 17.77 days in the second case. If consider CV passed from 0.59 to 0.46. The correlation of Pearsons as result of comparison enter CP and CF was 0.40 (P<0.001). Results are also showed in Graphic 9 and 10.

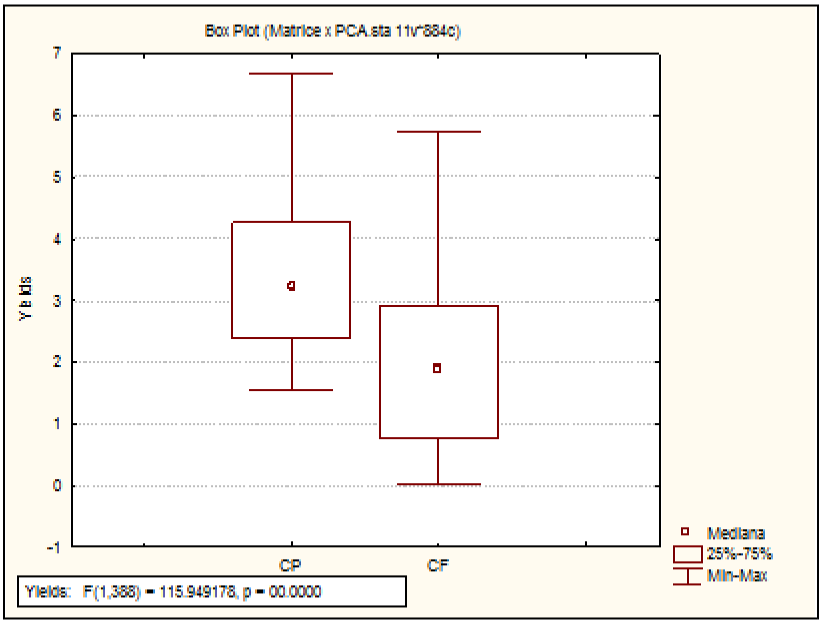
3.4 Climatic change effects with same CO_2 concentrations and any crop stress

The fourth set of results was obtained considering the same climatic conditions of the previous results (CO_2: CP=CF=378 ppm) but any water and nitrogen crop stress (autoirrigation and autofertlization with value same as 1).

3.4.1 Oristano

Impacts of climate change on yield

The simulated average durum wheat yield for the baseline period was 3.5 t/ha, with a CV of 0.32, and ranged from 2.2 to 5.3 t/ha. while under future climate conditions was 2.84 t/ha, with a CV of 0.28, and ranged from 1.31 to 4.33 t/ha, showing a decrease of 15% (ranging from -21.8% to + 44.9 %), respect to baseline conditions. Considering the two series of data, the Pearson's correlation coefficient was 0.70 (p<0.001). Results are also showed throught the box plot in Figure 1.



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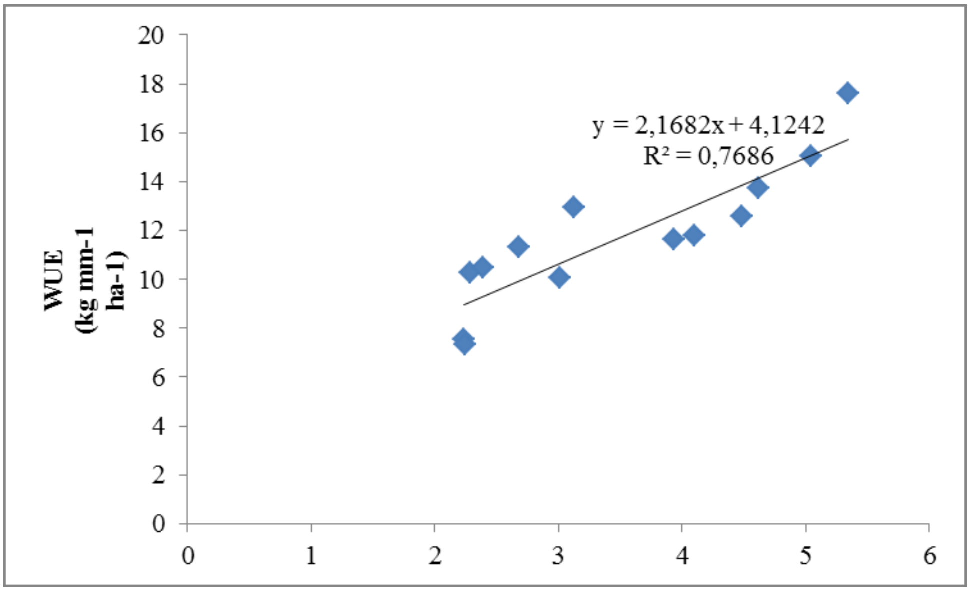


Figure 2 – Correlation between crop and WUE under climatic baseline conditions

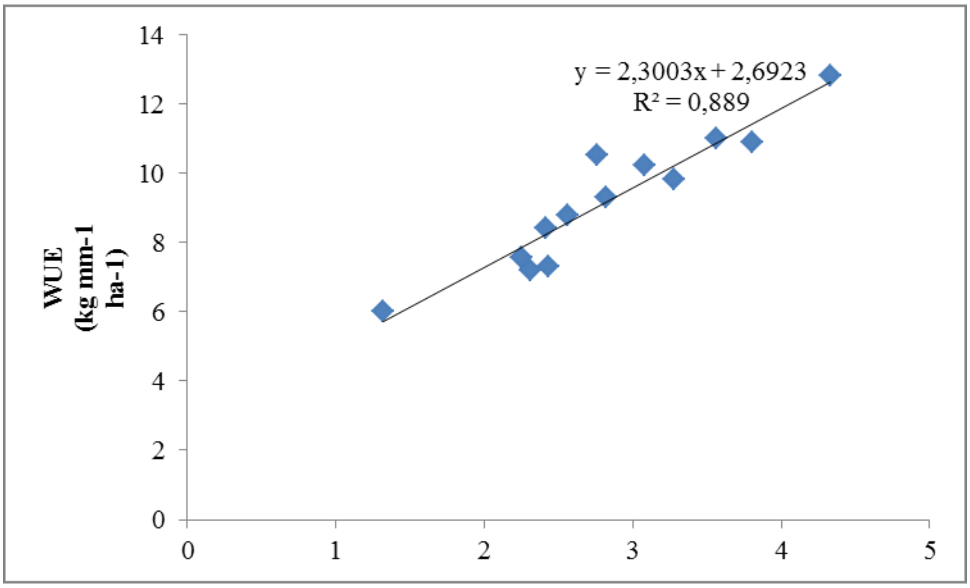
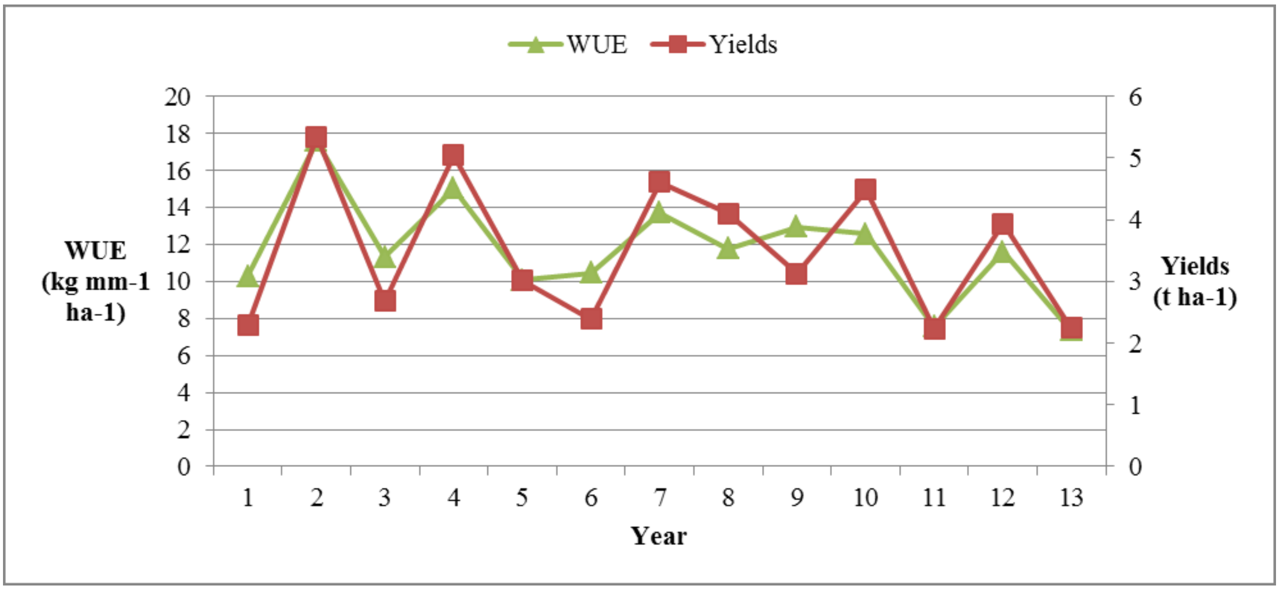


Figure 3 – Correlation between crop yields and wue under climatic future conditions



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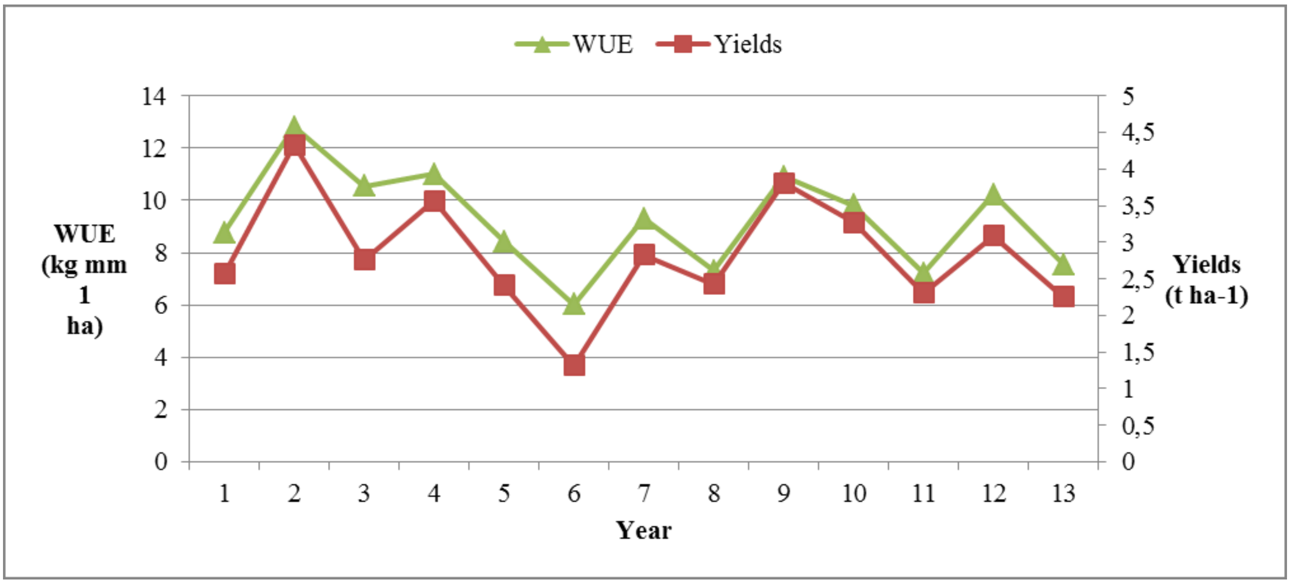

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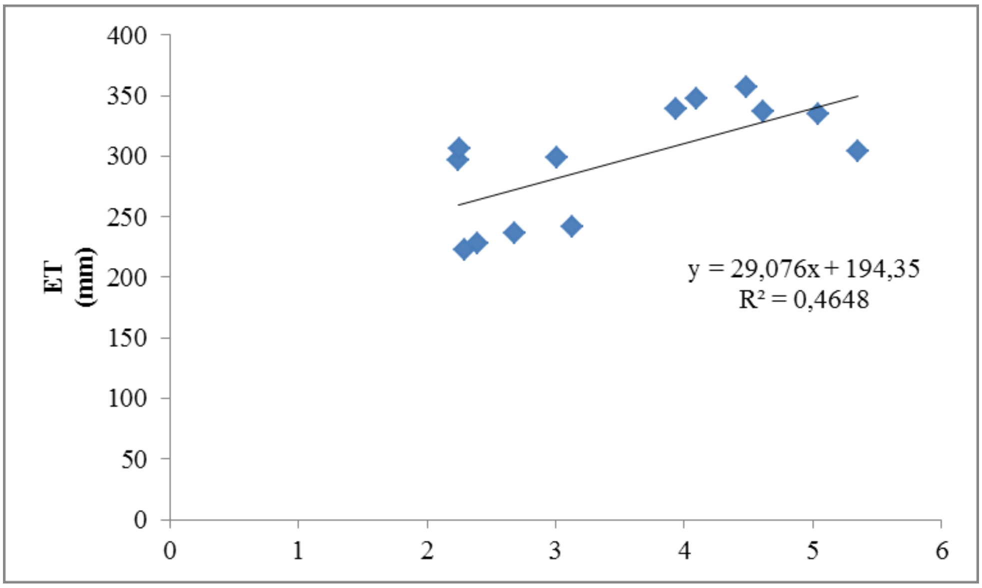

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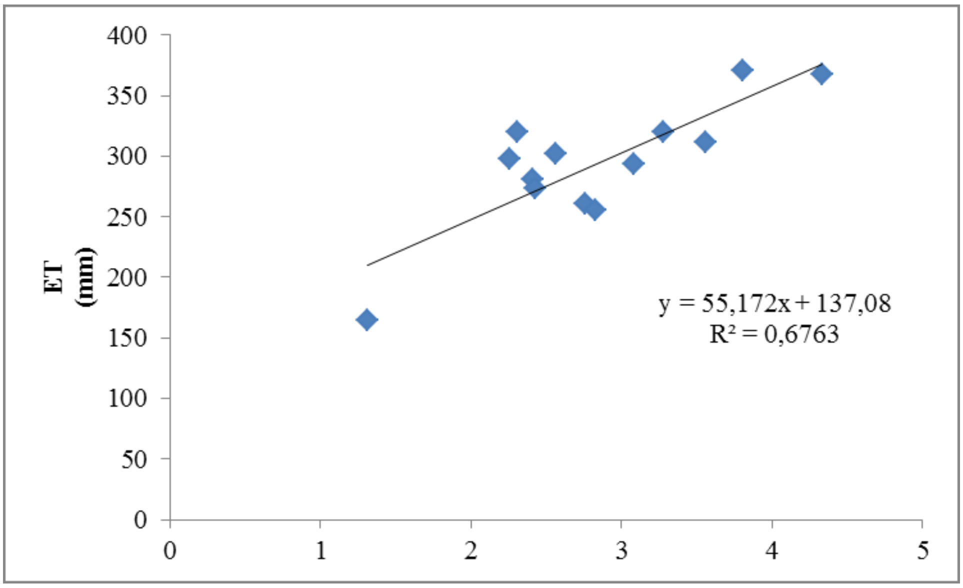
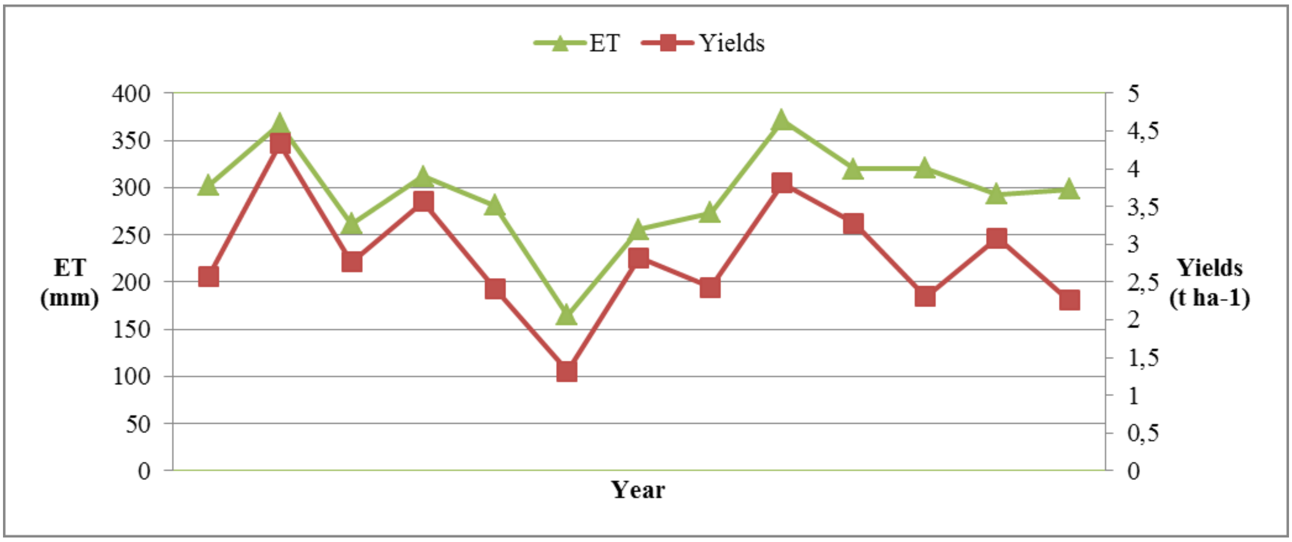


Figure 5 – Correlation between crop and ET under climatic future conditions

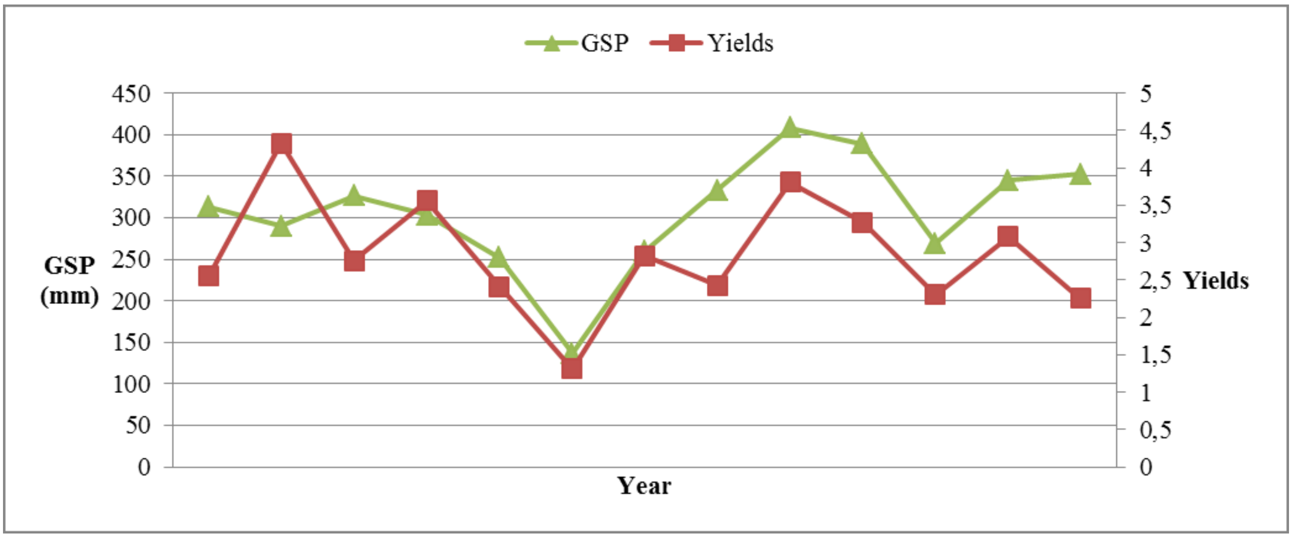
Graphic 3 – Relation between average Evapotranspiration and crop yields under climate baseline conditions.



Graphic 4 – Relation between average Evapotranspiration and crop yields under climate future conditions.

Changes in Growing Season Precipitation

Graphic 5 – Relation between average GSP and crop yields under climate baseline conditions.



Graphic 6 – Relation between average GSP and crop yields under climate future conditions.

Considering GSP, baseline scenario showed an average of 338.5 mm, slightly higher respect to future scenario, when 306 mm were observed. GSP ranged from 206.2 to 506.8 mm in CP, while from 137 to 408 mm in CF. In % values, a decrease of about 6 % was observed in the CF, ranging from – 33.3 to + 53.3 %. Also CV and dev.st. were higher in the CP respect to CF: 0.27 and 93.5 respectively in the fist case, and 0.22 and 66.4 in the second case. Results are also showed in Graphic 5 and 6.

Water Stress

In contrast with ET, future water stress decreased, with a increasing of 107 % (range from 9.16 to 330 %). In fact under baseline climatic condition resulted higher than under future climatic conditions: in CP the average was 41.32 days while in CF was 72.6 days. Also the range changed, so in first situation ET was in the interval 15.32 and 67.67 days, while from 51.70 to 11.46 days. If consider CV passed from 41.32 to 72.56. The correlation of Pearsons as result of comparison enter CP and CF was 0.40 (P<0.001). Figure 6 and 7 showed the correlation between Yields and ET in the baseline and future conditions respectively. Results are also showed in Graphic 7 and 8.

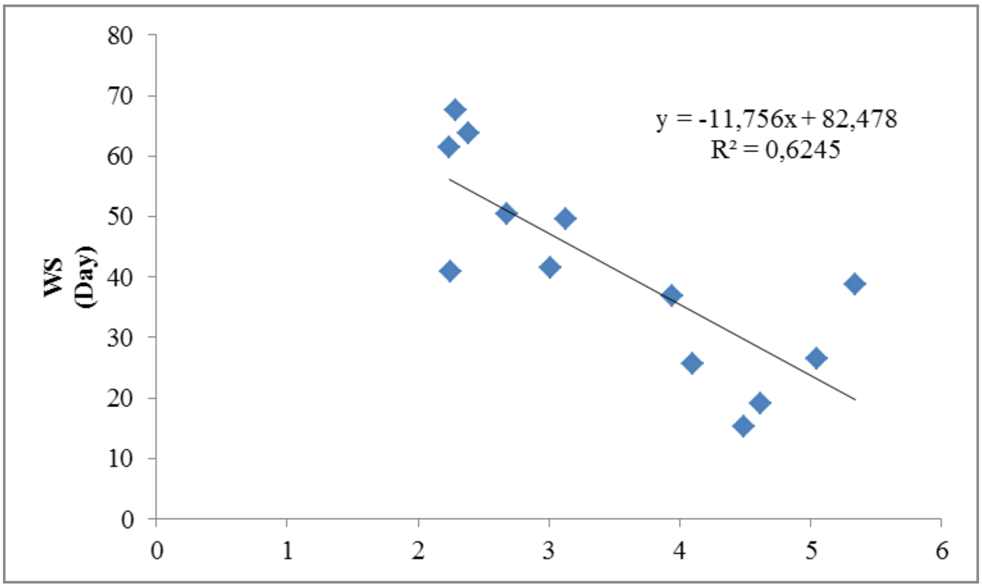


Figure 6 – Correlation between crop and WS under climatic baseline conditions

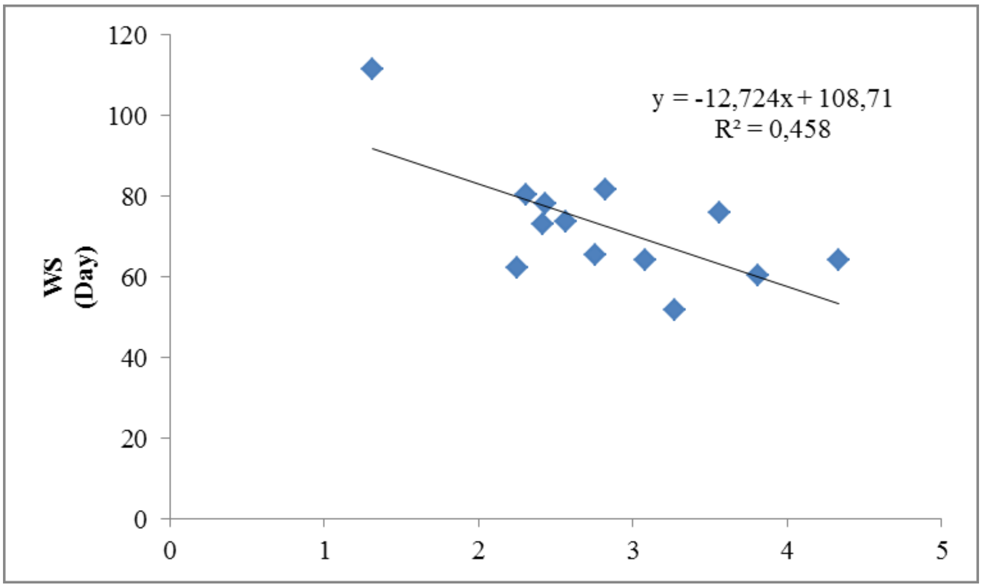
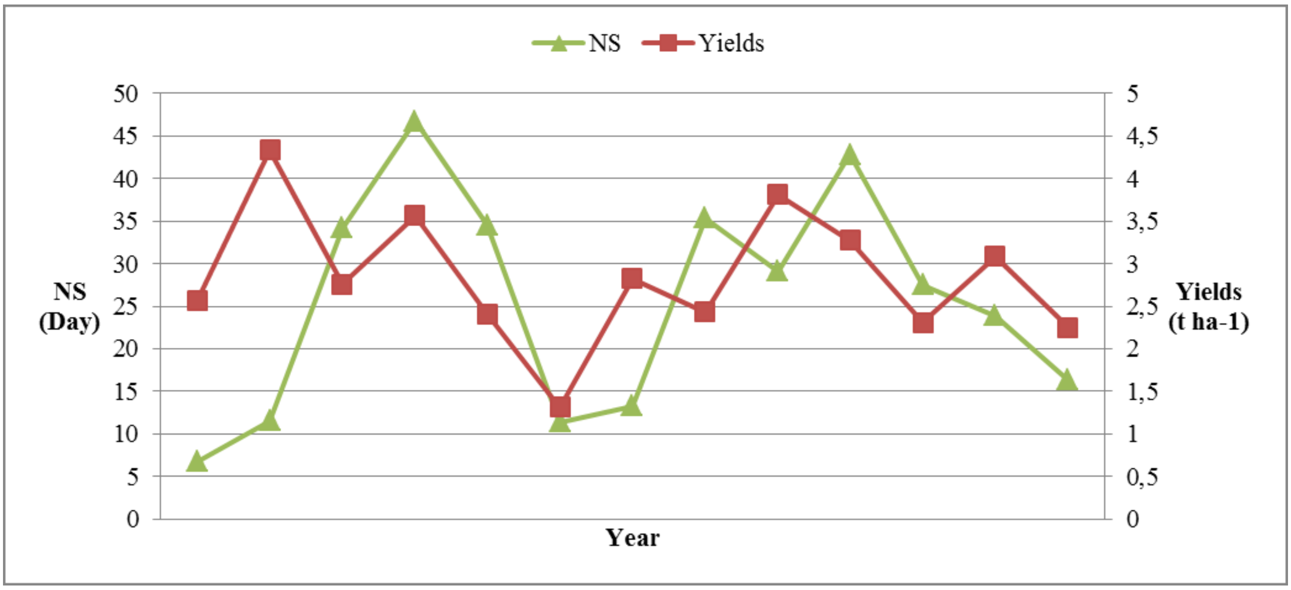


Figure 7 – Correlation between crop and WS under climatic future conditions

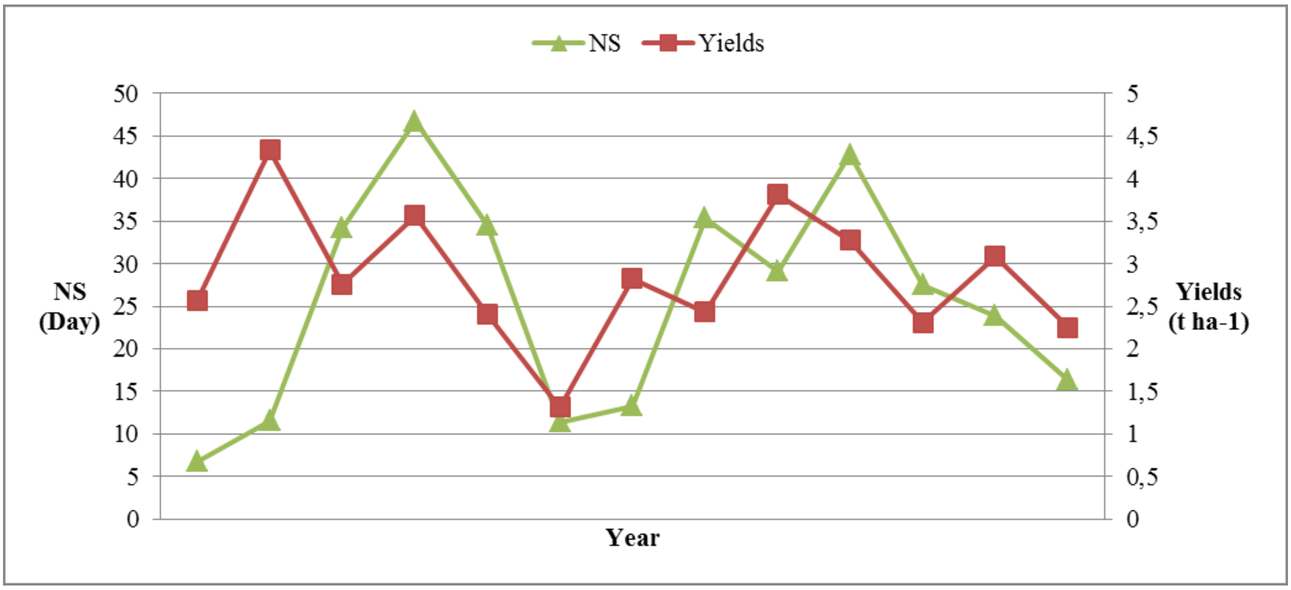
Graphic 7 – Relation between average Water Stress Day and crop yields under climate baseline conditions.

Graphic 8 – Relation between average Water Stress Day and crop yields under climate future conditions.

Nitrogen stress



Graphic 9 – Relation between average Nitrogen stress and crop yields under climate baseline conditions.



Graphic 10 – Relation between average Nitrogen stress and crop yields under climate future conditions.

Future nitrogen stress decreased, with a decreasing of 13.2 % (range from -56 to + 125 %). In fact under baseline climatic condition resulted higher than under future climatic conditions: in CP the average was 10.51 days while in CF was 9 days. Also the range changed, so in first situation NS was in the interval 3.3 and 23.26 days, while from 2.65 to 17.77 days in the second case. If consider CV passed from 0.59 to 0.46. The correlation of Pearsons as result of comparison enter CP and CF was 0.40 (P<0.001). Results are also showed in Graphic 9 and 10.

3.4.2 Benevento

Impacts of climate change on yield

The simulated average durum wheat yield for the baseline period was 3.5 t/ha, with a CV of 0.32, and ranged from 2.2 to 5.3 t/ha. while under future climate conditions was 2.84 t/ha, with a CV of 0.28, and ranged from 1.31 to 4.33 t/ha, showing a decrease of 15% (ranging from -21.8% to + 44.9 %), respect to baseline conditions. Considering the two series of data, the Pearson's correlation coefficient was 0.70 ($p<0.001$). Results are also showed throught the box plot in Figure 1.

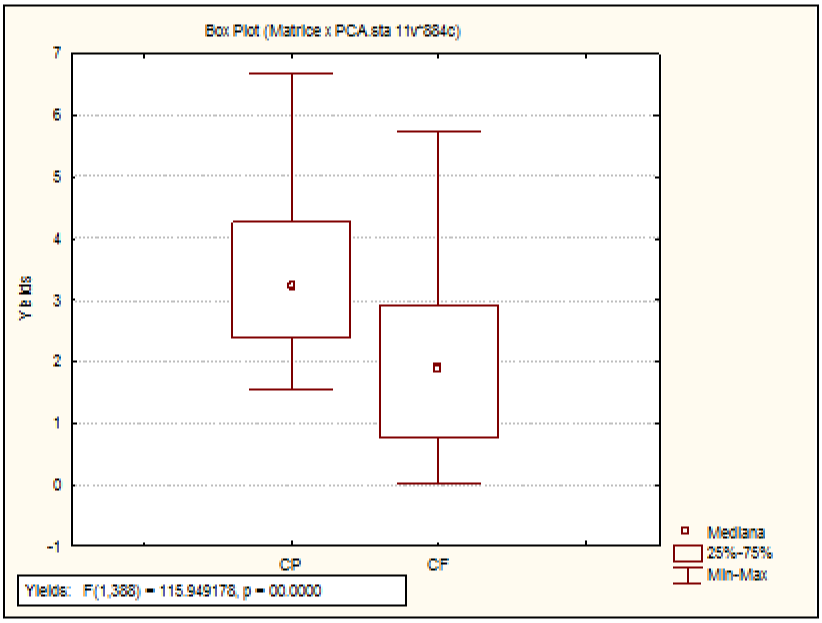


Figure 1 – Durum wheat yields under baseline and future climate in Oristano site.

Water Use Efficiency

Considering the Water Use Efficiency, there was a decrease in the future of 19 % respect to the baseline conditions, with a range from – 42.4 to 2.78%. Analysis of interannual variability under baseline condition indicated an average WUE of 11.71 kg biom/mm H_2O and a range from 7.35 to 17.59 kg biom/mm H_2O. Under future climate, the average WUE was 9.22 kg mm^{-1} ha^{-1}, and it ranged from 6.03 to 12.8 kg biom/mm H_2O. Respect to CP, in the CF was registered a minor variation for WUE, that maybe found a stabilization. Comparison of values under the two climatic scenarios showed a Pearson's correlation coefficient of 0.78 ($p< 0.001$). Figure 2 and 3 showed the correlation between Yields and WUE in the baseline and future conditions respectively. Results are also showed in Graphic 4 and 5.

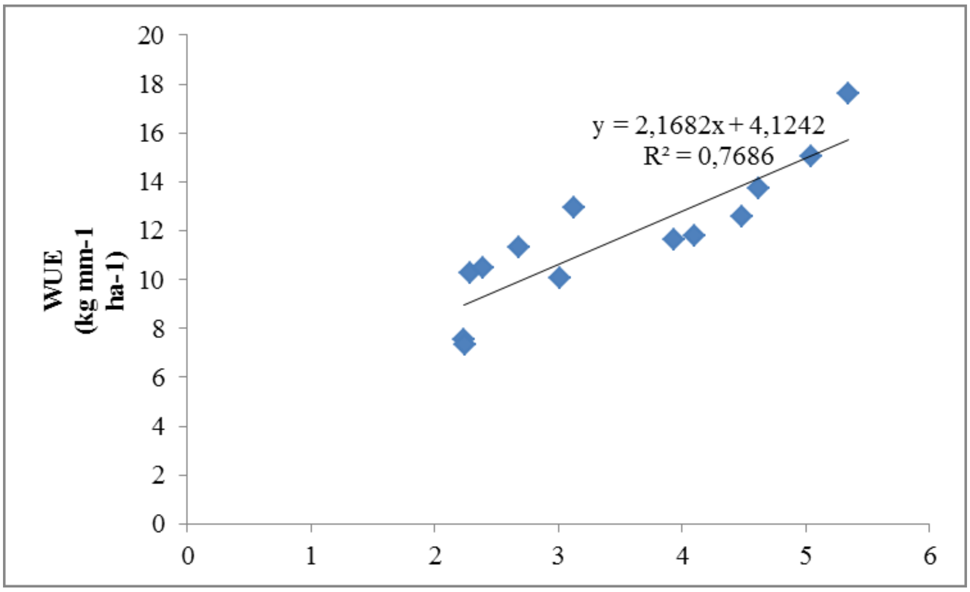


Figure 2 – Correlation between crop and WUE under climatic baseline conditions

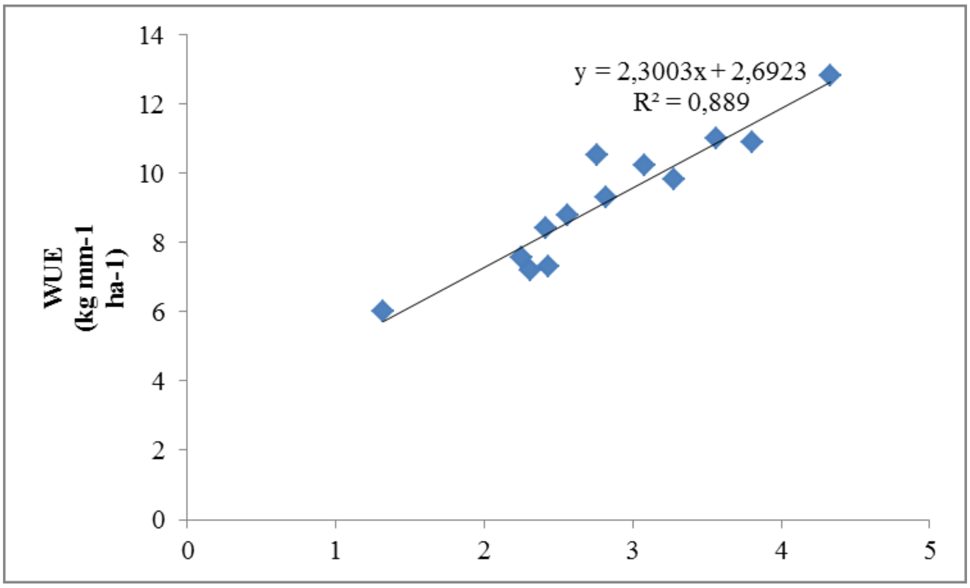
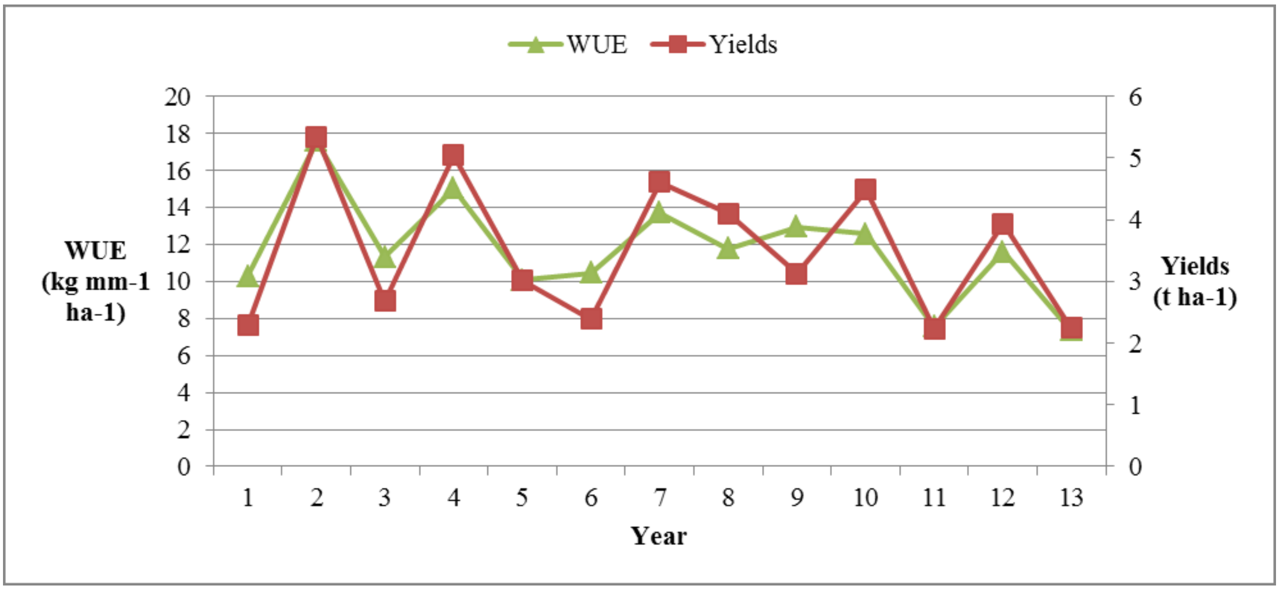
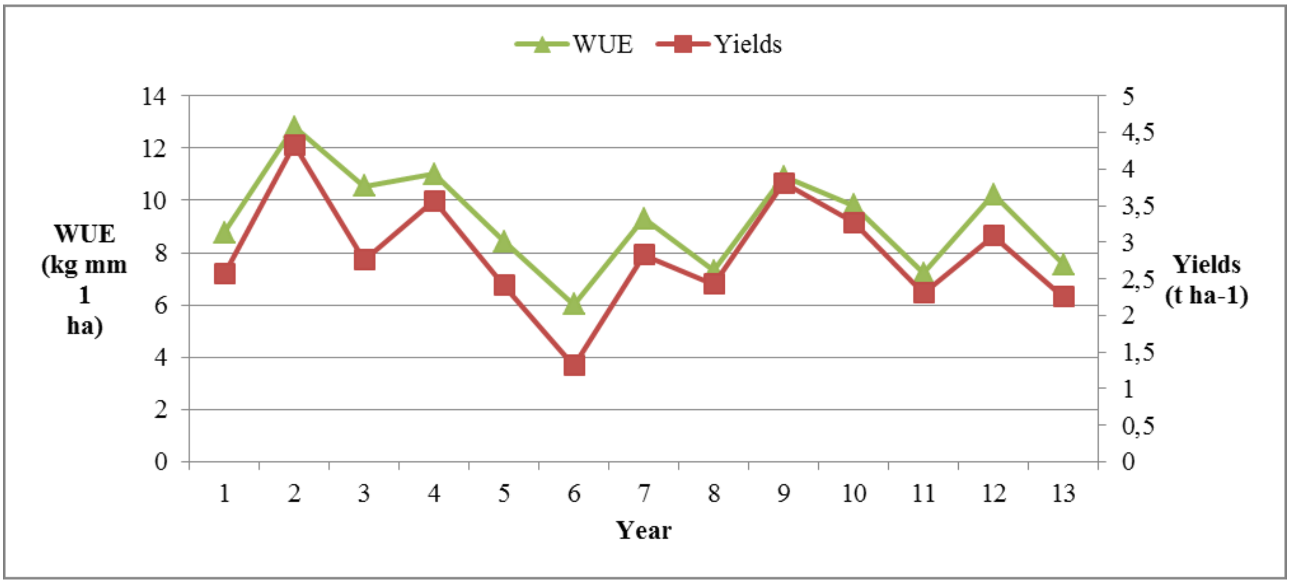


Figure 3 – Correlation between crop yields and wue under climatic future conditions



Graphic 1 – Relation between average Water Use Efficiency and crop yields under climate baseline conditions.



Graphic 2 – Relation between average Water Use Efficiency and crop yields under climate future conditions.

Evapotranspiration

Deviations between baseline climate and future have been observed also for Evapotranspiration. Under baseline climatic conditions average ET was 296,44 mm, with a CV of 0.24 , and a range from 222.47 to 357.17 mm. Respect to the previous conditions, future ET, with an average of 293.8 mm, increased of 1.21 % (-27.7 - + 53.7) and ranged from 164,66 to 371.28 mm, with a CV of 0.17. Comparison of values under the two climatic scenarios showed a Pearson's correlation coefficient of 0.20 ($p< 0.44$). Analysis among wheat yields and evapotranspiration show a higher correlation under future climate ($R^2 = 0.67$). Figure 4 and 5 showed the correlation between Yields and ET in the baseline and future conditions respectively. Results are also showed in Graphic 3 and 4.

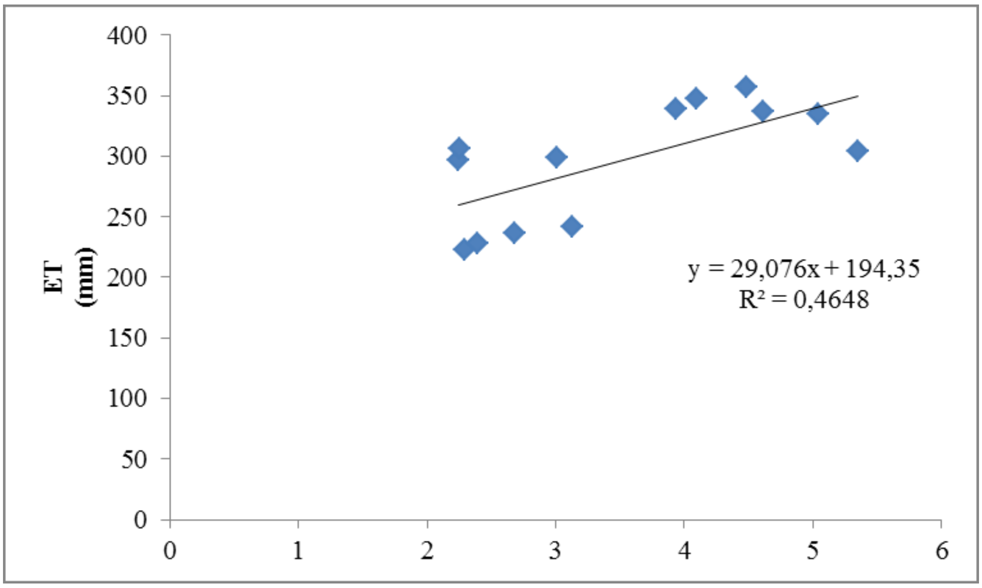


Figure 4 – Correlation between crop and ET under climatic baseline conditions

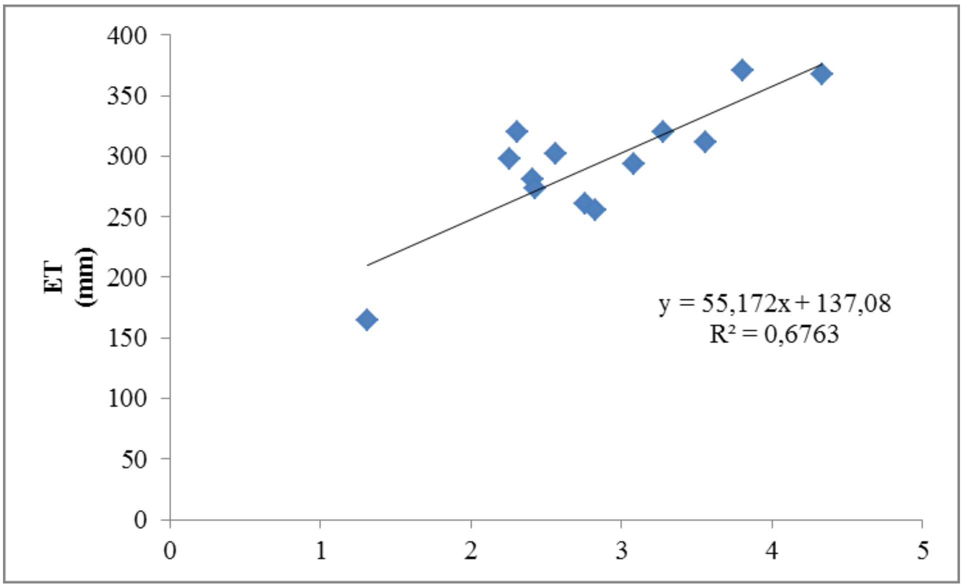
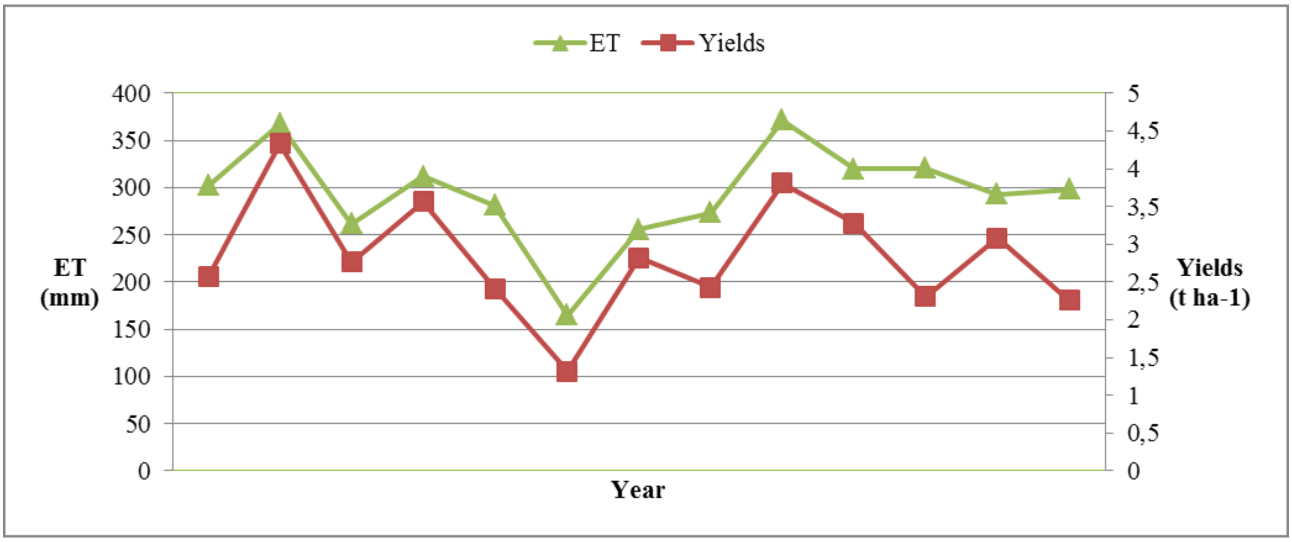


Figure 5 – Correlation between crop and ET under climatic future conditions

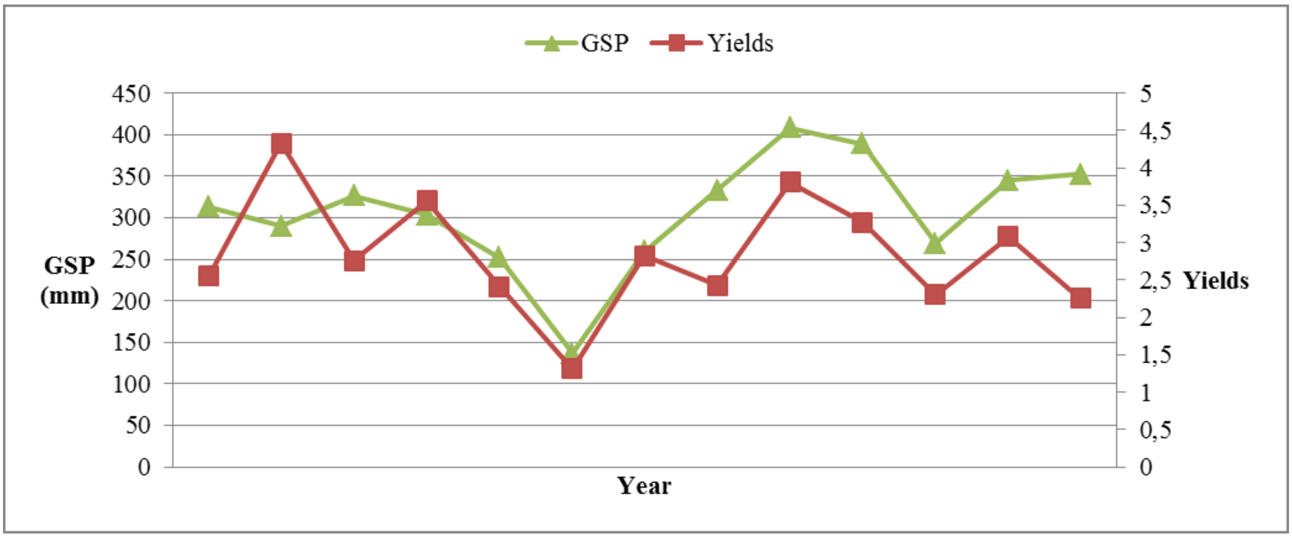
Graphic 3 – Relation between average Evapotranspiration and crop yields under climate baseline conditions.



Graphic 4 – Relation between average Evapotranspiration and crop yields under climate future conditions.

Changes in Growing Season Precipitation

Graphic 5 – Relation between average GSP and crop yields under climate baseline conditions.



Graphic 6 – Relation between average GSP and crop yields under climate future conditions.

Considering GSP, baseline scenario showed an average of 338.5 mm, slightly higher respect to future scenario, when 306 mm were observed. GSP ranged from 206.2 to 506.8 mm in CP, while from 137 to 408 mm in CF. In % values, a decrease of about 6 % was observed in the CF, ranging from – 33.3 to + 53.3 %. Also CV and dev.st. were higher in the CP respect to CF: 0.27 and 93.5 respectively in the fist case, and 0.22 and 66.4 in the second case. Results are also showed in Graphic 5 and 6.

Water Stress

In contrast with ET, future water stress decreased, with a increasing of 107 % (range from 9.16 to 330 %). In fact under baseline climatic condition resulted higher than under future climatic conditions: in CP the average was 41.32 days while in CF was 72.6 days. Also the range changed, so in first situation ET was in the interval 15.32 and 67.67 days, while from 51.70 to 11.46 days. If consider CV passed from 41.32 to 72.56. The correlation of Pearsons as result of comparison enter CP and CF was 0.40 (P<0.001). Figure 6 and 7 showed the correlation between Yields and ET in the baseline and future conditions respectively. Results are also showed in Graphic 7 and 8.

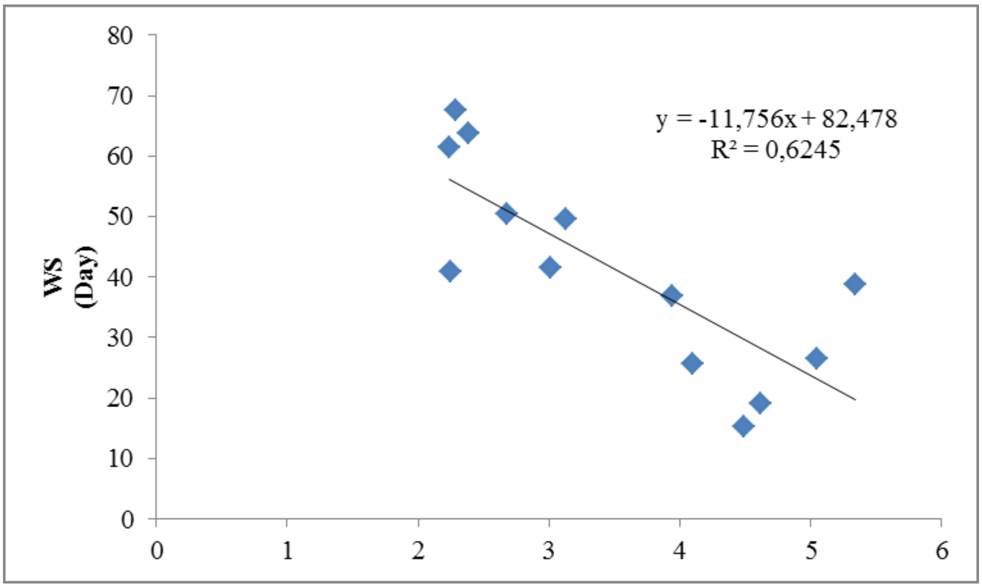


Figure 6 – Correlation between crop and WS under climatic baseline conditions

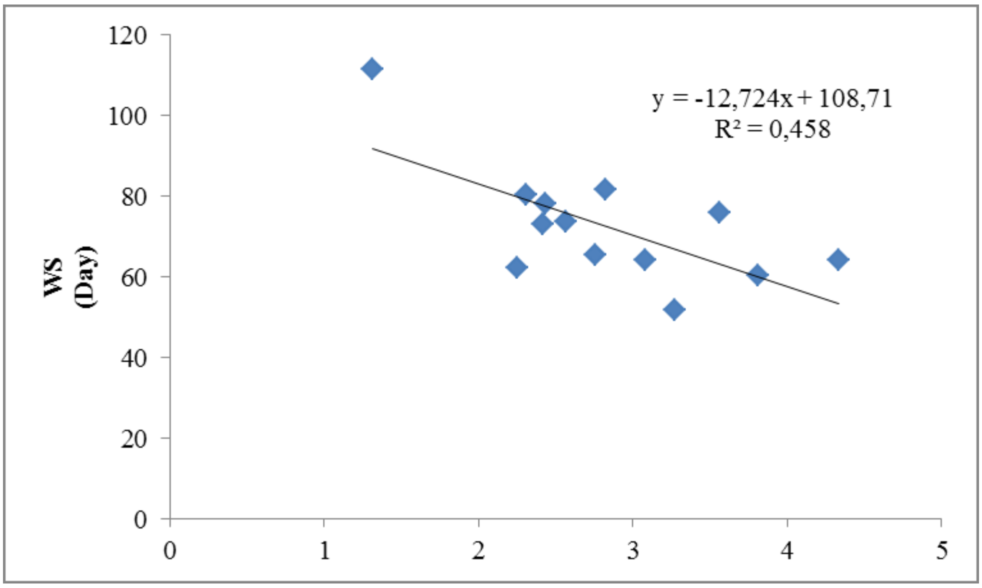
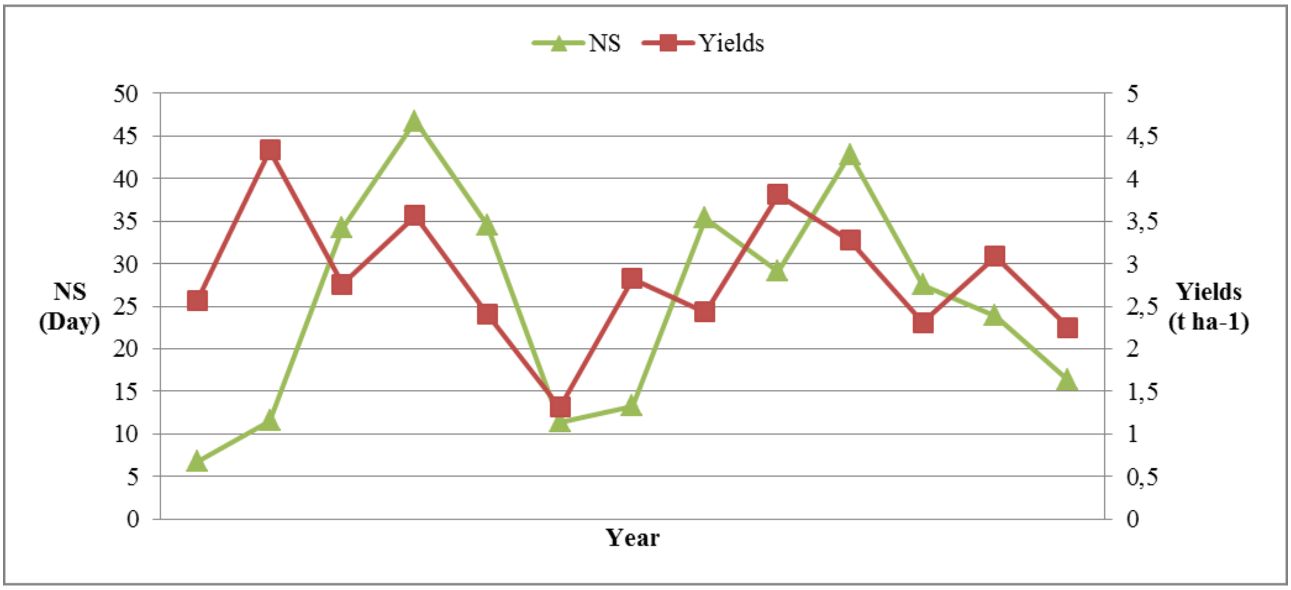


Figure 7 – Correlation between crop and WS under climatic future conditions

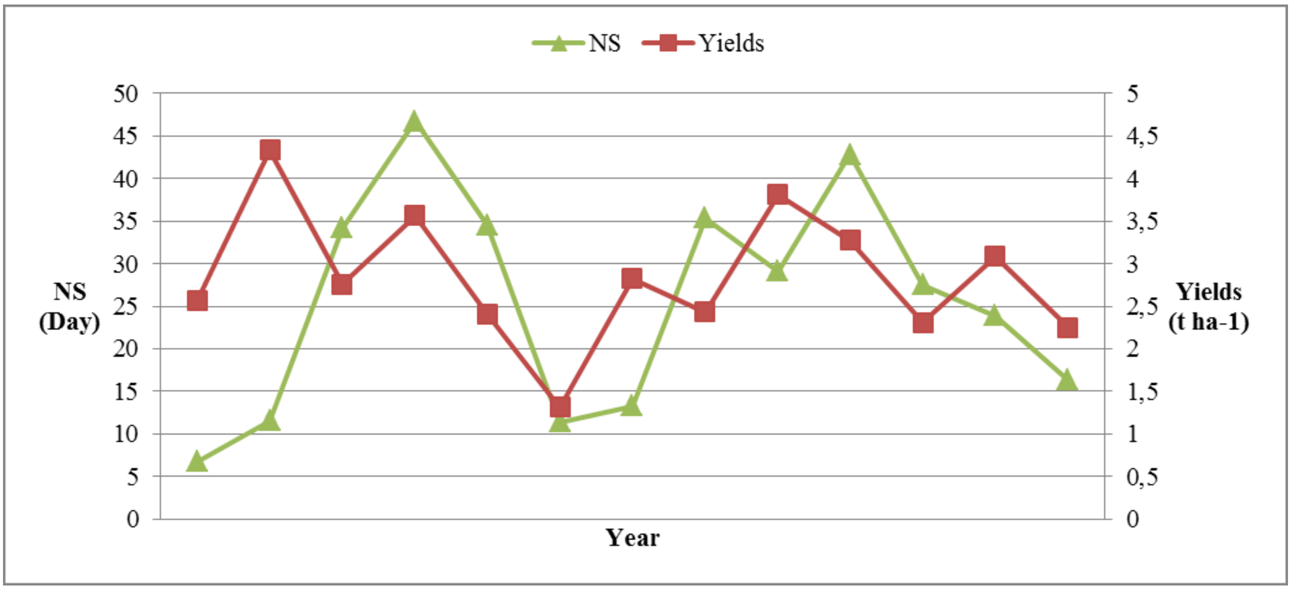
Graphic 7 – Relation between average Water Stress Day and crop yields under climate baseline conditions.

Graphic 8 – Relation between average Water Stress Day and crop yields under climate future conditions.

Nitrogen stress



Graphic 9 – Relation between average Nitrogen stress and crop yields under climate baseline conditions.



Graphic 10 – Relation between average Nitrogen stress and crop yields under climate future conditions.

Future nitrogen stress decreased, with a decreasing of 13.2 % (range from -56 to + 125 %). In fact under baseline climatic condition resulted higher than under future climatic conditions: in CP the average was 10.51 days while in CF was 9 days. Also the range changed, so in first situation NS was in the interval 3.3 and 23.26 days, while from 2.65 to 17.77 days in the second case. If consider CV passed from 0.59 to 0.46. The correlation of Pearsons as result of comparison enter CP and CF was 0.40 (P<0.001). Results are also showed in Graphic 9 and 10.

3.4.3 Ancona

Impacts of climate change on yield

The simulated average durum wheat yield for the baseline period was 3.5 t/ha, with a CV of 0.32, and ranged from 2.2 to 5.3 t/ha. while under future climate conditions was 2.84 t/ha, with a CV of 0.28, and ranged from 1.31 to 4.33 t/ha, showing a decrease of 15% (ranging from -21.8% to + 44.9 %), respect to baseline conditions. Considering the two series of data, the Pearson's correlation coefficient was 0.70 ($p<0.001$). Results are also showed throught the box plot in Figure 1.

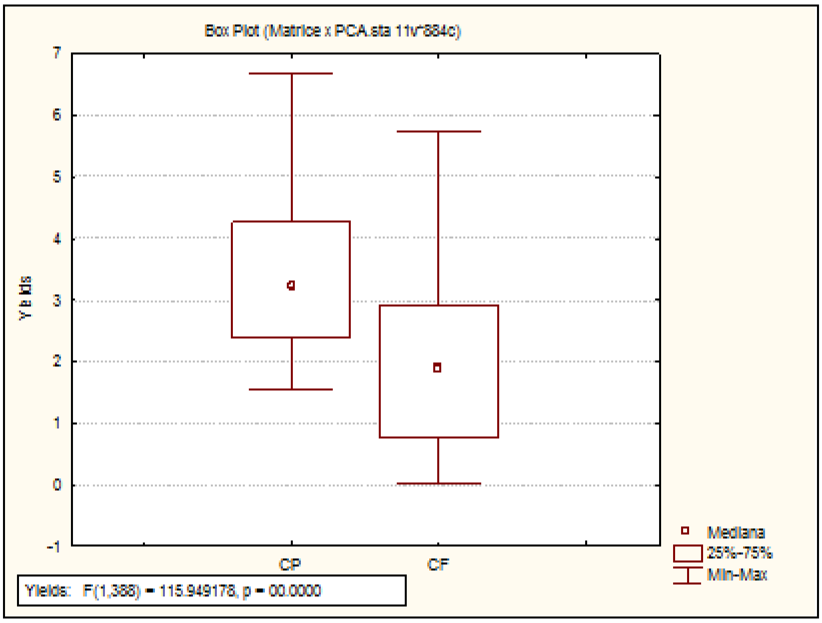


Figure 1 – Durum wheat yields under baseline and future climate in Oristano site.

Water Use Efficiency

Considering the Water Use Efficiency, there was a decrease in the future of 19 % respect to the baseline conditions, with a range from – 42.4 to 2.78%. Analysis of interannual variability under baseline condition indicated an average WUE of 11.71 kg biom/mm H_2O and a range from 7.35 to 17.59 kg biom/mm H_2O. Under future climate, the average WUE was 9.22 kg mm^{-1} ha $^{-1}$, and it ranged from 6.03 to 12.8 kg biom/mm H_2O. Respect to CP, in the CF was registered a minor variation for WUE, that maybe found a stabilization. Comparison of values under the two climatic scenarios showed a Pearson's correlation coefficient of 0.78 ($p< 0.001$). Figure 2 and 3 showed the correlation between Yields and WUE in the baseline and future conditions respectively. Results are also showed in Graphic 4 and 5.

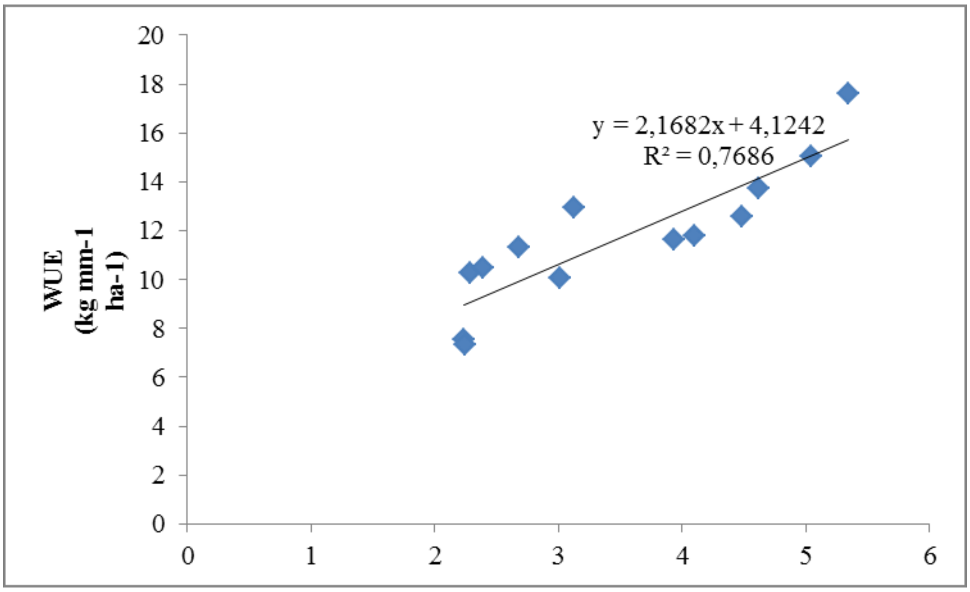


Figure 2 – Correlation between crop and WUE under climatic baseline conditions

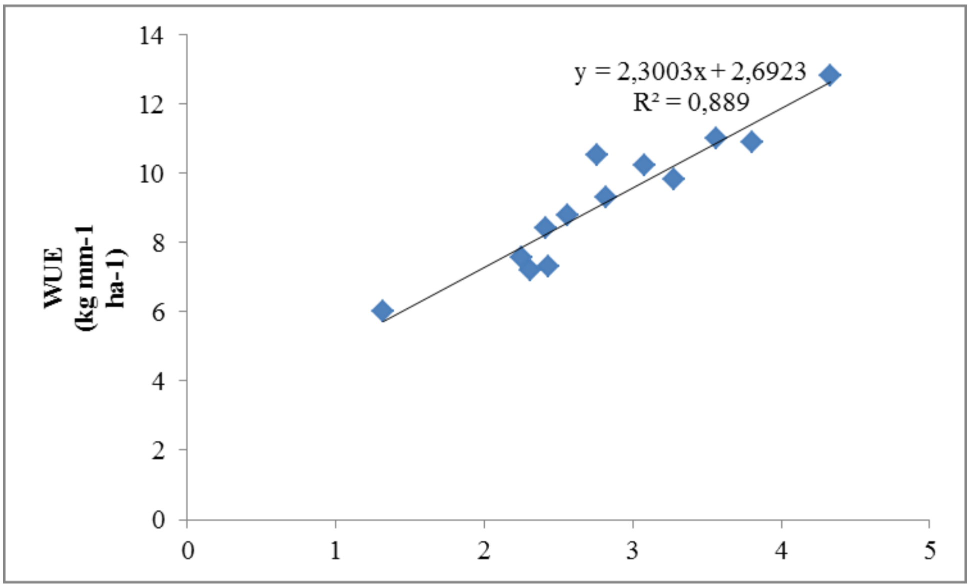
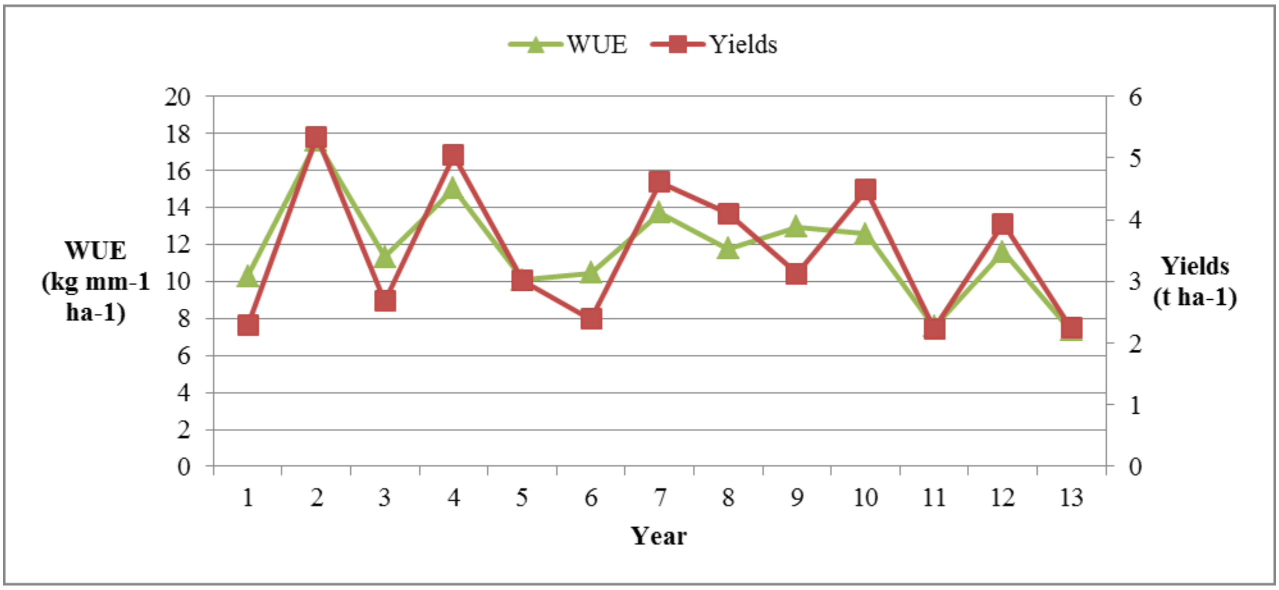
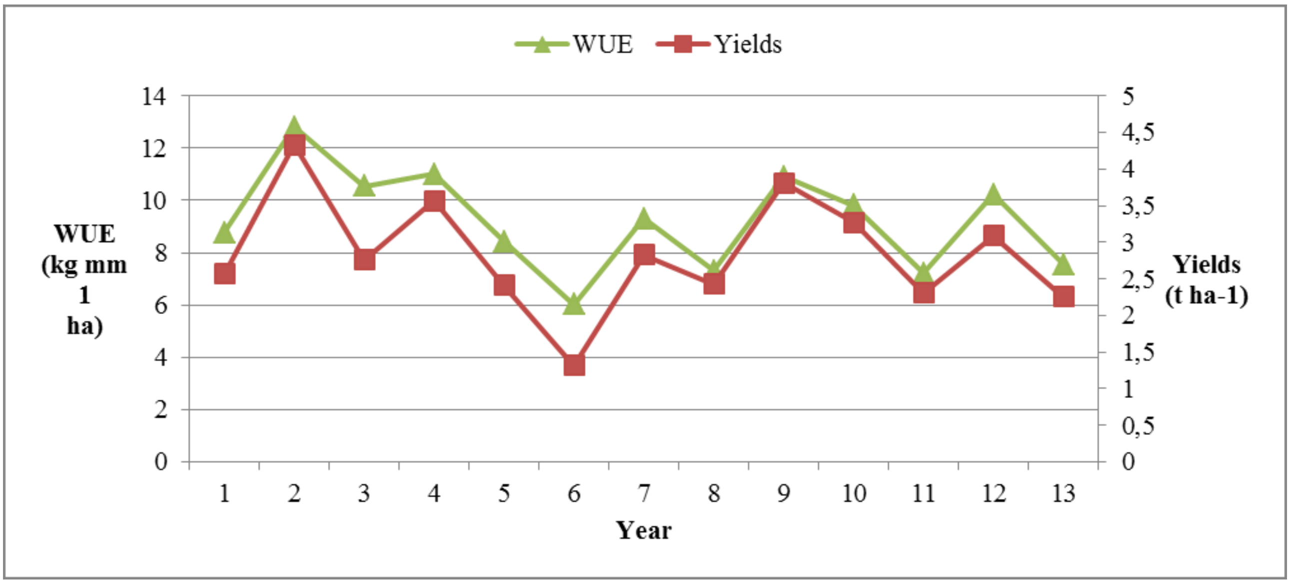


Figure 3 – Correlation between crop yields and wue under climatic future conditions



Graphic 1 – Relation between average Water Use Efficiency and crop yields under climate baseline conditions.



Graphic 2 – Relation between average Water Use Efficiency and crop yields under climate future conditions.

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Deviations between baseline climate and future have been observed also for Evapotranspiration. Under baseline climatic conditions average ET was 296,44 mm, with a CV of 0.24 , and a range from 222.47 to 357.17 mm. Respect to the previous conditions, future ET, with an average of 293.8 mm, increased of 1.21 % (-27.7 - + 53.7) and ranged from 164,66 to 371.28 mm, with a CV of 0.17. Comparison of values under the two climatic scenarios showed a Pearson's correlation coefficient of 0.20 ($p< 0.44$). Analysis among wheat yields and evapotranspiration show a higher correlation under future climate ($R^2 = 0.67$). Figure 4 and 5 showed the correlation between Yields and ET in the baseline and future conditions respectively. Results are also showed in Graphic 3 and 4.

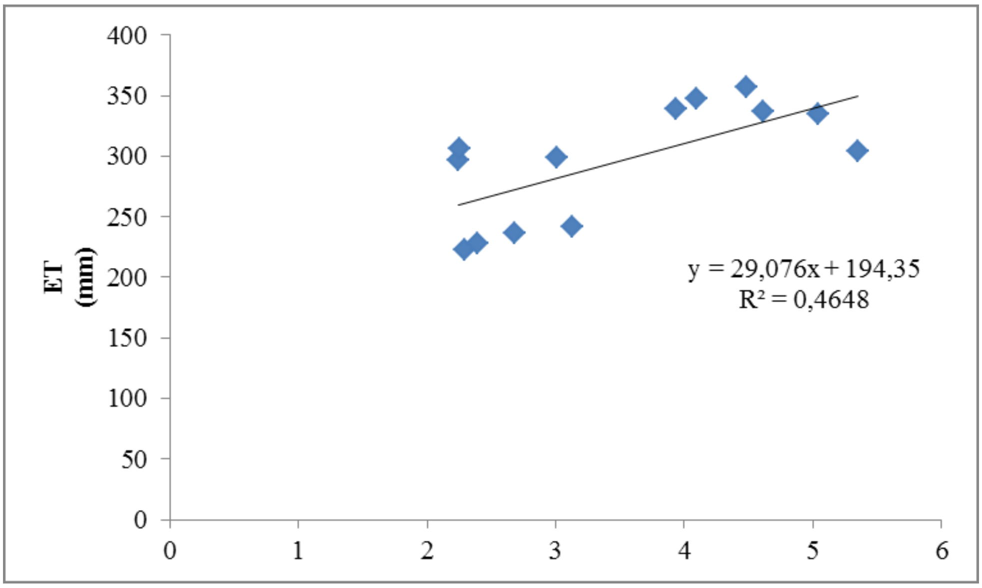


Figure 4 – Correlation between crop and ET under climatic baseline conditions

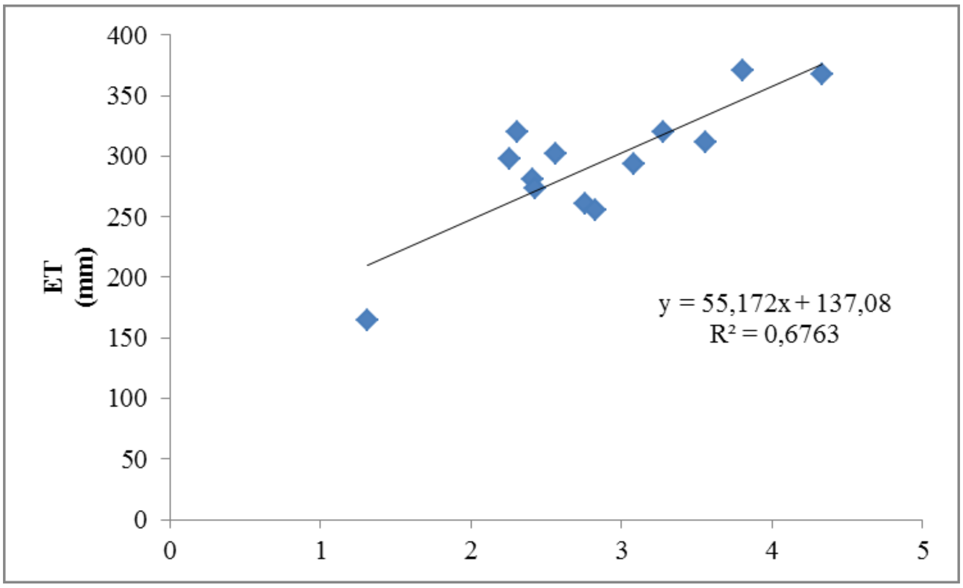
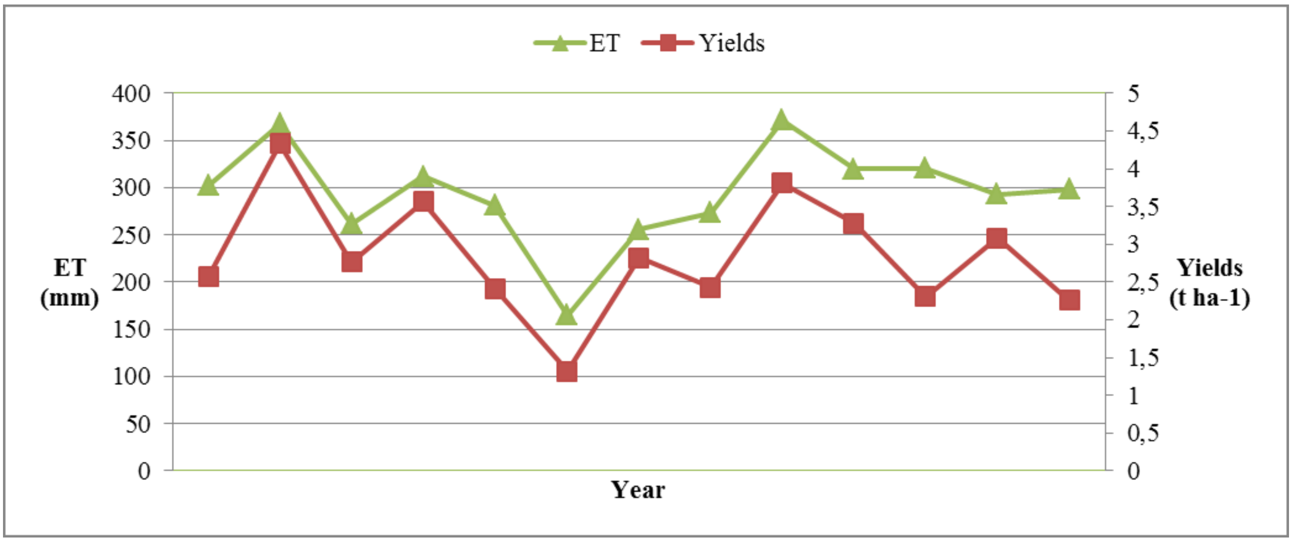


Figure 5 – Correlation between crop and ET under climatic future conditions

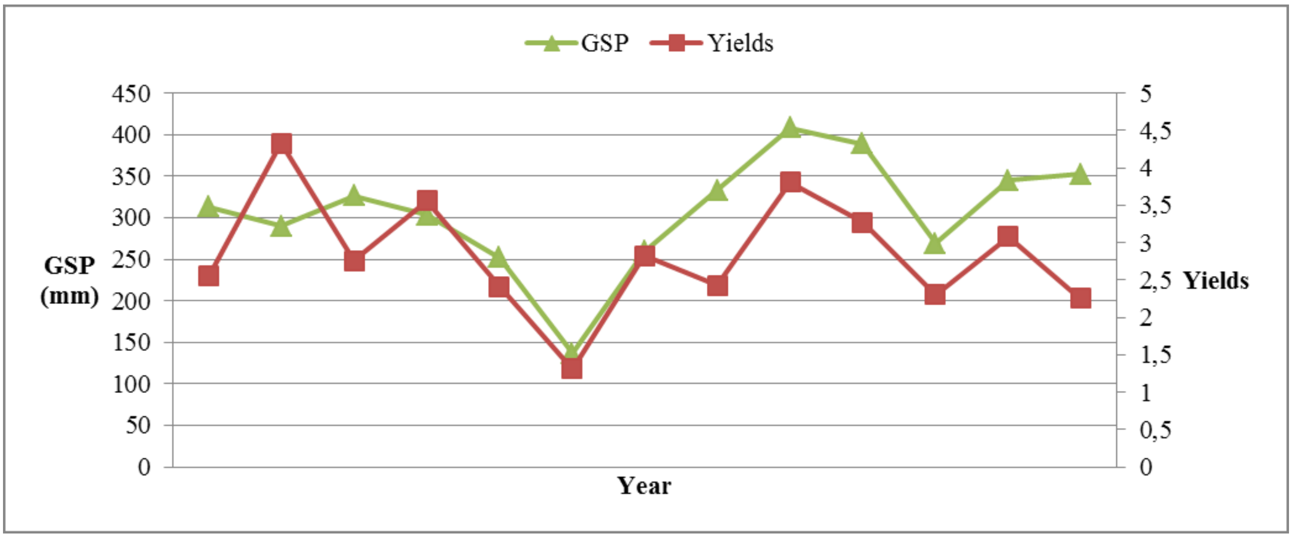
Graphic 3 – Relation between average Evapotranspiration and crop yields under climate baseline conditions.



Graphic 4 – Relation between average Evapotranspiration and crop yields under climate future conditions.

Changes in Growing Season Precipitation

Graphic 5 – Relation between average GSP and crop yields under climate baseline conditions.



Graphic 6 – Relation between average GSP and crop yields under climate future conditions.

Considering GSP, baseline scenario showed an average of 338.5 mm, slightly higher respect to future scenario, when 306 mm were observed. GSP ranged from 206.2 to 506.8 mm in CP, while from 137 to 408 mm in CF. In % values, a decrease of about 6 % was observed in the CF, ranging from – 33.3 to + 53.3 %. Also CV and dev.st. were higher in the CP respect to CF: 0.27 and 93.5 respectively in the fist case, and 0.22 and 66.4 in the second case. Results are also showed in Graphic 5 and 6.

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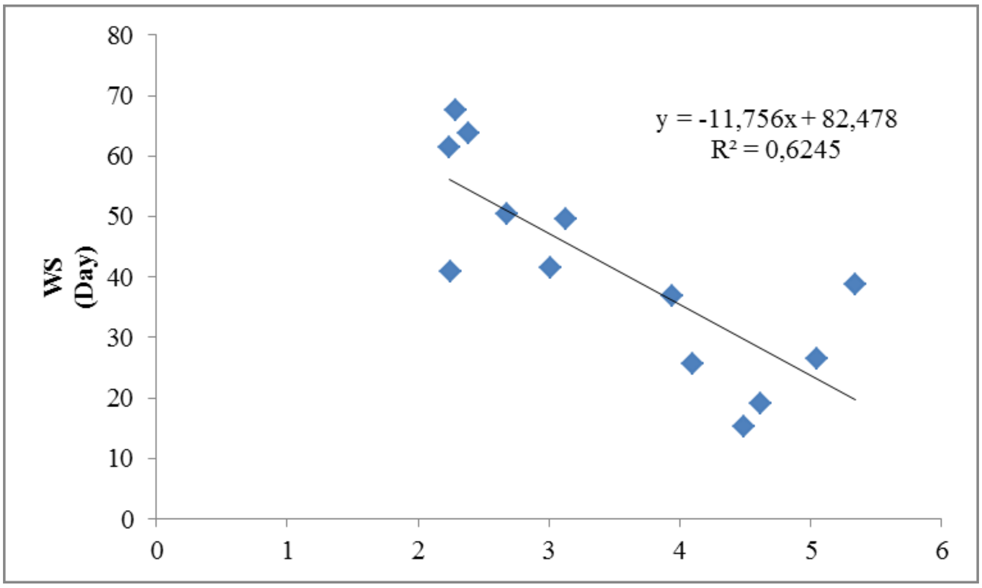

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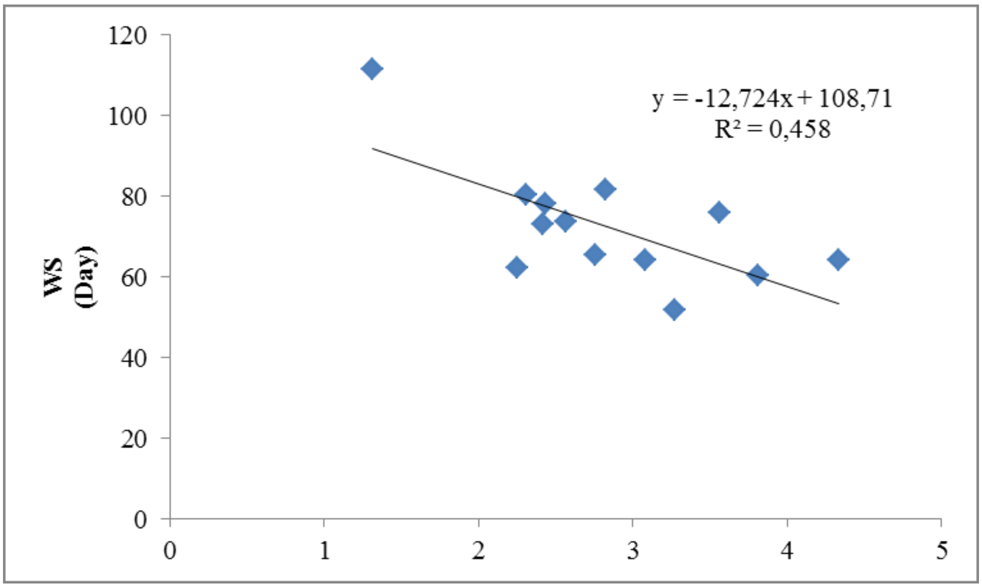
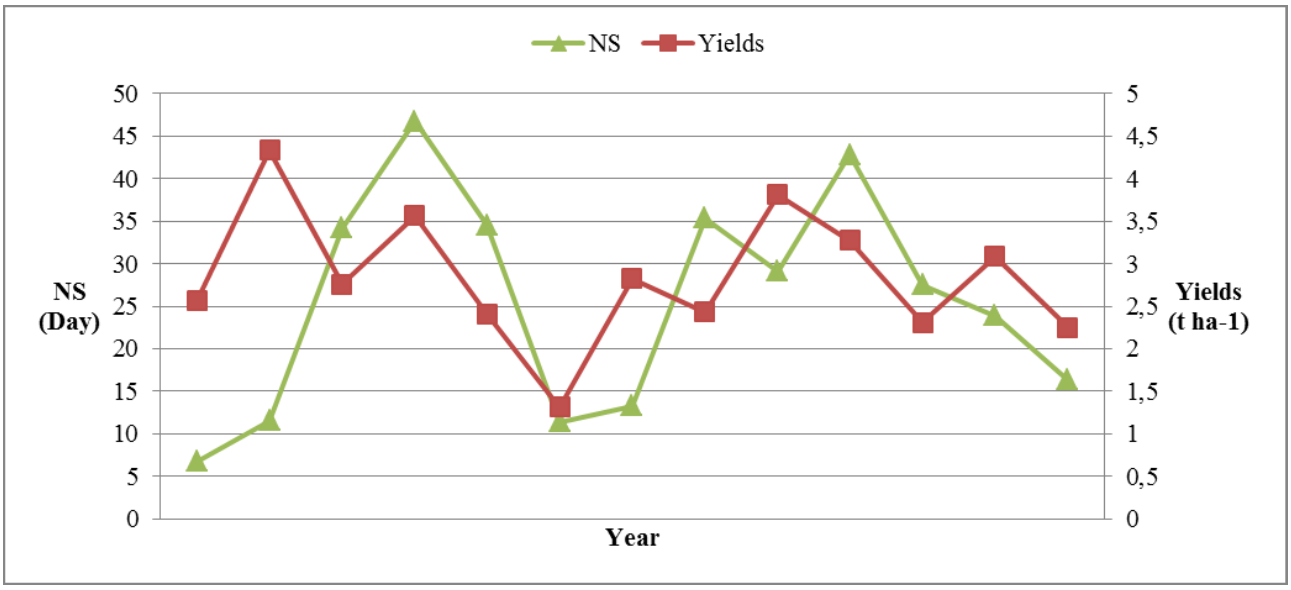


Figure 7 – Correlation between crop and WS under climatic future conditions

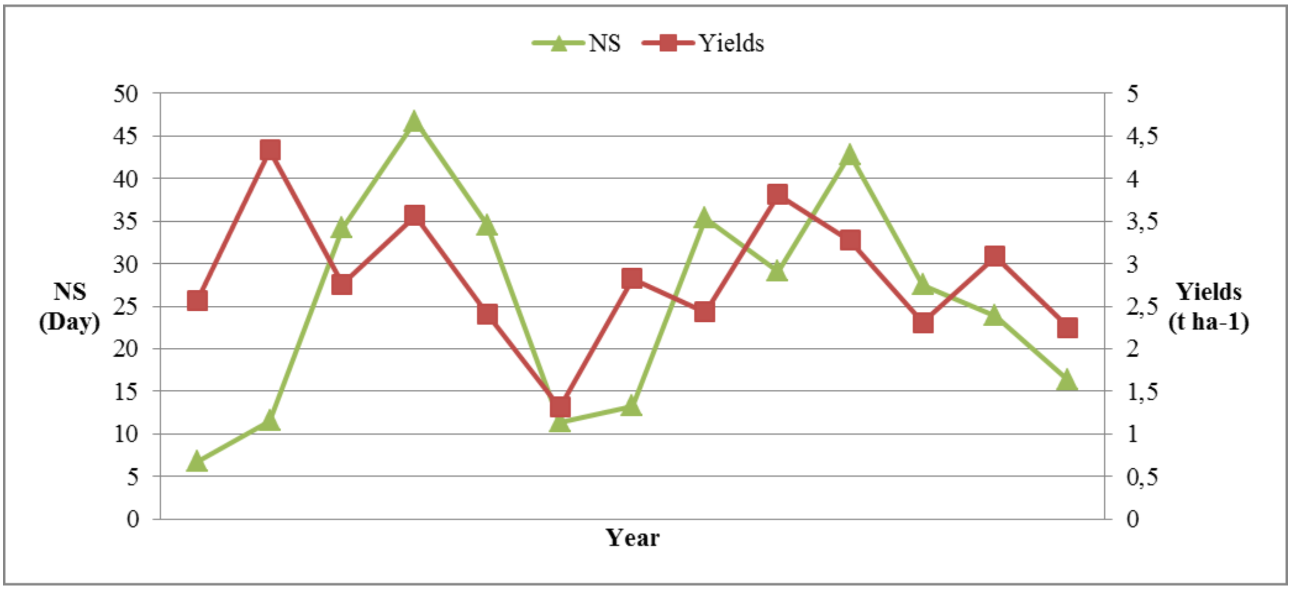
Graphic 7 – Relation between average Water Stress Day and crop yields under climate baseline conditions.

Graphic 8 – Relation between average Water Stress Day and crop yields under climate future conditions.

Nitrogen stress



Graphic 9 – Relation between average Nitrogen stress and crop yields under climate baseline conditions.



Graphic 10 – Relation between average Nitrogen stress and crop yields under climate future conditions.

Future nitrogen stress decreased, with a decreasing of 13.2 % (range from -56 to + 125 %). In fact under baseline climatic condition resulted higher than under future climatic conditions: in CP the average was 10.51 days while in CF was 9 days. Also the range changed, so in first situation NS was in the interval 3.3 and 23.26 days, while from 2.65 to 17.77 days in the second case. If consider CV passed from 0.59 to 0.46. The correlation of Pearsons as result of comparison enter CP and CF was 0.40 ($P<0.001$). Results are also showed in Graphic 9 and 10.

Chapter 4

Discussion

Epic model performance

The first observation concerned the performance of the Epic model that was useful to model crop growth in relation to climate change. It can be considered a good tool to retained and used to predict yield response to climate change under Mediterranean conditions and for decision supports at farm level to test crop management strategies and at global scale to evaluate crop response to climate change (Rinaldi, 2011). The model showed a good capacity to simulate wheat yields, as observed in the validation section, especially to simulate area characterized by homogeneus weather, soil, landscape, crop rotation and management system parameters[85], according with the experience of many authors that used it to compared simulated winter wheat with actual yields (Thomson et al., 2006)[88a] and other epic studies The same was consistent with the results reported by Farina et al., 2011, where Epic model was chosen for its capacity to simultaneously simulating soil and plant processes in response to climate, including simulated processes as fertilizer and irrigation effects on crop yield [68-69-85]. This is also in according with results reported by Zhao et al., 2013.

4.1 Baseline climate effects

4.1.1 Vulnerabilities and climate impacts

4.1.1.1 Impacts on crop productivity

Generally, in Mediterranean countries cereal yields were limited by water availability, heat stress and the short duration

Results showed for Oristano site were in according to Ferrise (2011) that estimated wheat yields, down to 3.5 t/ha for southern areas of the Mediterranean Basin. However, the climatic future scenario shown a wheat yields decreasing of 15 %. This negative trend was in according with other studies (Rinaldi et al., 2011) and were also in agreement with other European – scale assessment of the productivity of wheat (Harrison et al., 1995). For both the other two sites, simulated yields in the future increased of 21 and 4 % for Benevento and Ancona respectively. Similar results were in according to Semenov and Shewry, where modeled yields were on average 15% higher than for the baseline. It is possible to explain the decline of biomass production with the decreasing of WUE.

An important increase of Water Stress days was registered, also with a small decreasing of Evapotraspiration. This is in contrast with some previous studies as the explanation done by Rinaldi et al, 2011 where the main factor responsible for the reduction of crop yields was the increase of average temperatures in the future, that also influenced the duration of growth. However the same study put rainfall like an other major factor which influenced the crop yield, more in rainfed conditions like in Oristano site. These results suggest that the effect of precipitation patterns have important consequences for wheat production in Mediterranean area, in particular for site characterized by low rainfall. Average yields of cereal crops under water limited conditions, such as in Mediterranean area, are also determined by crop water use and water use efficiency. The same patterns could not be applied with CO_2 increases (378 ppm of present scenarios against 408 ppm of future scenario). In fact in any site considered, this factor had an important rule on crop yields: only in Oristano site future wheat yields decreased.

4.1.1.2 Impacts on the main variables: WUE, ET, GSP, WS and NS

A first parametric analysis, considering as main discriminants Year, Site, Climate, Water Use Efficiency, Evapotranspiration, Growing Season Precipitation, Nitrogen Stress and Water Stress, showed a positive correlation between yields and site. The same trend was not observed between yields and climate. Positive correlation existed also analyzing yields and the other parameters (WUE, ET, GSP e WS) while resulted less evident for NS. The first series of results were obtained considering any manual irrigation and fertilization ratio distributed by Epic Model.

In the same way of Oristano wheat yields, also Water Use Efficiency decreased of about 15 and 19 % respectively, as shown in Rinaldi et al., 2011, while Benevento and Ancona showed an increase of WUE of 8.5 and 4.8 %.If consider the crop daily evapotranspiration, it increased in the future in all the site less in Oristano and Ancona, with respectively 1.2 and 0.01 %, then in Benevento with 11.9 %. The results indicate also increased growing season evapotranspiration, suggesting lower WUE in the future. Given model – derived variability in predicting climate variables important for crop production studies, the question arises as to which models or strategies should be used to distill information to be of use to stakeholders. The results of this analysis , in contrast to previous studies, indicate that the projected warmer and drier climate over the Mediterranean basin will increase the risk of yield loss, while the positive effects of increasing CO2 are not able to completely counterbalance this trend.

4.2 Future climate effects with fixed CO_2 concentration

4.2.1 Vulnerabilities and climate impacts

4.2.1.1 Impacts on crop productivity

Results showed for Oristano site were in according to Ferrise (2011) that estimated wheat yields, down to 3.5 t/ha for southern areas of the Mediterranean Basin. However, the climatic future scenario shown a wheat yields decreasing of 15 %. This negative trend was in according with other studies (Rinaldi et al., 2011) and were also in agreement with other European – scale assessment of the productivity of wheat (Harrison et al., 1995).

For both the other two sites, simulated yields in the future increased of 21 and 4 % respectively for Benevento and Ancona. Similar results were in according to Semenov and Shewry, where modeled yields were on average 15% higher than for the baseline.
It is possible to explain the decline of biomass production with the decreasing of WUE. An important increase of Water Stress days was registered, also with a small decreasing of Evapotraspiration. This is in contrast with some previous studies as the explanation done by Rinaldi et al, where the main factor responsible for the reduction of crop yields was the increase of average temperatures in the future, that also influenced the duration of growth. However the same study put rainfall like an other major factor which influenced the crop yield, more in rainfed conditions like in Oristano site.
These results suggest that the effect of precipitation patterns have important consequences for wheat production in Mediterranean area, in particular for site characterized by low rainfall. Average yields of cereal crops under water limited conditions, such as in Mediterranean area, are also determined by crop water use and water use efficiency. The same patterns could not be applied with CO_2 increases (378 ppm of present scenarios against 408 ppm of future scenario). In fact in any site considered, this factor had an important rule on crop yields.
In fact only in Oristano site future wheat yields decreased in the same way of Water Use Efficiency (15 and 19 % respectively), as shown in Rinaldi et al., 2011, while Benevento and Ancona showed an increase of WUE of 8.5 and 4.8 %.
If consider the crop daily evapotranspiration, it increased in the future in all the site less in Oristano and Ancona, with respectively 1.2 and 0.01 %, then in Benevento with 11.9 %.

4.2.1.2 Impacts on the main variables: WUE, ET, GSP, WS and NS

WUE

The results indicate increased growing season evapotranspiration, suggesting lower WUE in the future. Given model – derived variability in predicting climate variables important for crop production studies, the question arises as to which models or strategies should be used to distill information to be of use to stakeholders.

The results of this analysis , in contrast to previous studies, indicate that the projected warmer and drier climate over the Mediterranean basin will increase the risk of yield loss, while the positive effects of increasing CO2 are not able to completely counterbalance this trend.

4.3 Future climate effects with increased CO2 concentration

4.3.1 Vulnerabilities and climate impacts

4.3.1.1 Impacts on crop productivity

Results showed for Oristano site were in according to Ferrise (2011) that estimated wheat yields, down to 3.5 t/ha for southern areas of the Mediterranean Basin. However, the climatic future scenario shown a wheat yields decreasing of 15 %. This negative trend was in according with other studies (Rinaldi et al., 2011) and were also in agreement with other European – scale assessment of the productivity of wheat (Harrison et al., 1995).

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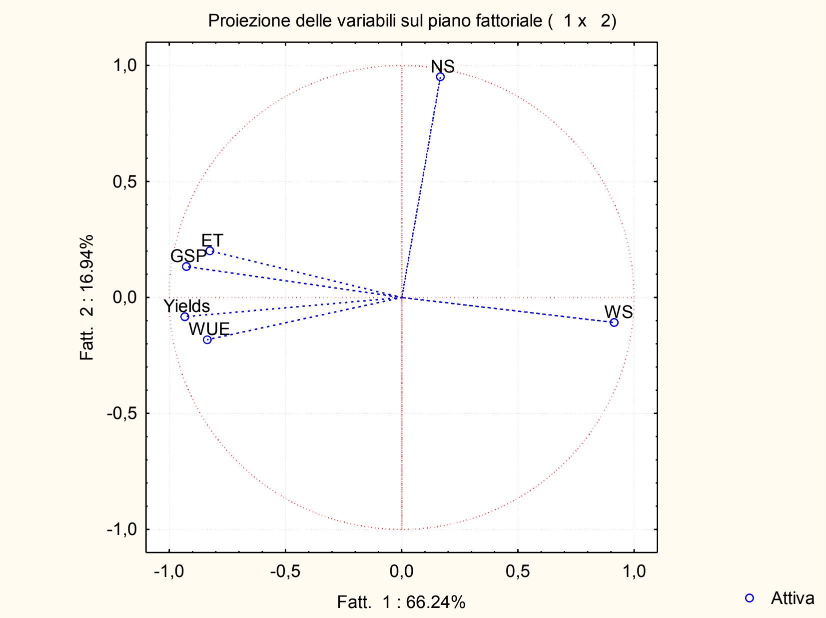
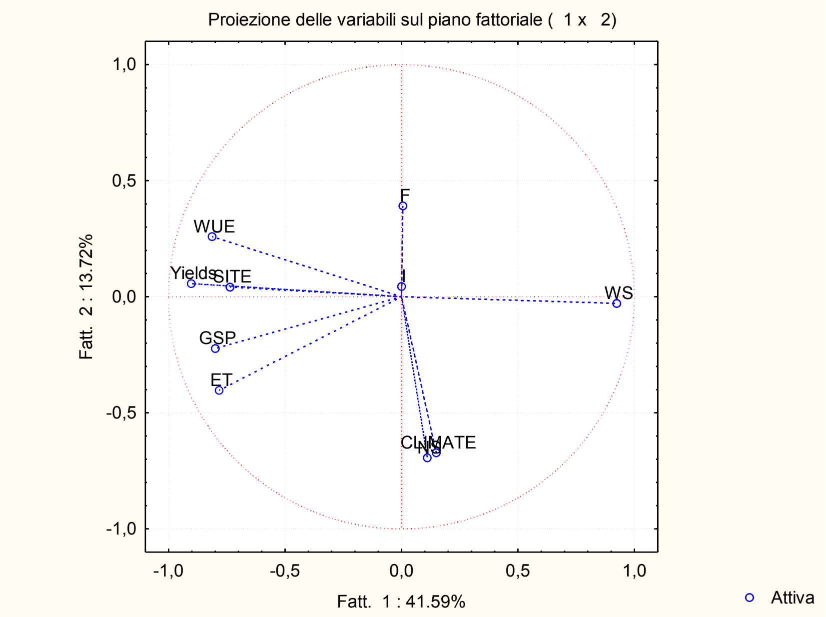
4.4 Site comparison

The analysis of all the site considered in the study project were carried on throught multivariate statistical analysis, in order to evaluate the interaction among the parameters and the effect of each of them on wheat yields.

Below were shown the factorial projection of each parameter considered (Graphic and x).



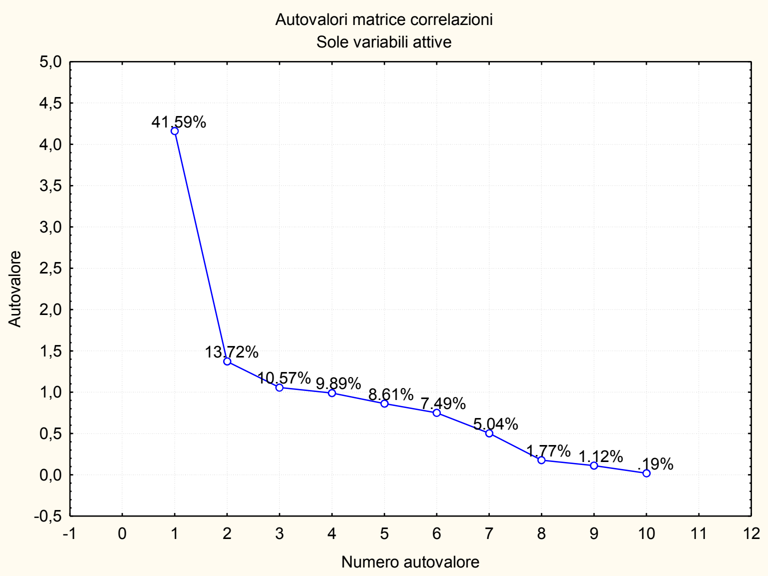
Graphic – PCA 1



Graphic – PCA 2

The relationships among different indices were graphically displayed in a biplot of PCA1 and PCA2 (Fig. 1). The PCA1 and PCA2 axes which justify 66.24% and 16.94% respetively of total variation, mainly distinguish the indices in different groups. The angles are informative enough to allow a whole picture about the interrelationships among the considered variales (Yields, Site, Climate, WUE, ET, GSP, WS, NS).

The weight of which variable was evaluated calculating the single value (Graphic). The first six had a high weight (Site, Climate, Irrigation, Fertilization and Yields), considering the values superior than 0.7.



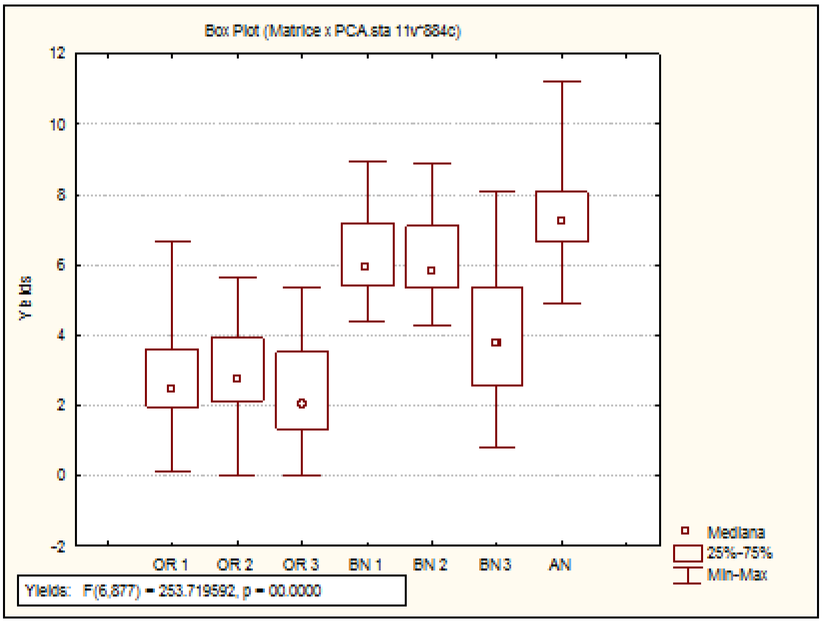
Comparisons of the three sites were shown in tables below. Comparing yields of the three different sites and under the two climatic scenarios, was shown a decreasing only for Oristano site, while an increase for the other two, Benevento and Ancona. This was maybe connected with a known decrease of rainfall, only for the first site, and to the positive correlation between yields and WUE. Significance levels ($p<0.05$) between main variables were determined by analysis of variance (ANOVA) shown in the table below.

SITE	CLIMATE	Yields	h	g	f	e	d	c	b	a	
OR 3	CF	1,544400	****								h
OR 1	CF	2,100462		****							g
OR 2	CF	2,219846		****							g
OR 3	CP	3,024077			****						f
OR 2	CP	3,529785				****					e
OR 1	CP	3,641431				****					e
BN 3	CF	3,726108				****	****				de
BN 3	CP	4,099400					****				d
BN 2	CP	5,448646						****			c
BN 1	CP	5,496308						****			c
AN	CP	6,927654							****		b
BN 2	CF	6,933108							****		b
BN 1	CF	7,035708							****		b
AN	CF	7,917365								****	a

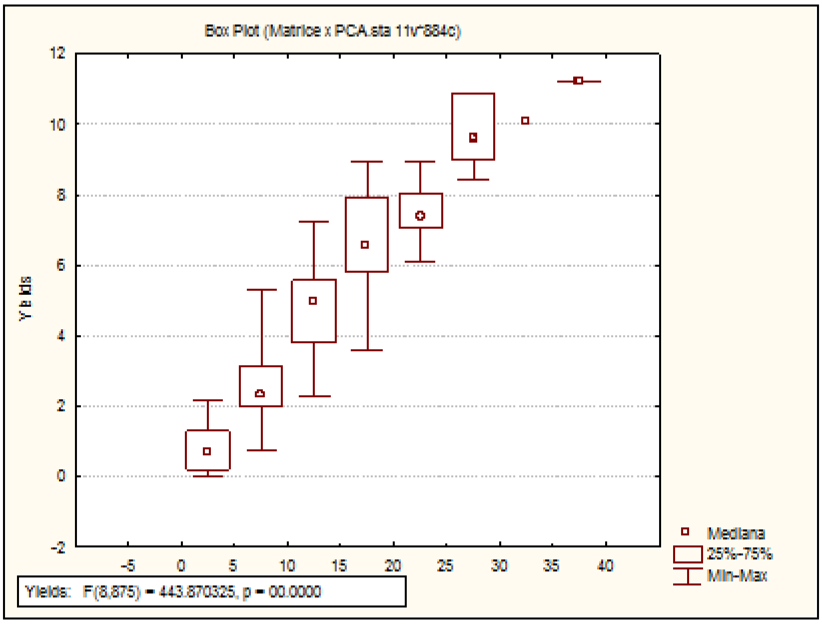
Table –Analysis of variance

	SITE	**CLIMATE**	**I**	**F**	**YIELDS**	**WUE**	**ET**	**GSP**	**WS**	**NS**
SITE	1,00	-0,02	0,02	-0,05	0,56	0,51	0,44	0,54	-0,66	-0,19
CLIMATE	-0,02	1,00	0,00	-0,03	-0,06	-0,23	0,15	-0,06	0,30	0,17
I	0,02	0,00	1,00	0,03	-0,01	-0,01	0,00	0,00	0,00	-0,01
F	-0,05	-0,03	0,03	1,00	0,01	0,01	0,00	-0,02	0,02	-0,17
YIELDS	0,56	-0,06	-0,01	0,01	1,00	0,93	0,65	0,57	-0,76	-0,11
WUE	0,51	-0,23	-0,01	0,01	0,93	1,00	0,41	0,40	-0,71	-0,14
ET	0,44	0,15	0,00	0,00	0,65	0,41	1,00	0,78	-0,69	0,08
GSP	0,54	-0,06	0,00	-0,02	0,57	0,40	0,78	1,00	-0,73	-0,03
WS	-0,66	0,30	0,00	0,02	-0,76	-0,71	-0,69	-0,73	1,00	0,00
NS	-0,19	0,17	-0,01	-0,17	-0,11	-0,14	0,08	-0,03	0,00	1,00

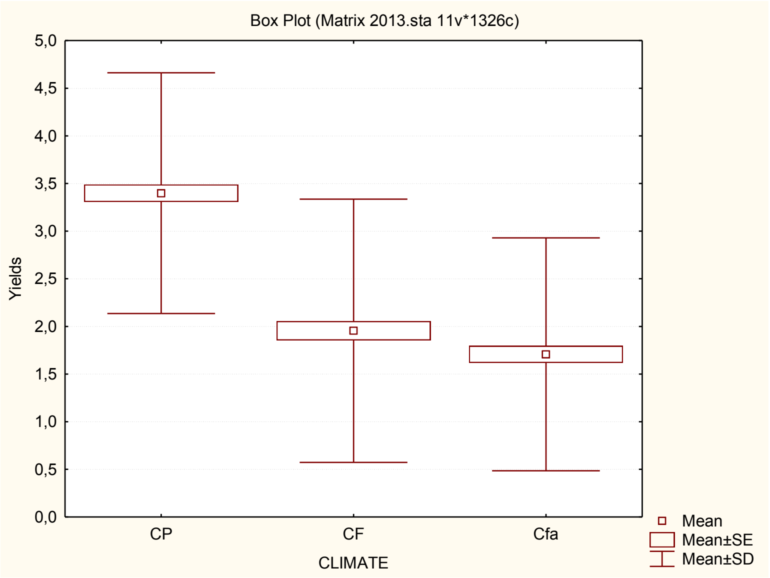
Table - Correlation among all the variables

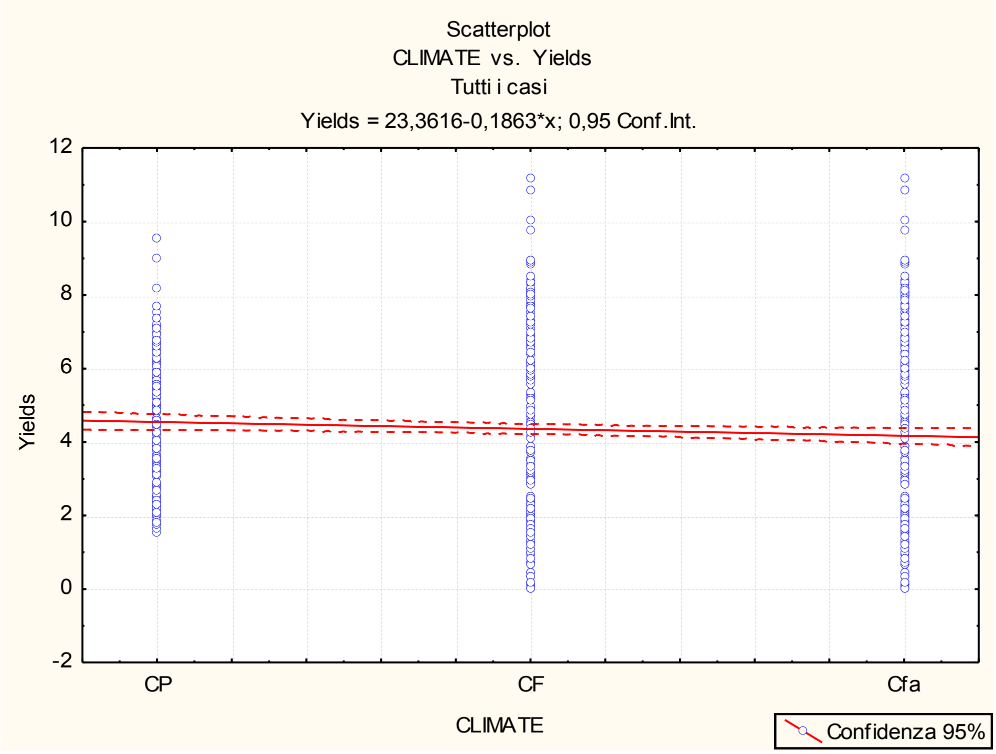


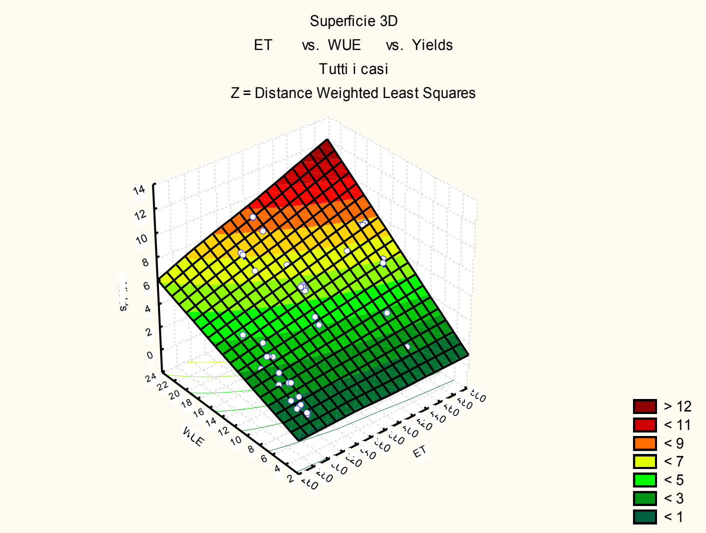
Box plots of the three sites and wheat yields.



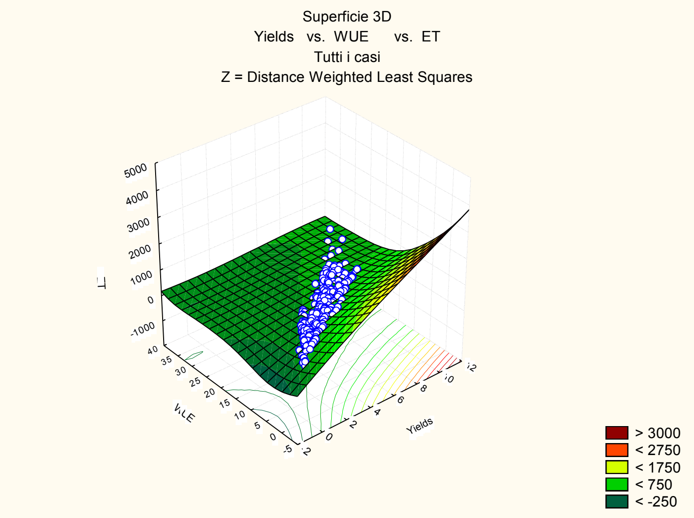
Box plot yields of the three sites.


Box Plot (Matrix 2013.sta 11v*1326c)
Yields
5,0
4,5
4,0
3,5
3,0
2,5
2,0
1,5
1,0
0,5
0,0
CP
CF
Cfa
CLIMATE
Mean
Mean±SE
Mean±SD

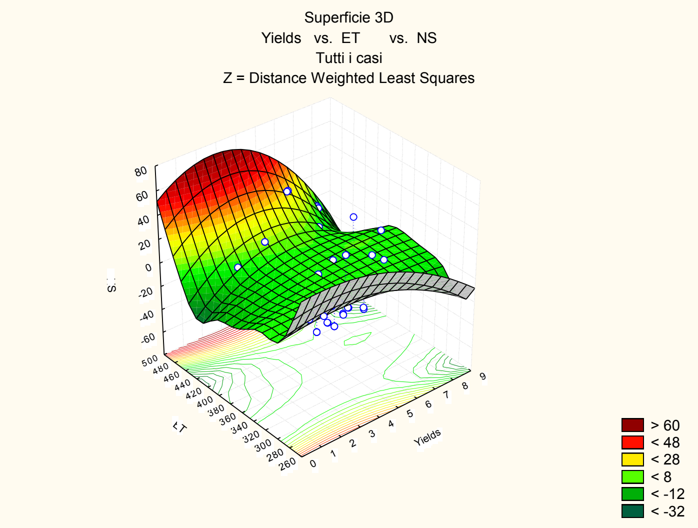

Scatterplot
CLIMATE vs. Yields
Tutti i casi
Yields = 23,3616-0,1863*x; 0,95 Conf.Int.
Yields
12
10
8
6
4
2
0
-2
CP
CF
Cfa
CLIMATE
Confidenza 95%



Superficie 3D
ET vs. WUE vs. Yields
Tutti i casi
Z = Distance Weighted Least Squares



Superficie 3D
Yields vs. WUE vs. ET
Tutti i casi
Z = Distance Weighted Least Squares



Superficie 3D
Yields vs. ET vs. NS
Tutti i casi
Z = Distance Weighted Least Squares

6 Conclusion

This study work is carried out within the Agroscenari Project - Scenarios of adaptation to climate change in Italian agriculture, funded by the Ministry of Agriculture and Forestry with DM 8608/7303/08 of 7 August 2008. Within the different agricultural systems, this is the only work that considered rainfed agricultural systems with cereals as main crop, and specifically durum wheat.

In our simulation there are sources of uncertainty that ought to be considered. According to many of the future expectations we simulated considering an increasing of CO_2 concentrations, but we used the same crop variety and similar cropping system for all simulations, thus assuming no adaptation to expected climate change. Neverthless, our simulated yields under projected climate change are comparable to those simulated by other authors and measured in many studies. Furthermore the understanding relative changes in yields under climate change from baseline conditions, and thus erroneus model results from these calibration experiments may not be important.

If consider wheat yields as main parameter influenced by climate change, drought conditions were the main factors limiting grain yields on clay soil in a Mediterranean-type environment, in particular this condition was observed for the Oristano site. The simulation experiments with long - term historical weather records suggest that environments characterized by low rainfall have negative impacts on crop growth: future climate change including higher temperatures and less rainfall will reduce grain yields despite elevated atmospheric CO_2. In fact the CO_2 positive effects fail when we consider temperature and precipitations patterns in association with increased CO_2 concentrations. Probably yields reduction, for Oristano site in the first set of results, was connected both to the falling of rain.

The same simulation experiments carried out in the other two sites, Benevento and Ancona, showed a different situation: higher yields were observed in the future, maybe caused by higher future rainfall respect to the future condition.

Considering all the results, the main factor that affected crop yields was the site. This means that the climate have an important rule, but maybe management as tillage, fertilization and irrigation could modify the productivity. In fact, in particular for Benevento and Oristano, we observed a clear difference between site if we considered the factors irrigation and fertilization, and specifically if analyse the same, but with or any crop stress.

The results suggest priorization of adaptation strategies in the regions condisidered, including development of local cultivars of drought – and het resistant crop varieties, earlier planting to avoid heat stress, development and adoption of slower-maturing varieties to increase the grain filling period.

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Annexes 1 – Tables

Oristano soil data

Parameter	**OR 1**			**OR 2**			**OR 3**		
	Layer 1	**Layer 2**	**Layer 3**	**Layer 1**	**Layer 2**	**Layer 3**	**Layer 1**	**Layer 2**	**Layer 3**
Sand (%)	36.02	35.61	36.99	16.26	26.43	26.00	36.81	36.31	36.02
Silt (%)	24.50	23.29	35.61	45.60	47.70	60.82	45.60	47.70	37.00
Clay (%)	39.48	41.10	41.11						
Depth (mm)	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Rocks fragment 2-5 mm	0.39	0.38	0.29	3.06	2.77	4.26	0.25	0.23	0.26
Rock fragment 5-10 mm	0.24	0.23	0.24	3.20	3.86	4.14	0.14	0.08	0.40
Rocks fragment >10 mm	-	-	-	2.35	4.61	2.08	-	0.38	0.60
pH in H2O	8.00	12.40	12.50	8.33	8.11	8.27	8.37	8.16	8.15
Organic nitrogen (ppm)	0.15	-	-	0.15	-	-	0.15	-	-

Initial nitrate concentration	0.15	-	-	0.15	-	-	0.15	-	-
Organic matter (%)	2.10	3.33	2.80	1.14	1.21	1.14	2.76	3.33	3.09
Crop residue (t ha $^{-1}$)	6.00	-	-	6.00	-	-	6.00	-	-
C.S.C. (Cmol/kg)	31.11	31.10	31.29	31.00	31.10	31.29	31.11	31.10	31.29
Bulk density	1.13	1.13	1.17	0.73	0.75	0.58	0.63	0.75	1.17
Bulk density oven dry	1.26	1.30	1.30	1.26	1.30	1.30	1.26	1.30	1.30
Saturated conductivity	0.13			0.13			0.13		
Field capacity (%)	37.30	41.70	26.80	25.50	25.30	16.00	37.70	37.70	38.20
Wilting point (%)	24.60	30.40	13.70	15.40	15.50	10.48	25.20	25.20	25.70
Total CaCO3%	12.00	10.00	6.00	12.00	10.00	6.00	12.00	10.00	6.00
P_2O_5 ppm	19.00	-	-	19.00	-		19.00	-	

Values of principal parameters obtained by chemical analysis

Chemical analysis of Benevento Soil

Field	Horizon	Depth (cm)	pH-H2O	CE (dS/m)	CaCO$_3$ (g/kg)	C org. (g/kg)	Org. matter (g/kg)	Sand (g/kg)	Silt (g/kg)	C (g/kg)	CSC (cmol$_{[+]}$/kg)	mg/kg Mg^{2+}	mg/kg Na^{+}	mg/kg K^{+}	mg/kg Ca^{2+}	Sum of bases
Bn 1	Ap1	0-7	8,5	0,8	41,2	11,2	19,4	330,7	334,4	334,9	22,3	478,8	101,3	2296,3	8522,5	52,8
	Ap2	7-32	8,4	0,8	48,8	10,2	17,5	381,1	345,6	273,3	24,4	483,8	141,3	2343,8	8811,3	54,6
	Bss1	32-70	8,3	0,8	37,1	9,8	16,9	421,8	328,9	249,3	22,4	476,3	305,0	2092,5	8583,8	53,5
	Bss2	70-110	8,2	0,8	48,8	9,4	16,2	431,2	318,5	250,2	20,5	491,3	920,0	1563,8	8652,5	55,3
	Bss3	110-150	8,2	0,8	38,4	9,0	15,4	505,6	296,9	197,6	21,5	501,3	987,5	1137,5	8616,3	54,4
	Bw4	150-210 sx	8,3	0,7	39,1	8,2	14,2	530,7	281,2	188,1	21,0	506,3	961,3	1075,0	8447,5	53,3
	Bg5	150-210 dx	8,4	0,7	147,3	4,7	8,1	526,4	283,3	190,3	20,7	510,0	958,8	841,3	8322,5	52,1
Bn 2	Ap1	0-7	8,1	0,8	34,5	11,5	19,9	412,7	332,1	255,2	21,5	503,8	210,0	2036,3	7457,5	47,5
	Ap2	7-30	8,2	0,8	35,0	11,9	20,6	416,9	344,9	238,2	21,9	506,3	230,0	2046,3	8262,5	51,7
	Bss1	30-65 sx	8,2	0,8	183,3	8,9	15,3	455,1	281,7	263,3	22,0	511,3	682,5	1597,5	8231,3	52,4
	Bssk2	50-80 dx	8,3	0,8	94,7	4,4	7,6	482,2	297,6	220,3	23,3	517,5	822,5	748,8	8192,5	50,7
	Bssk3	80-130	8,3	0,8	86,5	3,6	6,1	489,2	291,8	219,0	19,6	518,8	900,0	597,5	7242,5	45,9
	Bw1	130-180	8,3	0,8	91,4	3,7	6,4	470,9	302,8	226,3	17,1	523,8	948,8	765,0	6886,3	44,8
	Bw2	180-190	8,3	0,8	57,1	3,3	5,8	507,2	291,5	201,3	16,0	526,3	928,8	735,0	6226,3	41,4
Bn 3	Ap1	0-15	7,5	0,3	16,6	11,5	19,9	372,7	332,1	295,2	21,3	493,8	226,3	2880,0	7738,8	51,1
	Ap2	15-40	7,6	0,4	27,0	9,0	15,6	397,2	337,4	265,4	20,9	495,0	248,8	2946,3	7967,5	52,5
	Bss1	40-55	7,7	0,5	32,9	4,9	8,5	396,2	345,3	258,5	21,0	492,5	215,0	2927,5	8162,5	53,3
	Bss2	55-90	7,8	0,5	35,3	2,8	4,8	421,5	328,7	249,8	20,4	486,3	185,0	2372,5	8083,8	51,3
	Bkss	90-110	8,4	0,5	20,8	1,7	2,9	453,2	321,6	225,2	20,1	433,8	91,3	687,5	7761,3	44,5
	Bss4	110-135	8,3	0,5	35,0	1,6	2,8	472,2	308,8	219,0	23,0	468,8	252,5	1083,8	8142,5	48,4
	Bss5	135-200	8,8	0,5	56,1	1,7	2,9	429,8	320,6	249,6	21,9	516,3	940,0	1035,0	7755,0	49,7

Crop data

Oristano crop data

Table 1

Date	***Field***	***As***	***Stock/mq***	***Leaves/mq***	***cul_mq***	***Biomass/mq***	***LAI***
05/07/2010	OR 1	1	116	381,1	98,3	282,80	0,87
05/07/2010	OR 1	2	74	547,1	141,2	405,90	1,64
05/07/2010	OR 1	3	140	314,6	81,2	233,40	0,94
05/07/2010	OR 1	1	154	526,7	135,9	390,80	3,34
05/07/2010	OR 1	2	146	459,7	148,5	311,20	2,56
05/07/2010	OR 1	3	130	537,7	138,7	399,00	2,64
14/4/2010	OR 2	1	133	800,4	230,5	569,90	5,69
14/4/2010	OR 2	2	303	539,5	155,3	384,20	4,12
14/4/2010	OR 2	3	113	636,8	183,4	453,41	4,59
05/07/2010	OR 3	1	154	103,4	46,1	57,30	0,38
05/07/2010	OR 3	2	118	80,4	30,7	49,70	0,24
05/07/2010	OR 3	3	150	103,9	46,5	57,40	0,35
26/04/2011	OR 1	1	426	51,9	180,8	232,8	0,98
26/04/2011	OR 1	2	321	42,8	163,9	206,7	0,94
26/04/2011	OR 1	3	419	48,6	114,2	162,9	0,62
26/04/2011	OR 1	1	126	87,4	120,1	207,5	1,06
26/04/2011	OR 1	2	131	93,2	129,4	222,6	1,00

26/04/2011	OR 1	3	132	92,5	141,5	234,0	1,08
26/04/2011	OR 2	1	428	39,2	172,8	212,0	0,56
26/04/2011	OR 2	2	425	38,5	170,5	209,0	0,85
26/04/2011	OR 2	3	331	42,6	148,4	191,0	0,61
26/04/2011	OR 3	1	454	30,1	136,7	166,7	0,23
26/04/2011	OR 3	2	451	35,2	161,0	196,1	0,16
26/04/2011	OR 3	3	460	34,0	143,4	177,3	0,13

Table 2

Date	***Field***	***As***	***Spikes/mq***	***N° glumes***	***N° grain***	***Weight_1000***	***biom_kgha***	***prod_kgha***
14/06/2010	OR 1	1	218	18	53	21,0	8000	4540
14/06/2010	OR 1	2	224	14	39	22,0	8500	5010
14/06/2010	OR 1	3	230	14	37	17,0	8800	5130
14/06/2010	OR 1	1	350	14	31	30,7	7800	2330
14/06/2010	OR 1	2	342	15	32	25,4	7600	1360
14/06/2010	OR 1	3	350	15	39	27,8	11100	3010
14/06/2010	OR 2	1	234	20	26	20,5	12820	5000
14/06/2010	OR 2	2	224	21	21	22,0	12220	4700
14/06/2010	OR 2	3	228	21	29	16,8	12420	4100
14/06/2010	OR 3	1	216	14	26	28,0	3800	1933

14/06/2010	OR 3	2	238	15	30	27,0	3800	2337
14/06/2010	OR 3	3	306	13	22	24,0	3200	2300
22/06/11	OR 1	1	290	18	45	49,0	5252	1754
22/06/11	OR 1	2	267	19	53	52,0	6168	2104
22/06/11	OR 1	3	310	21	55	54,0	5863	2326
22/06/11	OR 2	1	190	18	39	64,0	3277	1822
22/06/11	OR 2	2	166	14	43	67,0	2774	1280
22/06/11	OR 2	3	214	14	43	60,0	2631	1712
22/06/11	OR 3	1	161	14	31	46,0	2342	1500
22/06/11	OR 3	2	205	15	32	46,0	3205	1337
22/06/11	OR 3	3	236	15	39	39,0	3908	1466

Chemical wheat analysis conducted in 2010 by ASSAM within Agroscenari project

Oristano

	Straw		Grain	
Field	**Protein (Nx6,25) % s.s.**	**Humidity at 105°C %**	**Protein (Nx6,25) % s.s.**	**Humidity at 105°C %**
Campo 1	4,73	6,1	14,8	8,7
Campo 2	2,74	6	12,68	8,7
Campo 3	2,77	7	10,9	9
Campo 4	4,35	8,2	12,12	9,8
Campo 5	2,81	6,2	12,86	8,6
Campo 6	3,25	6,8	13,87	8,5

Benevento

	Straw		Grain	
Field	**Protein (Nx6,25) % s.s.**	**Humidity at 105°C %**	**Protein (Nx6,25) % s.s.**	**Humidity at 105°C %**
Circelli	4,76	6,7	13,3	11,2
Agostinelli	3,56	6	14,35	8,7
Verrilli	2,55	6,5	12,62	10,6
Monaco Salvatore	6,09	7	13	10,5
Buccione	4,67	6,2	11,57	9,1

Chemical wheat analysis 2011

Oristano

	Straw		Grain	
Field	**Protein (Nx6,25) % s.s.**	**Humidity at 105°C %**	**Protein (Nx6,25) % s.s.**	**Humidity at 105°C %**
OR1	3,03	6,5	13,67	8,7
OR2	4,73	6,1	14,80	8,7
OR3	2,74	6,0	12,68	8,7

Benevento

	Straw		Grain	
Field	**Protein (Nx6,25) % s.s.**	**Humidity at 105°C %**	**Protein (Nx6,25) % s.s.**	**Humidity at 105°C %**
BN1	4,67	6,2	11,57	9,1
BN2	4,76	6,7	13,30	11,2
BN3	2,55	6,5	12,62	10,6