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Impacts of climate change on grapevine. The use of Crop model WinStics to estimate potential impacts on grapevine (Vitis vinifera L.) in Sardinia scale

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Abstract

Agriculture is extremely vulnerable to climate change. Higher temperatures eventually reduce yields of desirable crops while encouraging weed and pest proliferation. Changes in precipitation patterns increase the likelihood of short-run crop failures and long-run production declines. Although there will be gains in some crops in some regions of the world, the overall impacts of climate change on agriculture are expected to be negative, threatening global food security: in this contest , the aim of this study was to assess potential climate change changing in ambient on production and phenology for two of the most important varieties of grapevine at two experimental sites in Sardinia, The vine has been extensively studied in the context of climate change studies. These studies can be separated into two groups: first, studies on the impacts observed in recent years and related to climate change and on the other hand, studies which, through experimentation (mimicking future conditions) or modeling, try to determine the conditions of production of this crop in the future. In this study an analysis of the potential impacts of climate change on grapevine *(Vitis vinifera L.*) will be presented. Namely predicting the responses of two main Sardinian varieties - Cannonau and Vermentino, in order to ascertain reliable adjustment cultural practices as well to define possible mitigation strategies. The objectives of this research were to evaluate the effects of climate change and grapevine and phenology, at two experimental sites in Sardinia, differents for soil, climate conditions. To achieve these main objectives, the approach used in this study was: The application and assessment of a coupled climate scenario-crop model method, in which Atmosphere-Ocean General Circulation Models, used to generate future climate scenarios, are integrated into crop models to simulate future crop yields. The analysis of daily meteorological variables for current climatic conditions and climate change projections. These data are used as input variables for crop simulation models in conjunction with soil parameters and agronomic and management information, to simulate the dynamics of plant growth and development. The comparison of the results of these simulations for both current and future climatic conditions. Impacts of climate change are then expressed as changes in crop productivity and phenological phases.

To summarize, the specific aims of the work are:

to calibrate and validate Win-Stics model of the Cannonau and Vementino grapevin

- to assess the climate change impact on and phenological crop phases,

Riassunto

L'agricoltura è estremamente vulnerabile ai cambiamenti climatici. Temperature più elevate eventualmente ridurre le rese delle colture auspicabile incoraggiando nel contempo la proliferazione delle infestanti e dei parassiti. Cambiamenti nei modelli termici e di precipitazione possono far registrare un decremento dei prodotti agricoli sia in termini qualitativi che quantitativi. .

Secondo questa generale prospettiva si procede ad un l'analisi dei potenziali impatti dei cambiamenti climatici sulla vite (Vitis vinifera L.) delle due varietà principali della Sardegna - Cannonau e Vermentino,

Considerando infatti l'importanza economica del settore vitivinicolo , è indispensabile effettuare valutazioni finalizzate a fornire le informazioni necessarie per implementare adeguate strategie di adattamento tali da consentire una massimizzazione dei risultati in termini qualitativi e quantitativi. Per tale valutazione è stato impiegato il modello WinStics usando I dati climatici prodotti dallo scenario utilizzando un Runge Kutta 2 livello di regime tempo Hevi per l'integrazione tempo Clmcmm 8 km: per il periodo temporale 1965-2100 con risoluzione spaziale pari a 8 km,. generati dal modello globale CMCC-MED, il cui componente atmosferica è ECHAM5 (T159 80 km di risoluzione spaziale, 6 risoluzione temporale h) e considerando lo scenario A1B dell'IPCC.

Si è proceduto quindi a Calibrare e validare il modello Win-STICS per tre fasi fenologiche (dormienza, fioritura,maturazione) delle varietà di Cannonau e Vermentino coltivate in Sardegna e valutare l'impatto del cambiamento climatico e sulle fasi fenologiche delle suddette coltivazioni viticole .

1. Climate change impacts on grapevine

1.1. Introduction

Grapevine (Vitis vinifera L.) is a woody perennial plant that reaches reproductive maturity in 4 to 5 years, and may remain economically productive for 50 to 60 years. Bud break occurs annually over a characteristic range of variety-specific dates (from March to April) and it is followed by a period of intensive vegetative growth during which the shoots elongate and produce leaves very rapidly. Vegetative growth usually slows when flowering of the 1 to 3 clus- ters on each shoot begins. Relative earliness or lateness of bud break for a variety depends upon weather patterns. The number of viable fruits (berries) that continue the development is determined shortly after flowering, when the maturing fruit clusters become the primary sinks for photosynthate. Ripening fruits undergo 2 growth phases: (1) seed development and the building of the hard, green berry structure and (2) sugar accumulation, color change, and rapid enlargement, the start of which is called veraison. Full maturity, depending upon the variety and the site, is typically reached during August to September in the Northern Hemisphere. Growth and development of grapevine are influenced by environmental factors such as temperature and radiation, which make this crop sensitive to climate change. However, photosynthesis and growth are also stimulated by increasing CO_2 concentration (Kimball et al. 1993, Rogers & Dahlman 1993) and such an increase may result in greater accumulation of fruit and total biomass. The winegrape and wine industry provides a set of forward indicators for all agricultural industries as they confront climate change. This is because winegrapes are particularly challenged not only by the expected increased incidence of extreme weather-related events (heat, drought, frost, wind, hail, bushfires) but also by the expected higher temperatures in the growing season that will bring forward the harvest date to a hotter month. The temperature rise in the critical harvest month for winegrapes may therefore be two or three times greater than the expected temperature rise in the current harvest month. While the industry is highly sensitive to the effects of climate change, it also has a track record of a high level of adaptability to shocks. There is scope for further adaptation, in terms of both the relocation of its activities and within existing locations. Options for adaptation at the vine, vineyard, winery and consumer levels need to be explored, and choosing the best ones will take time and require significant research and development expenditures. The grapevine is one of the oldest cultivated plants that, along with the process of making wine, have resulted in a rich geographical and cultural history of development (Johnson, 1985; Penning-Roswell, 1989; Unwin, 1991). Today's viticultural regions for quality wine production are located in relatively narrow geographical areas and therefore climatic niches put them at greater risk from both short-term climate variability and long-term climate change than other more broad acre crops.

In general, the overall wine style that a region produces is a result of the baseline climate, while climate variability determines vintage quality differences. Climatic changes, which influence both variability and average conditions, therefore have the potential to bring about changes in wine styles. Our understanding of climate change and the potential impacts on viticulture and wine production has become increasingly important as changing levels of greenhouse gases and alterations in Earth surface characteristics bring about changes in the Earth's radiation budget, atmospheric circulation, and hydrologic cycle (IPCC, 2001). Observed warming trends over the last hundred years have been found to be asymmetric with respect to seasonal and diurnal cycles with greatest warming occurring during the winter and spring and at night (Karl et al., 1993; Easterling et al. 2000). The observed trends in temperatures have been related to agricultural production viability by impacting winter hardening potential, frost occurrence, and growing season lengths (Carter et al., 1991; Menzel and Fabian, 1999; Easterling et al., 2000; Nemani et al., 2001; Moonen et al., 2002; Jones, 2005c). To place viticulture and wine production in the context of climate suitability and the potential impacts from climate change, various temperature-based metrics (e.g., degree-days, mean temperature of the warmest month, average growing season temperatures, etc.) can be used for establishing optimum regions (Gladstones, 1992). For example, average growing season temperatures typically define the climate-maturity ripening potential for premium quality wine varieties grown in cool, intermediate, warm, and hot climates (Jones, 2006; Figure 1).

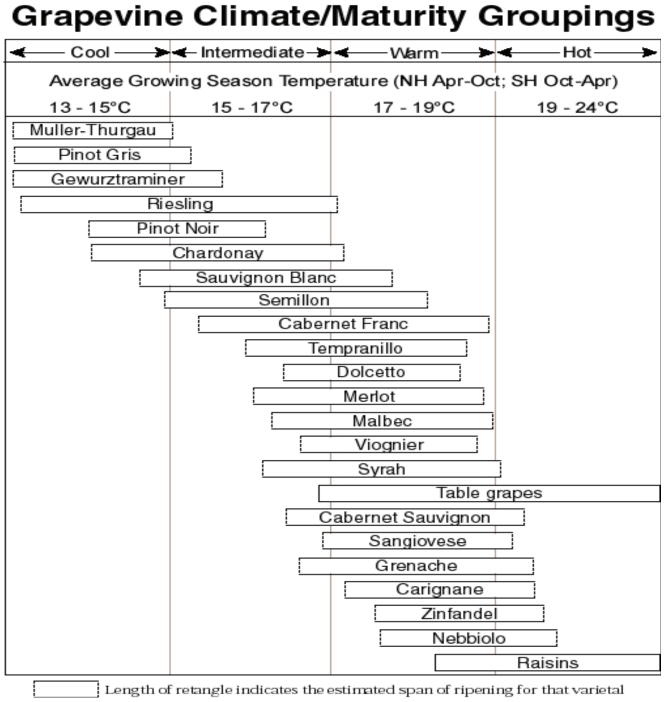


Figure 1 – The climate-maturity groupings given in this figure are based on relationships between phonological requirements and climate for high to premium quality wine production in the world's benchmark regions for each variety. The dashed line at the end of the bars indicates that some adjustments may occur as more data become available, but changes of more than +/- 0.2-0.6°C are highly unlikely.

For example, Cabernet Sauvignon is grown in regions that span from intermediate to hot climates with growing seasons that range from roughly 16.5-19.5ºC (e.g., Bordeaux or Napa). For cooler climate varieties such as Pinot Noir, they are typically grown in regions that span from cool to lower intermediate climates with growing seasons that range from roughly 14.0-16.0ºC (e.g., Northern Oregon or Burgundy)From the general bounds that cool to hot climate suitability places on high quality wine production, it is clear that the impacts of climate change are not likely to be uniform across all varieties and regions, but are more likely to be related to climatic thresholds whereby any continued warming would push a region outside the ability to produce quality wine with existing varieties. For example, if a region has an average growing season average temperature of 15ºC and the climate warms by 1ºC, then that region is climatically more conducive to ripening some varieties, while potentially less for others. If the magnitude of the warming is 2ºC or larger, then a region may potentially shift into another climate maturity type (e.g., from intermediate to warm). While the range of potential varieties that a region can ripen will expand in many cases, if a region is a hot climate maturity type and warms beyond what is considered viable, then grape growing becomes challenging and maybe even impossible.

Furthermore, observations and modeling has shown that climate change will not just be manifested in changes in the mean, but also in the variance where there are likely to be more extreme heat occurrences, but still swings to extremely cold conditions. Therefore, even if average climate structure gets better in some regions, variability will still be very evident and possibly even more limiting than what is observed today. Overall the impacts on wine quality and challenges related to climate change and shifts in climate maturity potential will likely be evidenced mostly through more rapid plant growth and out of balance ripening profiles. For example, if a region currently experiences a maturation period (véraison to harvest) that allows sugars to accumulate to favorable levels, maintains acid structure, and produces the optimum flavor profile for that variety, then balanced wines result. In a warmer than ideal environment, the grapevine will go through its phenological events more rapidly resulting in earlier and likely higher sugar ripeness and, while the grower or winemaker is waiting for flavors to develop, the acidity is lost through respiration resulting in unbalanced wines without greater after harvest inputs or adjustments in the winery. As a result, higher alcohol levels have been observed in many regions, for example Duchêne and Schneider (2005) found that potential alcohol levels of

Riesling at harvest in Alsace have increased by 2.5% (by volume) over the last 30 years and was highly correlated to significantly warmer ripening periods and earlier phenology. Godden and Gishen (2005) summarize trends in composition for Australian wines, and while not attributing any influence to the much warmer conditions experienced in Australia today (McInnes et al., 2003; Webb et al., 2005), they show increases in the alcohol content of 12.3% to 13.9% for red wines and 12.2% to 13.2% for white wines from 1984-2004. For Napa, average alcohol levels have risen from 12.5% to 14.8% from 1971-2001 while acid levels fell and the pH climbed (Vierra, 2004). While Vierra (2004) argues that this trend is due to the tendency for bigger, bolder wines driven by wine critics and the economics of vintage rating systems, Jones (2005d) and Jones et al. (2007c) find that climate variability and change are likely responsible for over 50% of the trend in alcohol levels. Besides changes in wine styles, one of the more germane issues related to higher alcohol levels is that wines typically will not age as well or as long as wines with lower alcohol levels. Finally, harvests that occur earlier in the summer, in a warmer part of the growing season (e.g., August or September instead of October in the Northern Hemisphere) will result in hotter harvested fruit and potentially desiccated fruit without greater irrigation inputs.

Preliminary studies on the effects of climate change on shifts in the areas suitable for grapevine growth have been carried out coupling the information from general circulation models (GCMs), or historical data-sets, with current knowledge about the environmental constraints that delimit the areas of grapevine cultivation (Kenny & Harrison 1992, Orlandini et al. 1993). For more detailed predictions on growth and yield of grapevine (as well as of other crops) under climate change, deterministic simulation models are used (see Kenny et al. 1993 and Harrison et al. 1995 for reviews). Models provide tools that allow us to use the hypotheses generated from experimental studies to simulate plant responses to novel climatic conditions, in order to understand the major climate change effects and to define appropriate measures for dealing with such changes. To date, no predictions are available on potential changes in mean yield and yield variability of grapevine resulting from global environmental change. The effects of increasing CO_2 concentration, and changes in temperature and radiation, on yield of grapevine were simulated with a simple mechanistic crop growth model. Field data obtained from a Free Air Carbon diox- grapevine. Enrichment (FACE) experiment were used for model parameterization under conditions of elevated CO2. Synthetically generated weather data for a location in northern Italy, and site-specific equilibrium scenarios

(UKHI and UKLO) and transient scenarios (UKTR and GFDL), were used as the baseline climate and as future climate scenarios, respectively. Therefore, mean yield and yield variability of 2 varieties (Sangiovese and Cabernet Sauvignon) were examined in terms of crop response characteristics across the years simulated.

Grapevine phenology, quality and yield are very dependent on climate either at a regional scale, or at a local scale (mesoclimate: altitude, slope aspect and nearness to water, wind). They are influenced by the microclimate (influenced by vine spacing, reflectance of radiation from soil, and canopy management) (Gladstones, 2004). Regional climate has been the focus of assessments of climate change impacts. At the local level, the impact of site selection and management are increased, and these are important for potential adaptations to climate change. In particular the temperature has the most influence on grapevines.

The sensitivity occurs through interrelated effects of temperature on the vegetative and reproductive growth:

- ✓ timing of key events in the annual cycle of growth and reproduction (phenology)
- ✓ other reproductive effects
- ✓ photosynthesis, respiration and transport of assimilated carbon
- ✓ biochemistry and transport of flavour molecules and precursors in the berry.

The physiological and morphological differences between varieties (genotypes) enable wine grape production over a relatively large range of climates than otherwise would occur with a more restricted range of genotypes. However, there are many obstacles to establishing a new variety and obtaining consumer acceptance (Rose, 2008). For each variety it is possible to define climates for premium wine production (Jones, 2008). Each grape variety grows in a range of temperature ranges and for some of them the range is large, e.g. Riesling compared to Pinot Noir (Fig 1)

Viticulture regions tend to lie in the 12–22°C isotherm (Jones, 2007). Grapes can be grown outside this range, at some cost in terms of other valuable characteristics foregone. Chardonnay for example, classified by Jones as an ‘intermediate group’ grape between cool and warm (Fig. 1), has 38% of total area cultivated in

Australia in hot climates with a mean January temperature MJT >23 C (1998 data, Paterson, 2004). Profitability ultimately drives the selection of location and particular grapes may be grown in areas which are 'too warm' according to the analysis in Figure 1. The difference between varieties is not stable over different regions and some varieties can show plasticity in their phenology, a feature of great interest in the context of climate change. Riesling can ripen earlier than Shiraz in warm regions, but later than Shiraz in cool regions (Dry 1984).

1.2. Impacts of climate change

The direct effects of climate change are summarised in this section, and they include:

- the earlier budburst, the earlier harvest and the shorter season (with variations by region and variety)the significance of harvesting in a warmer climate
- the compression of harvest dates among varieties
- the links between higher temperature and lower quality
- the links between higher temperature and higher yield
- the general reduction in gross returns and the degree of relocation required to maintain them
- the higher levels of aridity and the rising demand for irrigation water
- the negative effects of weather extremes
- the uncertain effects of higher levels of CO_2.

Webb et al. (2007) examined the effect of climate change in six regions with two varieties; Chardonnay (early season) and Cabernet Sauvignon (late season). Three climate models were used in order to capture the range in uncertainty in global warming using different climate sensitivities and different GHG emissions scenarios. VineLOGIC (Godwin et al. 2002) was used to determine the changes in the annual cycle of growth and reproduction (phenology) after confirming the model's predictive performance with past records. Budburst was predicted to be earlier in 5 regions with the range in uncertainty of timing overlapping for both varieties and regions. For Margaret River, budburst was predicted to be later due to insufficient chilling during winter, which would also cause erratic timing. Excluding Margaret River the other 5 regions had lower and upper bound average changes between 2030 and 2050 of: -3 to -10 days for budburst, -8 to -27 days for harvest, and -4 and -20 days for season duration.

Two important sets of findings from this work are worth emphasising. One is the 'dual warming impact', whereby the earlier harvest induced by the warming effects on phenology means that harvests will occur earlier, in a month that has a higher average temperature today. The temperature rise in the critical harvest month for winegrapes may therefore be two or three times greater than the expected temperature rise in the current harvest month. This could potentially reduce berry quality through greater loss of volatiles and greater water loss.

The second important finding is that differences in harvest dates between early and late-harvesting varieties will be compressed due to late varieties being more sensitive to warming than early varieties. This will put greater strain on the logistics of winery intake, and that impact will be compounded by increased volatility in future weather patterns.

The hot, dry conditions leading up to the 2008 vintage provided a natural experiment in dealing with both of these effects: the higher March temperatures in the cooler parts of South Australia brought forward harvest dates and compressed the difference across varieties in their optimal harvest date. As a result, harvesting labour and machines were in excess demand and wineries had difficulty sequencing their intakes optimally, so quality sufferedWebb et al. (2008a) used the historical statistical (negatively sloped or inverted u-shaped) relationships between temperature and prices paid for grapes by variety to estimate the effects of climate change. Allowing for the mix of outputs in different regions and assuming that mix remained constant, the predicted percentage change in prices paid for wine grapes are large for most regions and particularly those with a high proportion of national production, eg Riverland (2030, -5 to -32%; 2050, -9 to -87%) and Riverina (2030, -9% to -73%; 2050, -16 to -100%). Even cooler climates were predicted to show significant reductions in prices, again because of lower quality (eg Tasmania:

2030, -2 to -8%; 2050, -3 to -19%). Amongst the predicted least affected (percentage cost less than -18% (2050)), but with relatively high national production, were the Coonawarra, McLaren Vale an Langhorne Creek. Taking into account the uncertainties in both climate predictions and temperature sensitivities, the national impact was predicted to be between -7 and -39% (2030) and -9 to -76% by 2050.

At the same time, yield tends to increase with increased temperature, assuming no effect on water supply. Webb (2006) estimated changes in gross returns (change in yield times change in price). Most of the large producing regions show significant reductions in gross return, but there are notable exceptions including McLaren Vale, and Langhorne Creek. The national impact for both 2030 and 2050 were negative The previous results assume locations of grape growing remain the same. Webb's (2006) estimates of the maxima in gross return at a particular temperature for each variety allowed a spatial projection on to future climate maps of Australia. A southward shift of 40 km by 2030 and 65 to 115 km by 2050 would maintain gross returns. Shifts to higher altitude can have the same effect. This shift could affect areas currently listed as nature reserves, and there may be impact from fire (smoke taint) when vineyards are closer to forested areas. Fire frequency may increase with increased warming and aridity (Hennessy et al. 2005).

Another important channel of effect could be via weather extremes. Extreme heat days could be significant. From a study relevant to the USA, White et al (2006) showed that predictions based o average increase alone are likely to considerably underestimate the impact of climate change on viticulture. The differences in reduction in suitable area between using average temperature increase and increased frequency of extreme heat days are very substantial (60% versus 81% reduction in area). The studies by Webb reviewed above did not take into account the impact of increasing frequency of extreme heat days. Rising carbon dioxide will have a significant stimulatory effect on vegetative and fruit yield of grapevines (Bindi et al., 2001) through its influence as the source of carbon for photosynthesis. The predicted changes in carbon dioxide and temperature have only once been factored in to models to predict vine performance, relevant to Italy (Bindi et al. 2001). The CO_2 effect strongly interacts with temperature (Morison and Lawlor, 1999) and nutrition (McKee and Woodward, 1994). For example fo yield in soybean the negative effects of rising temperature are largely offset by the fertiliser effect of high carbon dioxide (Long et al. 2006). Higher carbon dioxide also increases transpiration efficiency, a component of crop water use efficiency (Kimball et al. 2002). There are also species-dependent secondary affects of high carbon dioxide for which we have no knowledge of for grapevines. These can include effects on phenology and growth patterns. It is unlikely that high CO_2 will have major effects on the phenology of grapevines because of the dominant effect of temperature, but based on effects observed in other woody deciduous plants it is likely that shoot branching and leaf morphology may be altered (Hättenschwiler et al. 1997) and this has implications for vine management and adaptation to climate change.

Following are summarised the key direct effects:

- higher temperatures across the growing season will bring forward the winegrape harvest date to hotter month, so the warming effect of climate change will have a double impact in lowering the
- quality of winegrapes
- differences in harvest dates between early and late-harvesting varieties will be compressed due
- to late varieties being more sensitive to warming than early varieties, which will strain the logistics
- of harvesting and winery intake
- that impact on the logistics of harvesting and winery intake will be compounded by greater
- volatility in future weather patterns
- quality of grapes will suffer as a consequence and, despite higher potential yields, gross margins
- in most areas are expected to fall
- re-locating vineyards to cooler locations (to lower latitudes and higher altitudes) could help but
- overall there will be a reduction in suitable areas for growing quality

winegrapes in Australia

- an increased frequency of extreme heat days and greater constraints on water supplies in the
- wake of more-frequent droughts will exacerbate the above trends.

1.3. Indirect effects

Soil also influences yield and quality and in some cases can largely define a region. The water and nutrients derived from the soil by the vine, combined with the climate, can strongly influence the ratio of vegetative to reproductive growth (vine balance), and it is this that the viticulturist is largely trying to manage to achieve the optimum for fruit quality and yield (Dry et al. 2005). There will be non-linear effects of climate change caused by interactions between soil, climate and nutrition, in part dependent on adaptation in vine management. With increased aridity often comes decline in soil structure and increased salinity (Clarke et al. 2002; Richards et al., 2008). Soil structure decline and increased sodicity can occur when saline water is used for summer irrigation and then subsequently the soil receives high quality rainwater during winter (Clarke et al., 2002)

Pest and disease pressure is likely to increase and also shift to new areas further south with warmer winters and warmer night temperatures. This is suggested by international experience. For example, Pierce's disease is predicted to move to Oregon and Washington wine regions where it is currently not present due to lower winter temperatures (Tate, 2001). In Italy, Downey mildew is predicted to increase disease pressure due to increasing temperatures (Salinari et al. 2006). Virus-vector nematodes are also predicted to spread at a rate of 160–200 km per 1°C in Great Britain aided by man (Neilson and Boag, 1996)

There is an increased risk of phylloxera spread based on the increased rate of emergence of the insect from the soil with warming, and making the spread of the insect more probable Also after a drought event or when water allocation to vines is reduced this results in more obvious phylloxera (visually) stress on the vine, more rapid decline and increased population abundance (ibid).

High CO2 may increase vine canopy size and density, resulting in higher biomass, nutritional quality and favourable microclimate for disease proliferation (Manning and Vontiedemann, 1995).

1.4. Winery level impacts

The major impact to wine quality and production with change in climate will be largely the result of impacts on the grapevine. Winemaking in theory may be undertaken in a variety of climates without a significant impact on the resulting wine, though costs may differ across climates related to refrigeration and requirements. Carbon offsets will be larger for wineries in warmer climates, though there are ways of increasing efficiency of wine production by reducing refrigeration costs (Pearce, 2008). De Bolt et al. 2006 discovered one of the key enzymes controlling the synthesis of tartaric acid in the berry. It would be possible through genetic modification to alter the expression of the gene in order to increase tartaric content of berries in warming climates, thereby maintaining optimal acid/sugar balance. Chardonnay, Cabernet Sauvignon and Shiraz from commercial crops across Australia has advanced at a rate between 0.5 and 3 days per year (Petrie and Sadras 2007). Faster maturity has been fully compensated by early harvest in Chardonnay, but not in Cabernet Sauvignon and Shiraz, which are therefore being harvested with higher sugar concentrations. This is consistent with the time trends in the composition of Australian wines reported by Godden and Gishen (2005). For red wine, they showed an increase in alcohol content at approximately 1% per decade. Also in red wines, there has been a trend for an increasing concentration of residual sugars. Remediation of high alcohol in the winery will require new yeasts that can ferment sugar but without creating alcohol, this could be done relatively easily by genetic modification of the yeast or by using adaptive evolution to rapidly select strains of yeast that have the desired characteristics (Thornton, 1985; McBryde et al. 2006). The alternative engineering solution is reverse osmosis procedures to de-alcoholise wine, but this can also take out flavour compounds.

1.5. Model Projections of Wine Region Climates

Projections of future climates are produced through models based upon knowledge of how the climate system works and used to examine how the environment, in this case viticulture and wine production, are likely to respond to these changes. These climate models are complex 3-D, mathematical representations of our Earth/Atmosphere system that represent spatial and temporal analyses of the laws of energy, mass, moisture, and momentum transfer in the atmosphere and between the atmosphere and the surface of the Earth. Additionally, climate models are based upon IPCC emissions scenarios (IPCC, 2001) which reflect estimates of how humans will emit CO2 in the future. The many models in use today, combined with the fact that they are modeling a non-linear system and using different emission scenarios, result in a range of potential changes in temperature and precipitation for the planet (IPCC, 2001). Work over the last three decades using model projections show that the observed warming trends in wine regions worldwide are predicted to continue. From one of the early analyses of the impacts climate change on viticulture, it was suggested that growing seasons in Europe should lengthen and that wine quality in Champagne and Bordeaux should increase (Lough et al., 1983). These results have largely been proven correct. Furthermore, spatial modeling research has also indicated potential shifts and/or expansions in the geography of viticulture regions with parts of southern Europe predicted to become too hot to produce high quality wines and northern regions becoming more stable in terms of consistent ripening climates and/or viable once again (Kenny and Harrison, 1992; Butterfield et al., 2000). Examining specific varieties (Sangiovese and Cabernet Sauvignon), Bindi et al. (1996) found that climate change in Italy should lead to shorter growth intervals but increases in yield variability. Other studies of the impacts of climate change on grape growing and wine production reveal the importance of changes in the geographical distribution of viable grape growing areas due to changes in temperature and precipitation, greater pest and disease pressure due to milder winters, changes in sea level potentially altering the coastal zone influences on viticultural climates, and the effect that increases in CO_2 might have on grape quality and the texture of oak wood which is used for making wine barrels (Tate, 2001; Renner, 1989; Schultz, 2000; McInnes et al., 2003). At the broadest scale of global suitability for viticulture, it has long been considered that viticulture zones are found between either the mean annual 10-20°C isotherms (de Blij, 1983; Johnson, 1985) or the growing season 12-22°C isotherms (Gladstones, 2005; Jones, 2006), however Jones (2007a) found that the growing season criteria is more valid as the 12-22°C isotherms more

completely encompasses the world's viticulture regions (not shown). To examine the global latitudinal bounds of viticulture suitability due to climate, Jones (2007a) used output from the Community Climate System Model (CCSM) on a 1.4°x1.4° latitude/longitude resolution and B1 (moderate), A1B (mid-range), and A2 (high) emission scenarios to depict the 12-22°C isotherms shifts for three time periods 1999, 2049, and 2099. Changes from the 1999 base period show both shifts in the amount of area suitable for viticulture and a general latitudinal shift poleward (Figure 2) By 2049, the 12°C and 22°C isotherms shift 150-300 km poleward in both hemispheres depending on the emission scenario. By 2099, the isotherms shift an additional 125-250 km poleward. The shifts are marginally greater on the poleward fringe compared to those on the equatorial fringe in both hemispheres. However, the

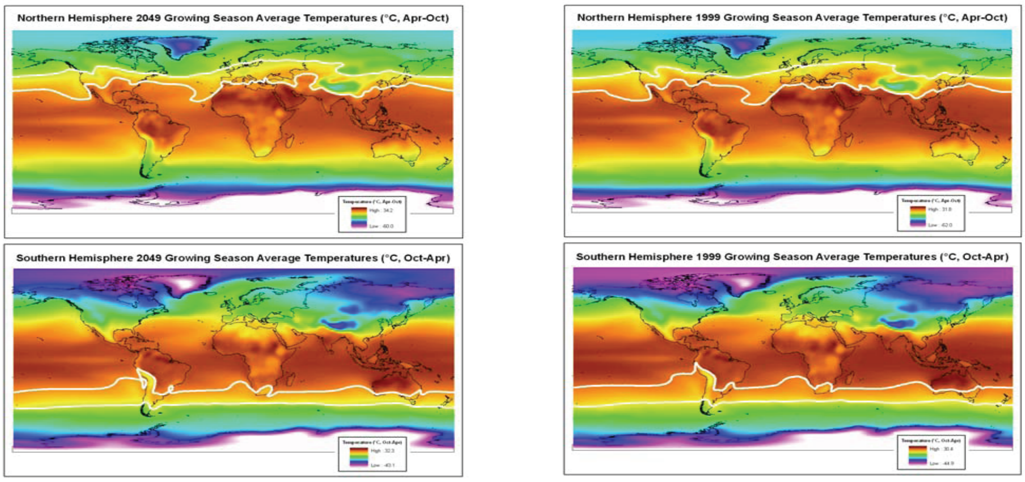


Figure 2 – Maps of growing season average temperatures (Northern Hemisphere, Apr-Oct upper panels; Southern Hemisphere, Oct-Apr lower panels) derived from observations and model runs from the Community Climate System Model (CCSM). The left panel is the 1999 run and the right panel is for the 2049 run. Future projections are driven by the A1B emission scenario (moderate future consumption). The highlighted isotherms (white) are the mean 12°-22°C representing the latitudinal limits of the majority of the world's grape growing areas (Gladstones, 2005; Jones, 2006)

relative area of land mass that falls within the isotherms across the continents expands in the Northern Hemisphere while contracting in the Southern Hemisphere due to land mass differences (Figure 2). Similar shifting is seen by 2099 for all scenarios Using Hadley Centre climate model (HadCM3) output and an A2 emission scenario (Pope et al. (2000) to 2049 for 27 of the world's top wine producing regions, Jones et al. (2005a) compared the average climates of two periods, 1950-1999 and 2000-2049. The results suggest that mean growing season temperatures will warm by an average 1.3ºC over the wine regions studied with Burgundy (Beaujolais), Rhine Valley, Barolo, and Bordeaux differences ranging from 0.9-1.4ºC (Figure 3).

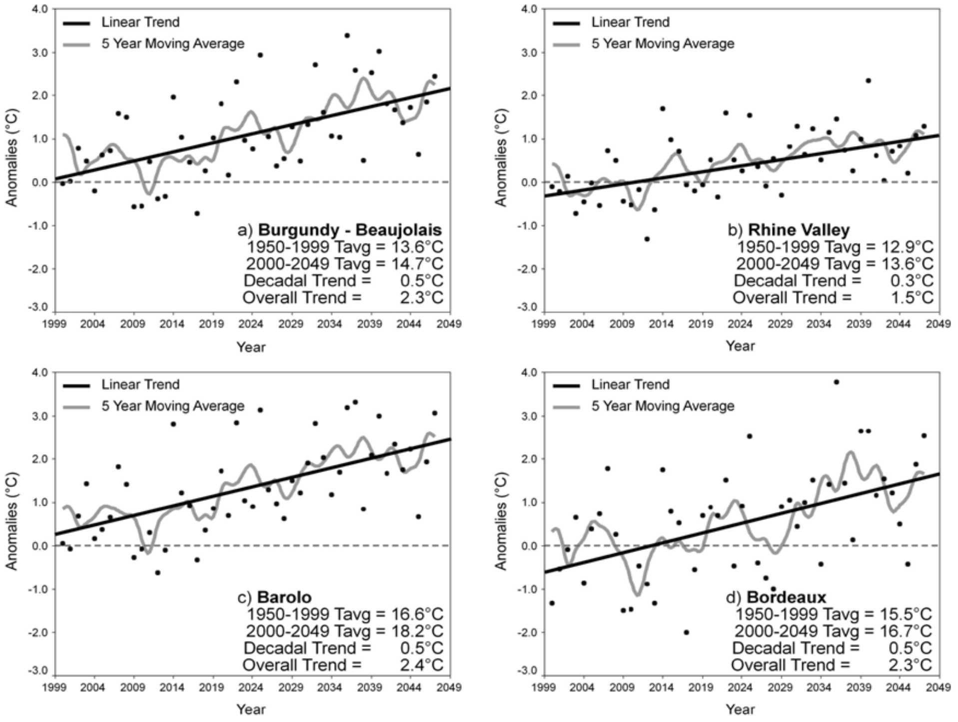


Figure 3 – Modeled growing season average temperature anomalies for a) the Beaujolais region of Burgundy, b) the Rhine Valley, c) Barolo, and d) Bordeaux as analyzed by (Jones et al., 2005a). The modeled temperature data are from the HadCM3 climate model on a monthly time scale extracted from a 2.5° x 3.75° grid centered over the wine producing regions for 2000-2049. The anomalies are referenced to the 1950-1999 base period from the HadCM3 model. Trend values are given as an average decadal change and the total change over the 50-year period.

Also, the projected changes are greater for the Northern Hemisphere (1.3ºC) than the Southern Hemisphere (0.9ºC). Examining the rate of change projected for the 2000-2049 period only reveals significant changes in each wine region with trends ranging from 0.2ºC to 0.6ºC per decade. Overall trends during the 2000-2049 period average 2ºC across all regions with the smallest warming in South Africa (0.9ºC/50 years) and greatest warming in Portugal (2.9ºC/50 years). For the Burgundy (Beaujolais), Rhine Valley, Barolo, and Bordeaux regions, decadal trends are modeled at 0.3-0.5ºC while the overall trends are predicted to be 1.5 2.4ºC (Figure 3). In addition, Jones et al. (2005a) showed that many of the wine regions may be at or near their optimum growing season temperature for high quality wine production and further increases, as predicted by the differences between the means of the 1950-1999 and 2000-2049 periods, will place some regions outside their theoretical optimum growing season climate. The magnitude of these mean growing season changes indicate potential shifts in climate maturity types for many regions at or near a given threshold of ripening potential for varieties currently grown in that region. Referring back to Figure 1, where Bordeaux's growing season climate of the last 50 years averaged 16.5ºC and add to it the overall trend in projected warming in Bordeaux of 2.3ºC by 2049. An 18.8ºC average growing season would place Bordeaux at the upper end of the optimum ripening climates for many of the red varieties grown there today and outside the ideal climates for the main white varieties grown. Still more evidence of these impacts come from Napa, where a 17.5ºC historical average is projected to warm by 2.2ºC to 19.7ºC by 2049. This would place Napa at the upper end of optimal ripening climates for nearly all of the most common varieties (Figure 1). Finally, the results also show warming during the dormant periods which could influence hardening potential for latent buds, but observations and models indicate continued or increased seasonal variability which could spell problems in freeze or frost prone regions. For the United States as a whole, White et al. (2006) used a high-resolution (25 km) regional climate model forced by an IPCC A premium winegrape production area in the conterminous United States could decline by up to 81% by the late 21st century. The research found that increases in heat accumulation will likely shift wine production to warmer climate varieties and/or lower-quality wines. Additionally the models show that while frost constraints will be reduced, increases in the frequency of extreme hot days (>35°C) in the growing season are projected to completely eliminate winegrape production in many areas of the United States. Furthermore, grape and wine production will likely be restricted to a narrow West Coast region and the Northwest and Northeast, areas where excess moisture is already problematic (White et al., 2006). From a more regional analysis, Jones (2007d) examined suitability for viticulture in the western U.S., which has long been based on a standard heat summation formulation originally proposed by Amerine and Winkler (1944). Winkler regions are defined by growing degree-days using a base of 10°C over the growing season of April-October. The resulting five regions show broad suitability for viticulture across cool to hot climates and the varieties that grow best in those regions. Using recent historical data at a 1 km resolution (Daymet; Thornton et al. (1997)) depicts that the cooler region I is found higher in elevation, more coastal, and more northerly (e.g., the Willamette Valley) while the warmest region V areas are mostly confined to the central valley and further south in California (e.g., the San Joaquin Valley; Figure 4).

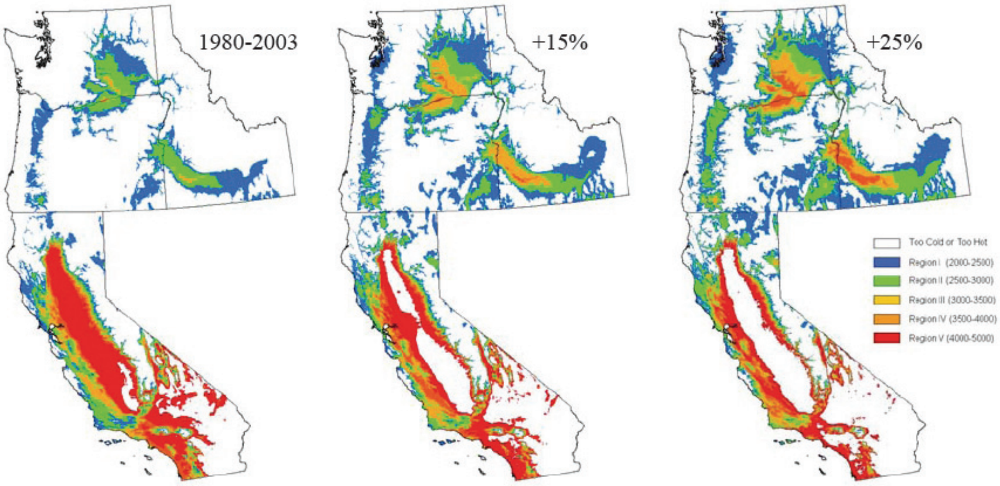


Figure4 Winkler Regions for the western U.S. based on Daymet (Thornton et al., 1997) daily 1 km resolution daily temperature data (growing degree-days, base 50°F over Apr-Oct). The left panel is the average over the 1980-2003 time period. The middle panel is a projection of a 15% increase over 1980-2003 (low range of climate change expected by 2049). The right panel is a projection of a 25% increase over 1980-2003 (high range of climate change expected by 2049).

Averaged over the 1980-2003 time period, 34% of the western U.S. falls into regions I-V with 59% being too cold (< 1111 °C units) and 7% too hot (>2778 °C units). Separated into individual regions finds that region I encompasses 34.2%, region II 20.8%, region III 11.1%, region IV 8.7%, and region V 25.2%. Therefore the western U.S. is predominately at the margins of suitability with 59.4% in the coolest and hottest regions (regions I and V, respectively). Using projections for average growing season temperatures from the Community Climate System Model (CCSM) of 1.0-3.0°C for 2049 results in a range of increases in growing degree-days of 15-30% (Figure 4). At a 15% increase in growing degree days by 2049, the area of the western U.S. in regions I-V increases 5% from 34% to 39% and at the higher range of a 25% increase in growing degree days, increases by 9% to 43%.

Overall the changes shown reduction in the areas that are too cold from 59% to 41% while the areas that are too hot increase from 7% to 16% in the greater warming scenario (Jones, 2007d). Similarly, by individual region there are shifts to predominately more land in region I (34.2% to 40.6%), smaller changes to region II (20.8% to 23.4%), region III (11.1% to 14.2%), and region IV (8.7% to 10.1%), and a reduction of region V area from 25.2% to 11.6%. Spatially the shifting of regions occurs toward the coast, especially in California, and upwards in elevation. In another regional analysis for the west coast of the U.S., Lobell et al. (2006) examined the impacts of climate change on yields of perennial crops in California. The research combined the output from numerous climate models (testing climate uncertainty) with multiple statistical crops models (testing crop response uncertainty) for almonds, walnuts, avocados, winegrapes, and table grapes. The results show a range of warming across climate models of ~1.0-3.0°C for 2050 and 2.0- 6.0°C for 2100 and a range of changes in precipitation from -40 to +40% for both 2050 and 2100. Winegrapes showed the smallest yield declines compared to the other crops, but showed substantial spatial shifts in suitability to more coastal and northern counties. The authors also note that yield trends have low attribution to climate trends and are more due to changes in technology (mostly) and an increase in CO_2 (likely). Other regional work in both Europe (Kenny and Harrison, 1992; Butterfield et al. 2000; Stock, 2005), Australia (McInnes et al., 2003; Webb et al., 2005), and South Africa (Carter, 2006) has examined climate change through different modeling approaches but has come up with similar results. Kenny and Harrison (1992) did some of the early spatial modeling of future climate change impacts on viticulture in Europe and indicated potential shifts and/or expansions in the geography of viticulture regions with parts of southern Europe predicted to become too hot to produce high quality wines and northern regions becoming viable once again. Examining changes in the Huglin Index of suitability for viticulture in Europe (Huglin, 1985), Stock (2005) shows increases of 100-600 units that result in broad latitudinal shifts with new areas on the northern fringes becoming viable, changes in varietal suitability in existing regions, and southern regions becoming so hot that overall suitability is challenged. Specifically in Spain, Rodriguez et al. (2005) examine different emission scenarios to place lower and upper bounds on temperature and precipitation changes and find trends of 0.4-0.7ºC per decade with summer warming greater than in the winter. Overall the changes result in warming by 2100 of between 5-7ºC inland and 3-5ºC along the coast. Concomitant with these temperature projections, Rodriguez et al. (2005) show much drier springs and summers and lower annual rainfall which is less homogeneous across Spain than is temperature. Furthermore, to examine grapevine responses to climate change, Lebon (2002) used model output to show that the start of Syrah ripening (véraison) in Southern France would shift from the second week of August today to the third week of

July with a 2ºC warming and to the first week of July with a 4ºC warming. Additionally the research found that significant warming during maturation and especially at night would disrupt flavor and color development and ultimately the wine's typicity (Lebon, 2002).

In Australia, Webb et al. (2005) analyzed climate change scenarios for viticulture showing that temperatures by 2070 are projected to warm in Australia by 1.0-

6.0ºC increasing the number of hot days and decreasing frost risk, while precipitation changes are more variable but result in greater growing season stress on irrigation. The changes projected for Australia has tied future temperature regimes to reduced wine quality with southerly and coastal shifts in production regions being the most likely alternative to maintaining viability.

In South Africa, regional projections of rising temperatures and decreased precipitation are projected to put additional pressure on both the phenological development of the vines and on the necessary water resources for irrigation and production (Carter, 2006). The research implies that the practice of winemaking in South Africa is likely to become riskier and more expensive with the most likely effects being shifts in management practices to accommodate an increasingly limited water supply. The author notes that the situation will likely exacerbate other economic issues such as increases in the price of wine, a reduction in the number of wine growers, and need for implementation of expensive and yet unknown adaptive strategies (Carter, 2006).

Together these studies, and those detailed previously, indicate that the challenges facing the wine industry include more rapid phenological development, changes in suitable locations for some varieties, a reduction in the optimum harvest window for high quality
wines, and greater management of already scarce water resources.

2. **Adaptation and mitigation strategies in viticulture**

A recent report raised concerns that the projected increase in the frequency of hot (>35°C) summer days might compromise and eventually eliminate wine grape production in warm areas of the USA, with production partly shifting to cooler areas (White et al. 2006). This fear seems tenuous, given the stunning success of the Australian wine industry over the past 20 years. Yields of both red and white V. vinifera cultivars have increased there significantly during the last two decades of the 20thcentury and have since levelled off in both warm and hot regions (Dry and Coombe 2004), while the total vineyard area for wine grapes has almost tripled. Nonetheless, Webb et al. (2008b) reported significant negative correlations between grape prices and mean summer temperatures across Australian wine regions. For comparison, average prices for Cabernet Sauvignon grapes from California's Napa Valley exceeded $4100/ton in 2006, while those from the Central Valley sold for ~$260/ton; the latter region having a 2.7°C higher mean annual temperature than the former (Cahill and Field 2008). Although the potential decline in prices may be partly, but by no means completely, compensated by possible increases in yield, these findings are important because, as discussed previously, by the middle of the 21st century the projected warming trend will shift many warm regions closer to climatic conditions currently experienced in hot regions. Although hot extremes and heat waves are set to become more frequent over the course of this century(IPCC 2007), the most imminent challenges facing the wine, table grape and raisin industries in arid and semiarid regions are probably not heat waves per se, but increasing drought and salinity because of higher evaporation coupled with declining water availability (Schultz2000, Stevens and Walker 2002). Rising salinisation of soils could pose a serious threat to grape growing, because most irrigated vineyards, especially deficit-irrigated vineyards, are at risk from salinisation owing to dissolved saltsin irrigation water (in contrast to rain water). Salinity limits vine growth, photosynthesis, productivity, and fruitquality (Downton and Loveys 1978, Walker et al. 1981,Downton 1985, Shani et al. 1993, Cramer et al. 2007).

Mitigation practices include abundant watering at the end of each season to leach salts down the soil profile (provided fresh water is available), application of straw or other mulch to limit evaporation, and less soil tilling to conserve soil structure. In addition, some rootstocks derived from American Vitis species (e.g. Ramsey, 1103Paulsen, Ruggeri 140, 101–14) are relatively tolerant of saline conditions (Downton 1985, Stevens and Walker2002). However, this tolerance may decrease with prolonged salt exposure. Sun-exposed grape berries are often subject to sunburn and subsequent shriveling as a consequence of overheating and excess UV and/or visible light. The projected increase in the frequency of hot summer days will undoubtedly exacerbate this problem, especially on the afternoon side of canopies (Spayd et al. 2002). This may require adaptations in row direction (e.g. away from the prevailing north-south orientation) and alterations in trellis design and training systems (e.g. away from the relatively common current practice of manually positioning shoots vertically upward toward 'sprawl' systems without shoot positioning). Sprawl systems are cheaper to construct: often, only one wire is required to support the permanent cordon, sometimes with the addition of one pair of 'foliage' wires to prevent excessive wind damage, which contrasts with the multiple wires necessary for vertical shoot-positioning systems. In addition, changes in cultural practices may include less shoot positioning and less leaf removal in the fruit zone, which would also reduce lab our costs. Other practices may include the use of cover crops or resident vegetation to improve the canopy microclimate through their cooling effect (Nazrala 2007), or installation of under vine or overhead sprinkler systems for evaporative canopy cooling. Both of these approaches would also tend to reduce soil temperature and limit daily thermal amplitudes in the root zone (Pradel and Pieri 2000). However, such practice swill not only increase overall vineyard water use but also make grape production more expensive (Tesic et al.2007, Celette et al. 2009). Maintaining a green cover crop throughout the growing season in dry regions typically requires installation of additional irrigation hardware, such as micro-sprinklers. Moreover, cover crops compete with grapevines for water and nutrients, especially in warm/dry regions, so that vineyard fertilizer requirements may increase if vine productivity is to be maintained (Keller et al. 2001, Keller 2005, Tesic et al. 2007,Celette et al. 2009). Such mitigating practices notwithstanding, excessive sunburn might lead to susceptible cultivars becoming unsuitable for planting in warmer regions, especially those that also experience high solar radiation during the growing season. A relatively simple strategy for wine grape growers to delay fruit maturation such that it occurs during the cooler end of the season would be to markedly increase the crop load carried by the vines. In the Napa and Sonoma Valleys of California, increasing yields have been accompanied by better wine quality because of an asymmetric warming trend (at night and in spring) after

1950 (Nemani et al.2001). However, while this may be an attractive option for growers, it is unpopular among winemakers and is often forbidden by law in Europe. Moreover, larger crops would tend to offset gains in irrigation water savings arising from better water-use efficiency. In many areas, the consequences for wine grape production of the projected decline in irrigation water availability may be relatively minor owing to their already low water use met by drip irrigation, usually combined with deficit irrigation strategies (Dry et al. 2001, Kriedemannand Goodwin 2003, Keller 2005). In the early 2000s,ultra-premium-quality Cabernet Sauvignon grapes were grown in eastern Washington, USA, with an annual water supply from both rainfall and drip irrigation of as little as 308 mm (Keller et al. 2008). This contrasts with table, raisin and juice grapes, whose larger canopies and heavier crops require substantially more water. For example, well-watered Concord grapes may use as much as three times more water than deficit-irrigated red wine grapes (Tarara and Ferguson 2006). Moreover, many on-wine-grape growers still supply water by flood, furrow or overhead-sprinkler irrigation, methods that are inherently far less water-efficient than is drip irrigation. For the most part, these vineyards will have to be converted to drip irrigation to conserve water. Although this will put an additional short-term financial burden on growers, there may be savings in the longer term, because lab our costs for operation and maintenance tend to be lower with drip irrigation. Because grape cultivars differ in their suitability for and adaptability to different climates, shifts in the cultivar profile of different regions, and possibly the emergence of hitherto unsuitable lesser-known or even novel cultivars, can be expected over the coming decades. A shift of grape production to cooler regions of the world, i.e. towards higher latitudes and altitudes, is another likely scenario as a result of global warming (cf. Schultz 2000). However, such shifts imply that some vineyards located in thewarmest and/or driest regions may be abandoned, which has implications for the quality of life in rural areas. Moreover, vineyard development in novel areas is dependent on the availability of affordable land, irrigation water and labour force. It will also require substantial investments in infrastructure and vineyard establishment. With the typical life of a vineyard exceeding 30 years, decision son cultivars, clones, rootstocks, and vineyard sites will have to be made on a long-term basis. Moreover, vineyards that are planted now will experience an essentially new climate 20 years from now (Cahill and Field 2008), making such decisions challenging. An additional issuethat has to be taken into account is harvest logistics: because grapes ripen more rapidly in warmer climates, the ‘harvest window’ tends to be more compressed, so that grape intake to accommodate ‘optimum’ maturity for different cultivars may pose scheduling, labour and capacity problems for growers and wineries alike.

From the above-mentioned overview of published information, one may conclude that grapevine reproductive development has an optimum temperature range from about 20 to 30°C, with temperatures below 15°C and above 35°C leading to marked reductions in yield formation and fruit ripening. But this conclusion has an important caveat: it is not clear whether this temperature range applies to ambient or to tissue temperatures. Most studies attempting to uncover temperature effects were conducted indoors, often in growth chambers, where tissue temperatures typically equal ‘room’ temperatures. In contrast, plant tissues exposed to sunlight normally are heated above ambient by solar radiation but fall below ambient at night. One elegant study conducted with field grown vines avoided this pitfall by heating the measured berry-skin temperature of shaded bunches to the berry skin temperature of sun-exposed bunches and cooling exposed bunches to the temperature of shaded bunches, thereby also separating the potential effects of temperature from those of light (Spayd et al. 2002, Tarara et al.2008). Without trying to diminish the value of growth chamber studies, it is probably fair to ask for more such innovative experiments that manipulate temperature and/or light in the field.The expected increase in climate variation (IPCC2007) flies in the face of growers’ attempts to minimize spatial and annual variation in grape yield and quality. This is a concern, for a recent analysis with Cabernet Sauvignon wines from California’s Napa Valley found that wine prices were closely related to seasonal weather between 1970 and 2004 (Ramirez 2009). Studies aimed at understanding the consequences of climatic change and variability are crucial for the many regional wine industries to remain competitive. The only free air CO_2 enrichment study conducted with grapevines thus far (Bindi et al. 2001, 2005, Tognetti et al. 2005) found increases of 40–50% in both vegetative and reproductive biomass with little change in fruit and wine composition. The authors concluded that rising atmospheric CO_2 may strongly stimulate vine growth and productivity while not affecting fruit and wine quality. One might add that‘no effect’ also implies that there may not be any beneficial effects on wine quality. Yet it is puzzling that to date not a single study has investigated the interactive effects on grapevines of the predicted simultaneous rise in temperature and atmospheric CO_2 In spite of the obvious importance for the global wine industry, we do not know how rising CO_2 influences the widely studied effects (see previous discussion) of temperature variation and water supply on vine growth, phenology, yield formation, fruit ripening and composition and, ultimately, wine quality. Such studies, conducted over long periods (multiple years), are critical to enable development of future mitigation strategies and to test cultivar suitability in a changing climate. Growers will require knowledge to choose from among alternative options to prepare for warmer growing seasons with less water and, in some areas, increasingly saline soils. One option is the choice of better-adapted planting material, but this requires a coordinated approach to evaluating alternative cultivars, clones, and rootstocks ina range of climates. With the roughly 500 million bases of the *V. vinifera* genome now sequenced (Jaillon et al. 2007,Velasco et al. 2007) and progress in genomics adding toour understanding of the function of important genes (e.g. Terrier et al. 2005, Cramer et al. 2007, Deluc et al.2007, Pilati et al. 2007), the new tools of the functional genomics, proteomics, metabolomics, etc.will need to be put to use to investigate in more detail the developmental and environmental regulation of yield formation, fruit development and ripening. They will also need to be integrated with more general grape physiology and viticulture research. And perhaps it is time to begin developing genetically modified cultivars that will be able not only to cope with warmer temperature, higher $CO_2$and less water of higher salinity, but will also produce high-quality fruit under such conditions. Unfortunately.we continue to have a poor understanding of the concept of fruit and wine quality. Professional judges do not agree or do not consistently recognize wine quality (Hodgson 2008),and there is no consensus on what constitutes quality relevant or quality-impact compounds in grapes. The identification and definition of such key components is critical for better vineyard management and harvest decisions to produce grapes according to end-use specifications. Clear specifications will enhance the ability to differentiate wines and other nutritionally valuable grape-related products according to consumer demand. Soil management will have to take its place alongside canopy management as a key component of the sustainable vineyard management ‘toolbox’ (Keller 2005). This calls for research into the integration of appropriate and refined (deficit) irrigation techniques with vine nutrition, salinity management and vineyard floor management to optimize vine productivity, maximize fruit quality and ensure long-term soil fertility, perhaps in conjunction with enhanced carbon sequestration (e.g. Morlat and Chaussod 2008). Crop load and canopy management should be fine-tuned according to the desired end-use of the grapes from a particular vineyard block. This will not only require more quantitative assessments of interactions among treatment combinations, but also integration with precision viticulture approaches, and adaptations of trellis designs to facilitate mechanization. Quantitative data will need to be incorporated into models, and hard and software, including (remote) sensor technology, will need to be developed for mechanization and, ultimately, automation of cultural practices and vineyard sampling that are fully integrated with real-time decision management support systems and precision viticulture technology. Interdisciplinary research conducted by teams of various combinations of molecular biologists, physiologists, viticulturists, oenologists, sensory scientists, chemists, physicists, mathematicians, computer scientists and economists will have to tackle these issues. In addition to the undisputed need for extension of applied research results to industry, there is also a requirement for fundamental research that can be used as a basis to develop practical outcomes. It should be clear that a one-sided focus on applied, practical research that promises short term returns on investment will eventually deplete the novel ideas that give rise to unforeseen applicable questions.

3. The instruments for evaluating the impacts of the climate change

3.1. Preface

In 1992 the IPCC released emission scenarios to be used for driving global circulation models to develop climate change scenarios. The so-called IS92 scenarios were path breaking. They were the first global scenarios to provide estimates for the full suite of greenhouse gases. Much has changed since then in our understanding of possible future greenhouse gas emissions and climate change. Therefore the IPCC decided in 1996 to develop a new set of emissions scenarios which will provide input to the IPCC Third Assessment Report but can be of broader use than the IS92 scenarios. The new scenarios provide also input for evaluating climatic and environmental consequences of future greenhouse gas emissions and for assessing alternative mitigation and adaptation strategies. They include improved emission baselines and latest information on economic restructuring throughout the world, examine different rates and trends in technological change and expand the range of different economic-development pathways, including narrowing of the income gap between developed and developing countries. To achieve this a new approach was adopted to take into account a wide range of scientific perspectives, and interactions between regions and sectors. Through the so-called “open process” input and feedback from a community of experts much broader than the writing team were solicited. The results of this work show that different social, economic and technological developments have a strong impact on emission trends, without assuming explicit climate policy interventions. The new scenarios provide also important insights about the interlinkages between environmental quality and development choices and will certainly be a useful tool for experts and decision makers.

3.2. The emission scenarios

The IPCC published a new set of scenarios in 2000 for use in the Third Assessment Report (Special Report on Emissions Scenarios - SRES). The SRES scenarios were constructed to explore future developments in the global environment with special reference to the production of greenhouse gases and aerosol precursor emissions. They use the following terminology:

- Storyline: a narrative description of a scenario (or a family of scenarios), highlighting the main scenario characteristics and dynamics, and the relationships between key driving forces.
- Scenario: projections of a potential future, based on a clear logic and a quantified storyline.
- Scenario family: one or more scenarios that have the same demographic, politico-societal, economic and technological storyline.

The SRES team defined four narrative storylines (see Figure 5), labeled A1, A2, B1 and B2, describing the relationships between the forces driving greenhouse gas and aerosol emissions and their evolution during the 21st century for large world regions and globally . Each storyline represents different demographic, social, economic, technological, and environmental developments that diverge in increasingly irreversible ways.

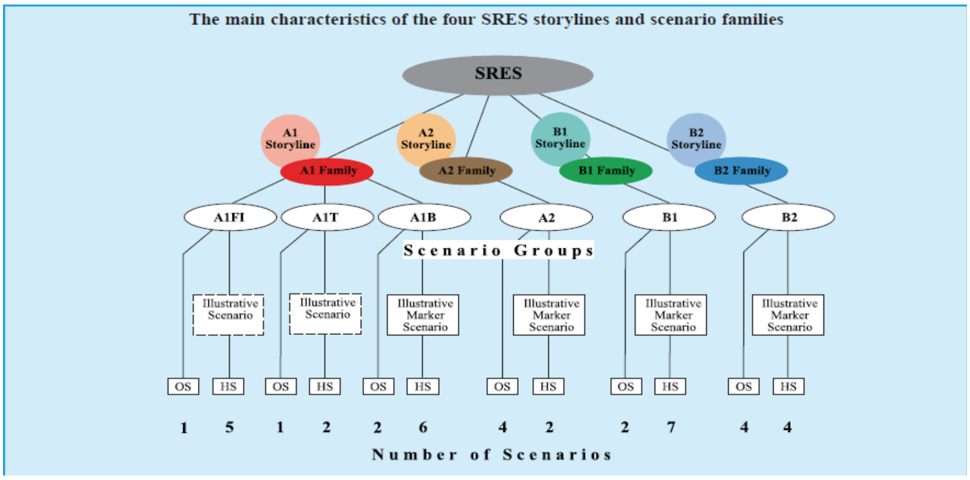


Figure5: Schematic illustration of SRES scenarios. Four qualitative storylines yield four sets of scenarios called "families": A1, A2, B1, and B2. Altogether 40 SRES scenarios .All are equally valid with no assigned probabilities of occurrence. The set of scenarios consists of six scenario groups drawn from the four families: one group each in A2, B1, B2, and three groups within the A1 family, characterizing alternative developments of energy technologies: A1FI (fossil fuel intensive), A1B (balanced), and A1T (predominantly non-fossil fuel). Within each family and group of

scenarios, some share "harmonized" assumptions on global population, gross world product, and final energy. These are marked as "HS" for harmonized scenarios. "OS" denotes scenarios that explore uncertainties in driving forces beyond those of the harmonized scenarios. The number of scenarios developed within each category is shown. For each ofthe six scenario groups an illustrative scenario (which is always harmonized) is provide

Within each scenario family two main types of scenarios were developed – those with harmonized assumptions about global population, economic growth, and final energy use and those with alternative quantification of the storyline. Together, 26 scenarios were harmonized by adopting common assumptions on global population and gross domestic product (GDP) development. Thus, the harmonized scenarios in each family are not independent of each other. The remaining 14 scenarios adopted alternative interpretations of the four scenario storylines to explore additional scenario uncertainties beyond differences in methodological approaches. They are also related to each other within each family, even though they do not share common assumptions about some of the driving forces. There are six scenario groups that should be considered equally sound that span a wide range of uncertainty, as required by the Terms of Reference. These encompass four combinations of demographic change, social and economic development, and broad technological developments, corresponding to the four families (A1, A2, B1, B2), each with an illustrative "marker" scenario. Two of the scenario groups of the A1 family (A1FI, A1T) explicitly explore alternative energy technology developments, holding the other driving forces constant, each with an illustrative scenario. Rapid growth leads to high capital turnover rates, which means that early small differences among scenarios can lead to a large divergence by 2100. Therefore the A1 family, which has the highest rates of technological change and economic development, was selected to show this effect. In accordance with a decision of the IPCC Bureau in 1998 to release draft scenarios to climate modelers for their input in the Third Assessment Report, and subsequently to solicit comments during the open process, one marker scenario was chosen from each of four of the scenario groups based on the storylines.

The scenarios span a wide range of future levels of economic activity, with gross world product rising to 10 times today's values by 2100 in the lowest to 26-fold in the highest scenarios. A narrowing of income differences among world regions is assumed in many of the SRES scenarios. Two of the scenario families, A1 and B1, explicitly explore alternative pathways that gradually close existing income gaps in relative terms. Technology is at least as important a driving force as demographic change and economic development. These driving forces are related. Within the A1 scenario family, scenarios with common demographic and socio-economic driving forces but different assumptions about technology and resource dynamics illustrate the possibility of very divergent paths for developments in the energy system and land-use patterns.

The SRES scenarios cover a wider range of energy structures than the IS92 scenarios. This reflects uncertainties about future fossil resources and technological change. The scenarios cover virtually all the possible directions of change, from high shares of fossil fuels, oil and gas or coal, to high shares of non-fossils. In most scenarios, global forest area continues to decrease for some decades, primarily because of increasing population and income growth. This current trend is eventually reversed in most scenarios with the greatest eventual increase in forest area by 2100 in the B1 and B2 scenario families, as compared to 1990. Associated changes in agricultural land use are driven principally by changing food demands caused by demographic and dietary shifts. Numerous other social, economic, institutional, and technological factors also affect the relative shares of agricultural lands, forests, and other types of land use. Different analytic methods lead to very different results, indicating that future land use change in the scenarios is very model specific. All the above driving forces not only influence CO2 emissions, but also the emissions of other GHGs.

In particular we can see as the SRES scenarios cover most of the range of carbon dioxide (figure 6), other GHGs, and sulfur emissions found in the recent literature and SRES scenario database. Their spread is similar to that of the IS92 scenarios

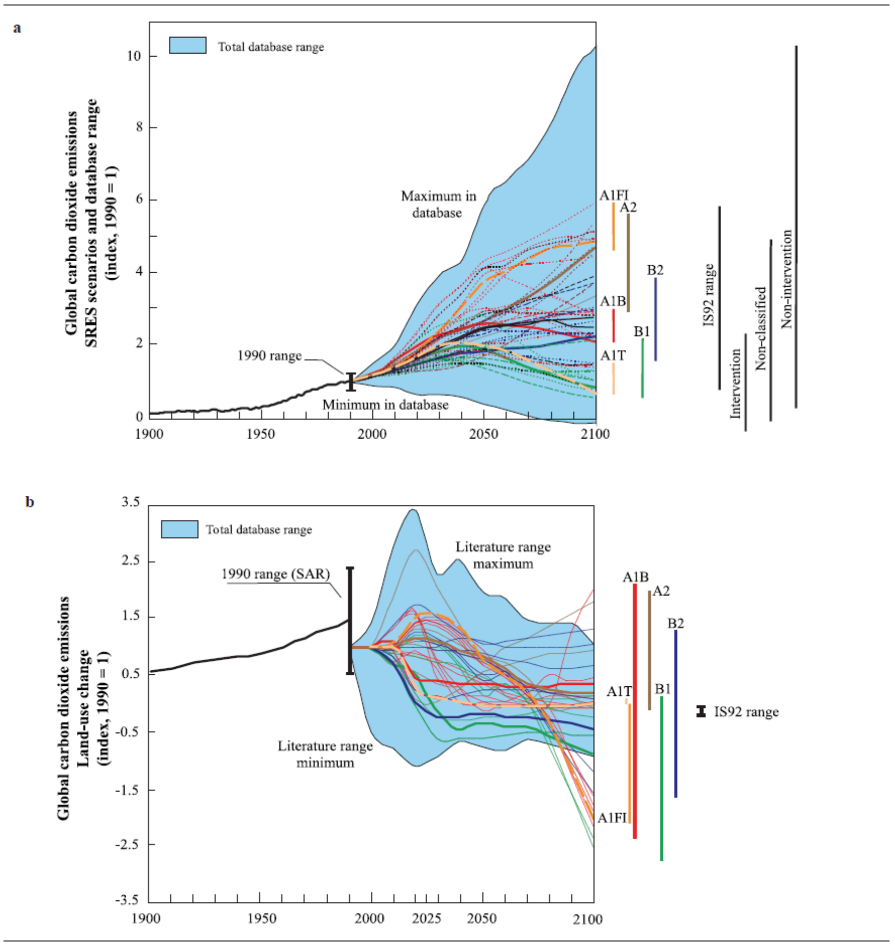


Figure 6 Global CO2 emissions related to energy and industry (Figure 2a) and land-use changes (Figure 2b) from 1900 to 1990, and for the 40 SRES scenarios from 1990 to 2100, shown as an index (1990 = 1).

for CO2 emissions from energy and industry as well as total emissions but represents a much wider range for land-use change. The six scenario groups cover wide and overlapping emission ranges. The range of GHG emissions in the scenarios widens over time to capture the long-term uncertainties reflected in the literature for many of the driving forces, and after 2050 widens significantly as a result of different socioeconomic developments. In figures 3 and 4 we can see in greater detail the ranges of total CO_2 emissions for the six scenario groups of scenarios that constitute the four families (the three scenario families A2, B1, and B2, plus three groups within the A1 family A1FI, A1T, and A1B).

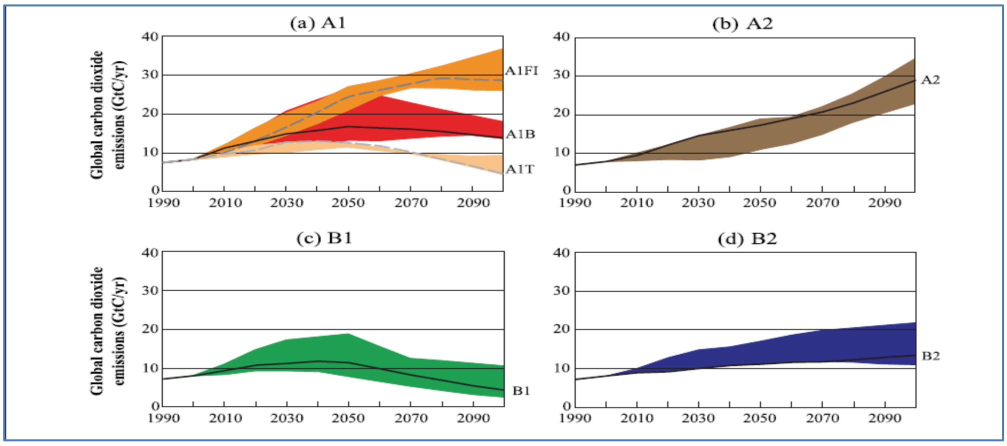


Figure 7 Total global annual CO2 emissions from all sources (energy, industry, and land-use change) from 1990 to 2100 (in gigatonnes of carbon (GtC/yr)) for the families and six scenario groups

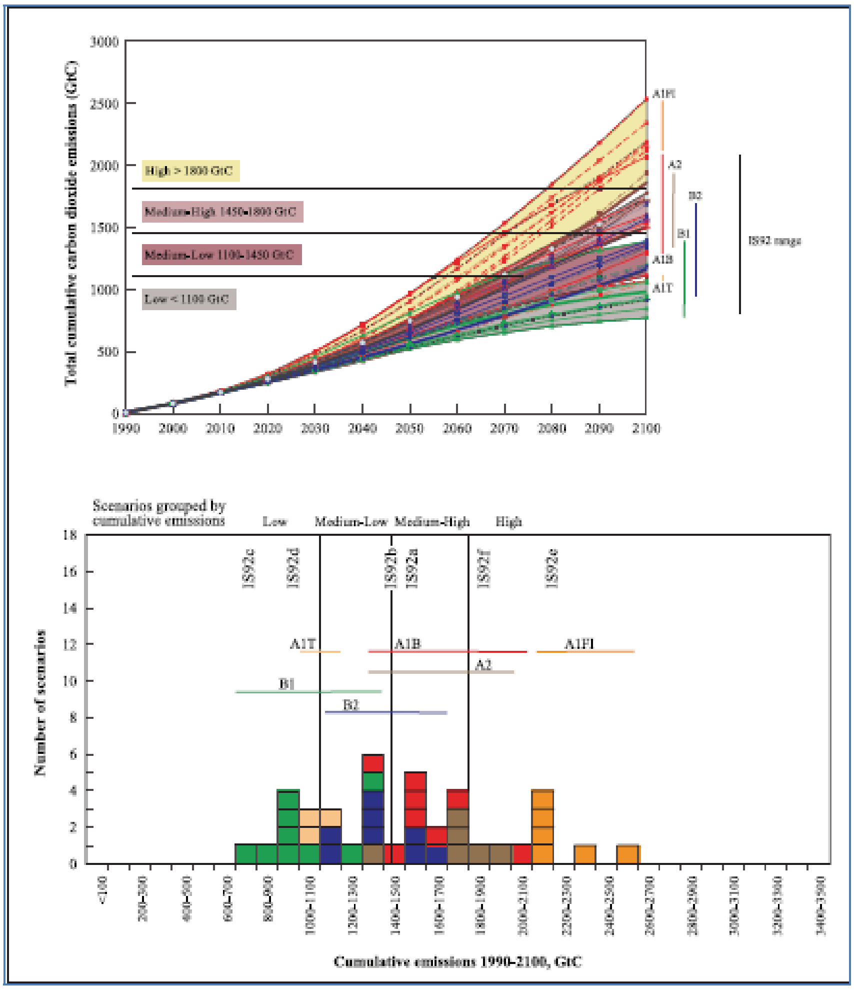


Figure 8: Total global cumulative CO2 emissions (GtC) from 1990 to 2100 (Figure 4a) and histogram of their distribution byscenario groups (Figure 4b).

3.3. The climate model

Understanding the climate system is a problem of great intrinsic scientific interest. Our growing understanding of interactions between the atmosphere, oceans, biosphere, cryosphere and land surface is revolutionizing the Earth sciences. Moreover, in recent years, a sense of urgency has infused research on modelling the climate system. The prospect of human activities altering atmospheric composition, affecting climate globally and regionally, and ultimately affecting human economies and natural ecosystems, has stimulated the development of models of the climate system.

An important concept in climate system modelling is the notion of a hierarchy of models of differing levels of complexity, dimensionality and spatial resolution, each of which may be optimum for answering different questions, but it is not meaningful to judge one level as being better or worse than another, independent of the context of analysis.

The most general computer models for climate change employed by the IPCC are the coupled, which solve the equations of the atmosphere and oceans approximately by breaking their domains up into volumetric grids, or boxes, each of which is assigned an average value for properties like velocity, temperature, humidity (atmosphere) and salt (oceans). The size of the box is the models' spatial resolution. The smaller the box, the higher the resolution. An assumption of research involving general circulation models (GCMs) is that the realism of climate simulations will improve as the resolution increases In practice, the approach has been to "parameterize" that is, to use empirical or semi-empirical relations to approximate net (or area-averaged) effects at the resolution scale of the model It is important to stress that all climate system models contain empirical parameterizations and that no model derives its results entirely from first principles. The main conceptual difference between simple and complex models is the hierarchical level at which the empiricism enters

3.4. The climate system

The climate system is a complex, interactive system consisting of the atmosphere, land surface, snow and ice, oceans and other bodies of water, and living things. The atmospheric component of the climate system most obviously characterises climate; climate is often defined as ‘average weather’. Climate is usually described in terms of the mean and variability of temperature, precipitation and wind over a period of time, ranging from months to millions of years (the classical period is 30 years). The climate system evolves in time under the influence of its own internal dynamics and due to changes in external factors that affect climate (called ‘forcings’). External forcings include natural phenomena such as volcanic eruptions and solar variations, as well as human-induced changes inatmospheric composition. Solar radiation powers the climate system.

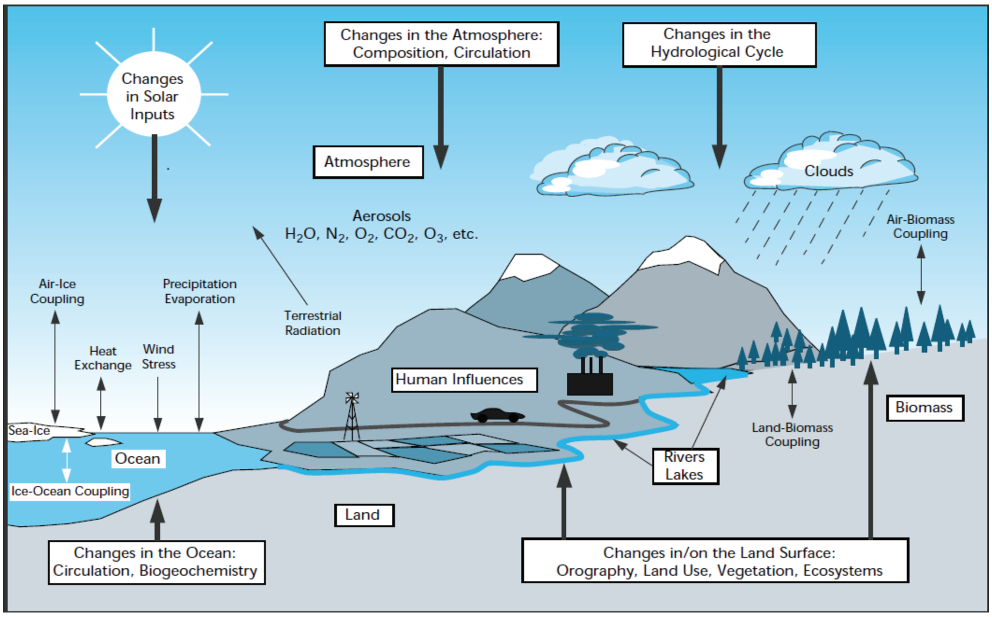


Figure 9 The climate system

There are three fundamental ways to change the radiation balance of the Earth:

1) by changing the incoming solar radiation (e.g., by changes in Earth’s orbit or in the Sun itself); 2) by changing the fraction of solar radiation that is reflected (called ‘albedo’; e.g., by changes in cloud cover, atmospheric particles or vegetation); 3) by altering the longwave radiation from Earth back towards space (e.g., by changing greenhouse gas concentrations). Climate, in turn, responds directly to such changes, as well as indirectly, through a variety of feedback

mechanisms. The amount of energy reaching the top of Earth's atmosphere each second on a surface area of one square metre facing the Sun during daytime is about 1,370 Watts, and the amount of energy per square metre per second averaged over the entire planet is one-quarter of this About 30% of the sunlight that reaches the top of the atmosphere is reflected back to space. Roughly two-thirds of this reflectivity is due to clouds and small particles in the atmosphere known as 'aerosols'. Light-coloured areas of Earth's surface – mainly snow, ice and deserts – reflect the remaining one-third of the sunlight. The most dramatic change in aerosol-produced reflectivity comes when major volcanic eruptions eject material very high into the atmosphere. Rain typically clears aerosols out of the atmosphere in a week or two, but when material from a violent volcanic eruption is projected far above the highest cloud, these aerosols typically influence the climate for about a year or two before falling into the troposphere and being carried to the surface by precipitation. Major volcanic eruptions can thus cause a drop in mean global surface temperature of about half a degree celsius that can last for months or even years. Some man-made aerosols also significantly reflect sunlight.

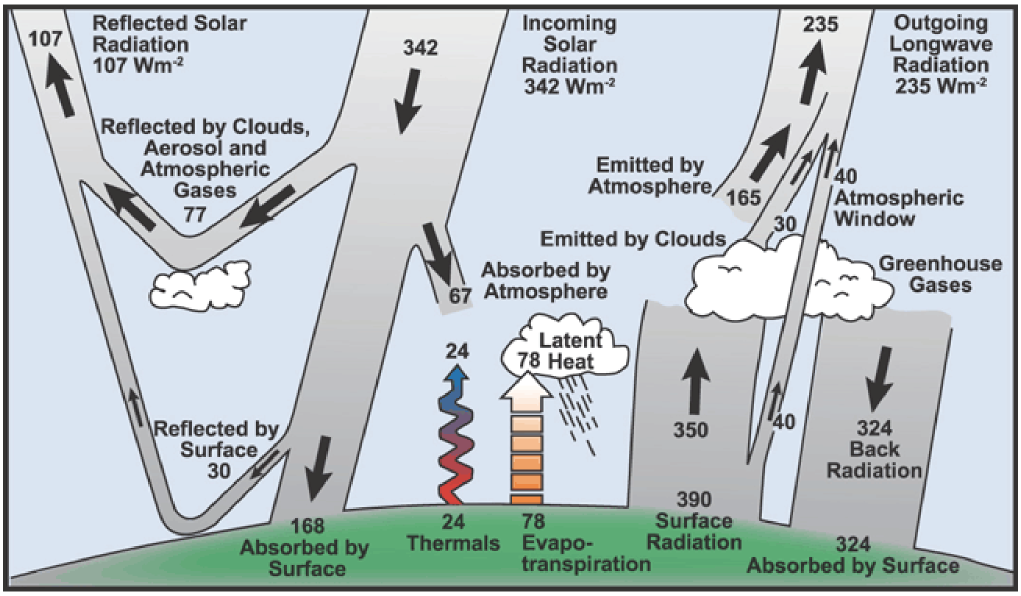


Figure 10 The energy balance in the atmospheric system

The energy that is not reflected back to space is absorbed by the Earth's surface and atmosphere. This amount is approximately 240 Watts per square metre (W m–2). To balance the incoming energy, the Earth itself must radiate, on average, the same amount of energy back to space. The Earth does this by emitting outgoing longwave radiation. Everything on Earth emits longwave radiation continuously. That is the heat energy one feels radiating out from a fire; the warmer an object, the more heat energy it radiates. To emit 240 W m–2, a surface would have to have a temperature of around –19°C. This is much colder than the conditions that actually exist at the Earth's surface (the global mean surface temperature is about 14°C). Instead, the necessary –19°C is found at an altitude about 5 km above the surface. The reason the Earth's surface is this warm is the presence of greenhouse gases, which act as a partial blanket for the longwave radiation coming from the surface. This blanketing is known as the natural greenhouse effect. The most important greenhouse gases are water vapour and carbon dioxide. The two most abundant constituents of the atmosphere – nitrogen and oxygen – have no such effect. Clouds, on the other hand, do exert a blanketing effect similar to that of the greenhouse gases; however, this effect is offset by their reflectivity, such that on average, clouds tend to have a cooling effect on climate (although locally one can feel the warming effect: cloudy nights tend to remain warmer than clear nights because the clouds radiate longwave energy back down to the surface). Human activities intensify the blanketing effect through the release of greenhouse gases. For instance, the amount of carbon dioxide in the atmosphere has increased by about 35% in the industrial era, and this increase is known to be due to human activities, primarily the combustion of fossil fuels and removal of forests. Thus, humankind has dramatically altered the chemical composition of the global atmosphere with substantial implications for climate.

Because the Earth is a sphere, more solar energy arrives for a given surface area in the tropics than at higher latitudes, where sunlight strikes the atmosphere at a lower angle. Energy is transported from the equatorial areas to higher latitudes via atmospheric and oceanic circulations, including storm systems. Energy is also required to evaporate water from the sea or land surface, and this energy, called latent heat, is released when water vapour condenses in clouds Atmospheric circulation is primarily driven by the release of this latent heat. Atmospheric circulation in turn drives much of the ocean circulation through the action of winds on the surface waters of the ocean, and through changes in the ocean's surface temperature and salinity through precipitation and evaporation. Due to the rotation of the Earth, the atmospheric circulation patterns tend to be more east-west than north-south. Embedded in the mid-latitude westerly winds are large-scale weather systems that act to transport heat toward the poles. These weather systems are the familiar migrating low- and high-pressure systems and their associated cold and warm fronts. Because of land-ocean temperature contrasts and obstacles such as mountain ranges and ice sheets, the circulation system's planetary-scale atmospheric waves tend to be geographically anchored by continents and mountains although their amplitude can change with time. Because of the wave patterns, a particularly cold winter over North America may be associated with a particularly warm winter elsewhere in the hemisphere. Changes in various aspects of the climate system, such as the size of ice sheets, the type and distribution of vegetation or the temperature of the atmosphere or ocean will influence the large-scale circulation features of the atmosphere and oceans. There are many feedback mechanisms in the climate system that can either amplify ('positive feedback') or diminish ('negative feedback') the effects of a change in climate forcing. For example, as rising concentrations of greenhouse gases warm Earth's climate, snow and ice begin to melt. This melting reveals darker land and water surfaces that were beneath the snow and ice, and these darker surfaces absorb more of the Sun's heat, causing more warming, which causes more melting, and so on, in a self-reinforcing cycle. This feedback loop, known as the 'ice-albedo feedback', amplifies the initial warming caused by rising levels of greenhouse gases. Detecting, understanding and accurately quantifying climate feedbacks have been the focus of a great deal of research by scientists unravelling the complexities of Earth's climate.

3.5. The climate sensitivity

Climate sensitivity is the term used by the Intergovernmental Panel on Climate Change (IPCC) to express the relationship between the human-caused emissions that add to the Earth's greenhouse effect — carbon dioxide and a variety of other greenhouse gases — and the temperature changes that will result from these emissions.

Specifically, the term is defined as how much the average global surface temperature will increase if there is a doubling of greenhouse gases (expressed as carbon dioxide equivalents) in the air, once the planet has had a chance to settle into a new equilibrium after the increase occurs. In other words, it's a direct measure of how the Earth's climate will respond to that doubling.

That value, according to the most recent IPCC report, is 3 degrees Celsius, with a range of uncertainty from 2 to 4.5 degrees.

This sensitivity depends primarily on all the different feedback effects, both positive and negative, that either amplify or diminish the greenhouse effect. There are three primary feedback effects — clouds, sea ice and water vapor; these, combined with other feedback effects, produce the greatest uncertainties in predicting the planet's future climate.

With no feedback effects at all, the change would be just 1 degree Celsius, climate scientists agree. Virtually all of the controversies over climate science hinge on just how strong the various feedbacks may be — and on whether scientists may have failed to account for some of them.

Clouds are a good example. Clouds can have either a positive or negative feedback effect, depending on their altitude and the size of their water droplets. Overall, most scientists expect this net effect to be positive, but there are large uncertainties.
It is important to note that climate sensitivity is figured on the basis of an overall doubling, compared to pre-industrial levels, of carbon dioxide and other greenhouse gases. But the temperature change given by this definition of climate sensitivity is only part of the story. The actual increase might be greater in the long run

because greenhouse gas levels in the atmosphere could more than double without strong policies to control emissions. But in the short run, the actual warming could be less than suggested by the climate sensitivity, since due to the thermal inertia of the ocean, it may take some time after a doubling of the concentration is reached before the climate reaches a new equilibrium.

There are various types of climate models. Some focus on certain things that affect climate such as the atmosphere or the oceans. Models that look at few variables of the climate system may be simple enough to run on a personal computer. Other models take into account many factors of the atmosphere, biosphere, geosphere, hydrosphere, and cryosphere to model the entire Earth system. They take into account the interactions and feedbacks between these different parts of the planet. Earth is a complex place and so many of these models are very complex too. They include so many math calculations that they must be run on supercomputers, which can do the calculations quickly. All climate models must make some assumptions about how the Earth works, but in general, the more complex a model, the more factors it takes into account, and the fewer assumptions it makes

There are currently several other complex global climate models that are used to predict future climatic change. The most robust models are compared by the IPCC (Intergovernmental Panel on Climate)

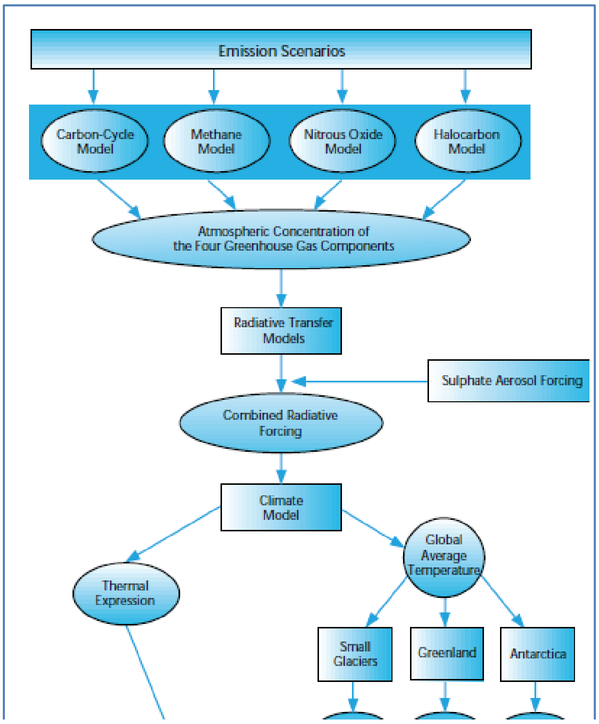


Figure 11Steps involved in calculating greenhouse gas and aerosol concentration changes, climatic change, and sea level rise using simple climate models

In general a wide range of models exists for most of the components of the climate system but we shall use the term "simple climate model" (SCM) to refer primarily to the upwelling-diffusion climate and ocean carbon cycle models and the term "complex model" to refer to the atmospheric and ocean GCMs, whether run as stand-alone models or as coupled models.

The essential difference between simple and complex models is the degree of simplification, or the level at which parametrization is introduced. Simple linked models have been used to go from emissions of a suite of gases to concentrations, climatic change, and sea level rise (Figure 11).

Agriculture, like most business, is a decision-making enterprise. Farmers and policy makers are constantly faced with the task of matching and allocating time and resources to efforts that are likely to produce desired outcomes. Agriculture involves biological factors for which, in many cases, the interactions with the environment are unknown. Deviations from expected outcomes are often caused by random environmental variables over which the decision maker has little or no control. Year-to-year variations in weather cause large variations in crop yields. Uncertainty in weather creates a risky environment for agricultural production. Thus chance, and therefore risk, enters the decision-making process, and farmers and policy makers are unwillingly forced to gamble with nature.

During the last decades the application of simulation and system analysis in agricultural research has increased considerably. The simulation model is one of the most complex methods among the approaches used to describe the soil-plant-atmosphere system. Models that use weather data and soil and plant data in simulating crop yields have the potential for being used to asses the risk of producing a given crop in a particular soil-climate regime and for assisting in management decisions that minimize the risk of crop production (e.g. *Tsuji et al., 1998*). Models, in general, are a mathematical representation of a real-world system (e.g. *Mize and Cox, 1968*). In reality, it is impossible to include all the interactions between the environment and the modeled system in a computer model. In most cases, a model is a simplification of a real-world system (e.g. *Hoogenboom, 2000*). A model might include many assumptions, especially when information that describes the interactions of the system is inadequate or does not exist. Depending on the scientific discipline, there are different types of models, ranging from very simple models that are based on one equation to extremely advanced models, that include thousands of equations (e.g. *Hoogenboom, 2000*). Crop models, in general, integrate current knowledge from various disciplines, including meteorology, soil physics, soil chemistry, crop physiology, plant breeding, and agronomy, into a set of mathematical equations to predict growth, development and yield (e.g. *Hoogenboom, 2000*).

Simulation models are robust tools to guide our understanding of how a system responds to a given set of conditions. Crop simulation models are increasingly being used in agriculture to estimate production potentials, design plant ideotypes, transfer agrotechnologies, assist strategic and tactical decisions, forecast real time yields and establish research priorities (e.g. *Bannayan and Crout, 1999; Penning de Vries and Teng, 1993; Uehera and Tsuji, 1993*). Numerous crop growth and yield models have been developed for a wide range of purposes in recent years (e.g. *Casanova et al., 2000; Hoogenboom, 2000*). These models range in complexity from the most sophisticated simulators of plant growth, primarily intended for research into plant physiological interactions, to multiple regression models using only a few monthly weather variables to forecast regional crop yields. Generally, plant-process yield models have been developed to predict yield at the level of an average plant in a specified field. Thus the input data required by these models include plant parameters specific to the variety or hybrid planted in some field and soils parameters describing the soil in that field. The prediction of crop development is an important aspect of crop growth modelling.

One use of the crop models developed in recent years is to simulate the effects of cultural practices and climatic scenarios on crop growth and yield. However, their use for predicting yields over large areas is limited by the difficulty in obtaining information about local conditions or crop characteristics at any given point. Some crop or soil features may be considered to be constant for a group of genotypes in a given region, but others depend on changes in local conditions (e.g. Guerif and Duke, 1998). Testing over a range of environmental conditions is required to establish confidence in applying models (e.g. Goudriaan and Van Laar, 1994). Crop models are available for almost all economically important crops and on many occasions they have been successfully used in research. In the future, models may be useful for improving the efficiency of agricultural systems and could be a tool for farmers trying to improve the profitability of their farms (e.g. Jacobson et al., 1995). Nevertheless, before this is possible, models must be calibrated and evaluated for each climatic region where they are intended for use in decision making (e.g. Sau et al. 1999).

Crop simulation models permit the summary of scientific knowledge on the biological processes that regulate plant growth. They integrate the work of experts in different fields and place it all at the disposal of any agronomist. As such, these models appear as very powerful tools. Low cost and time saving are their two major advantages over field experimentation. These models simulate final variables of the crop cycle, such as grain yield, but also simulate the evolution of some intermediate variables. They are generally built with an analytical purpose. Yet, these models are sometimes used as a predictive tool (e.g. Trousland-Kerdiles and Grondona, 1997).

Large area yield forecasting prior to harvest is of interest to government agencies, commodity firms and producers. Early information on yield and production volume may support these institutions in planning transport activities, marketing of agricultural products or planning food imports. Moreover, at world scale, agricultural market prices are affected by information on the supply or consumption of foodstuffs. Market price adjustments or change in agricultural supplies in one area of the world often causes price adjustments in other areas far distant (Supit and van der Goot, 2002).

It is no longer necessary nowadays to demonstrate the usefulness of simulation models to explain and predict crop yields or changes in the environment at various scales of agricultural production (e.g. Boote et al., 1996). The value of exploring agronomic situations not tried experimentally (or difficult to try out experimentally) is all the greater when the model can simulate several crops arranged in succession, and when as many cropping techniques and environmental limiting factors as possible are included (e.g. Cabelguenne et al., 1999). Crop models can also be used to generate input data for models for technical/economic optimisation, notably in the context of the analysis of European or national policies for competitiveness and environmental protection (e.g. Flichman, 1995; van Ittersum and Rabbinge, 1997). In an economic context in which techniques and regulations are rapidly evolving, or where the objectives and limitations applied to cropping systems are also very diverse, long-term experiments cannot provide answers quickly enough for action to be taken. Models are called upon more and more to contribute to the formulation of innovative cropping systems. Clearly, the credibility of the conclusions from long-term exploratory simulations rests heavily on the reliability of the models, and especially on a good prediction of the yields of crops subjected to various water and thermal stresses (e.g. Cabelguenne et al. 1999).

3.6. The crop models

This section will not discuss all crop models that are available for simulating crop growth, but will consider some examples that have been used by scientists throughout the world and will review some desirable characteristics for a crop model that is to be used for climate change impact assessment For a crop model to be useful as a climate change impact assessment tool, it has to reliably predict yield as a function of weather variables and have a relatively limited number of essential variables and parameters – models developed to express understanding derived directly from research are not particularly suited to practical application where limited data might be available for parameterization, calibration and testing. It must also be available to users in a robust yet flexible package that readily facilitates implementation, have a CO_2 response equation in the simulation, and operate at suitable spatial and temporal scales. A review of literature for regional studies using the CROPGRO model (for a review of the model, see Hoogenboom et al., 1992), the CERES model (a user manual is provided by Goodwin et al., 1990) and the SUBSTOR model (described by Singh et al., 1998) reveals a predominance of work conducted for more developed countries (perhaps because the necessary data of suitable quality are available for these regions). The impact assessments focus mainly on the effects of elevated CO_2, temperature, precipitation and radiation on yield, but some authors have examined how these factors influence crop suitability and changing spatial distributions of crops (for instance, Iglesias et al., 2000; Rosenzweig et al., 2002; Jones and Thornton, 2003). While workers tend to conclude that increases in yield are likely, they discuss issues of importance such as timing of water in Indian monsoon, which can cause reduced yield (Lal et al., 1998, 1999), and the uncertainty of the yield forecasts (soybean and peanut yield increases, maize and wheat yield decreases) in the south-eastern United States (Alexandrov and Hoogenboom, 2004). The potential effect of the daytime vs. night-time rise in temperature is discussed by Dhakhwa et al. (1997), who suggest that an asymmetrical change, with greater change at night-time, would have less impact on yield than a symmetrical change. Another important issue is the potential significance of cultivar selection (Alexandrov et al., 2002; Kapetanaki and Rosenzweig, 1997). There have been studies for Africa and other developing regions (for example, Jones and Thornton, 2003), but authors recognize that a model to predict yield changes is unlikely to capture the true impact of climate change on smallholders and non-mechanized farmers in these regions. Other crop models have been used for climate change impact assessment: EuroWheat (Harrison and

Butterfield, 1996; Hulme et al., 1999) for wheat crops; the Hurley pasture model (Thornley and Cannell, 1997) for grass; GLYCIM (Haskett et al., 1997) for soybean; and CropSyst (Stöckle et al., 1994; Tubiello et al., 2000) for various C3 and C4 crops, mainly cereals. A characteristic of the work published in scientific literature is that most models are not well adapted to subsistence and low-input production systems, and therefore example studies tend to focus on agricultural production in more developed countries, where mechanization and husbandry inputs are a significant part of the production systems used.

3.7. Animal models

A review of the literature reveals that there are many crop models available for climate change impact assessment, but there are few animal models that have been used to evaluate the impact of climate change on the animal. Most work focuses on how climate change affects animal production systems, with a particular emphasis on the supply of nutrients to the animal (for instance, the production of grass) and related environmental impacts (soil–water models). Two examples that can be found in the literature are A review of the literature reveals that there are many crop models available for climate change impact assessment, but there are few animal models that have been used to evaluate the impact of climate change on the animal. Most work focuses on how climate change affects animal production systems, with a particular emphasis on the supply of nutrients to the animal (for instance, the production of grass) and related environmental impacts (soil–water models). Two examples that can be found in the literature are:

- SPUR (Wight and Skiles, 1987), which stands for Simulation of Production and Utilization of Rangelands. It is an ecologically based model designed to help optimize rangeland management systems. By considering hydrology, plant growth, animal physiology and harvesting, the model can forecast the effects of environmental conditions on range ecosystems, in addition to the animal simulation based on the Colorado beef cattle production model. The detail and complexity of the animal model mean that it may be excessively detailed for climate change impact work (Mader et al., 2002). The inputs for the animal component include breeding season, calving season, castration date and day of weaning. Animal parameters include birth weight, yearling weight, mature weight, milk production, age at puberty and gestation length. The climate data required are precipitation, maximum and minimum temperature, solar radiation, and wind run. The SPUR model can also be regarded as a system model, as it simulates soil, plant and animal interactions. It is placed under the category of animal model because it has been used for climate change impact assessment for animals (Hanson et al., 1993; Eckert et al., 1995).
  National Research Council Nutrient Requirements of Beef Cattle (NRC, 1996). It was published as a book reviewing the literature on beef cattle nutrient requirements, and the accompanying computer models utilize current knowledge of factors that affect the nutritional needs of cattle and enable the user to define these factors to

customize the situation for a specific feeding program. The model uses information on diet type, animal status, management, environment and the feeds in the diet. The effect of temperature on voluntary feed intake (VFI) is at the centre of the model. The model uses climate variables, primarily average daily temperature, to generate an estimate of daily VFI. Based on daily VFI, estimates of production output (daily body weight gain) can then be produced. Frank et al. (1999) used the model to evaluate climate change impacts on animals in the United States Testing the validity of assumptions, parameterization and calibration of animal models for less-developed countries is of particular importance given the forecast of drought and heat stress on animals in tropical, semi-arid and Mediterranean regions, and the potential constraints that might hinder adaptation in these situations.

System models

The Decision Support System for Agrotechnology Transfer (DSSAT), which is currently available in version 4.0, is a good example of a system modelling tool. It has been used for the last 15 years for modelling crop (type and phenotype), soil, weather, and management or husbandry interactions (ICASA, 2006), and it has also been employed to assess climate change impacts (for instance, in Holden et al., 2003; Holden and Brereton, 2003).

The minimum dataset required for DSSAT consists of site weather data describing maximum and minimum air temperature, rainfall and radiation (stochastic weather generators are provided to create daily data if only monthly mean data are available); site soil data describing horizonation, texture, bulk density, organic carbon, pH, aluminium saturation and root distribution (basic soil descriptions can be used to parameterize a soil based on examples provided); and management data (planting dates, fertilizer strategies, harvesting, irrigation and crop rotations). Additional detail can be used as required by the research programme. The system then allows the user to define a crop/management scenario using a series of modules:

(a) Land module – defines the types of soils and fields when the system is being used for site-specific work. Can be generalized for climate change impact assessment.

(b) Management module – deals with planting, crop husbandry, rotation management, fertilizer, irrigation and harvesting.

(c) Soil module – a soil water balance submodule and two soil nitrogen/organic matter modules including integration of the CENTURY model. For climate change impact assessment much of the detail can be ignored if suitable data do not exist.

(d) Weather module – reads daily weather data or generates suitable data from monthly mean values.

(e) Soil–plant–atmosphere module – deals with competition for light and water among the soil, plants and atmosphere.

(f) Crop growth simulation modules – specific crop models (CROPGRO, CERES and SUBSTOR), each of which is well established in the scientific literature, are used to simulate the growth of 19 important crops (soybean, peanut, drybean, chickpea, cowpea, velvet bean, faba bean, pepper, cabbage, tomato, bahia grass, brachiaria grass, rice, maize, millet, sorghum, wheat, barley and potato).

The DSSAT systems can be regarded as a flexible system model, but there have been a number of other specific system models developed, many with a view to understanding more about climate change impacts. Typically, these models focus on a combination of agricultural production and biogeochemical cycling. Examples include:

PaSim (Riedo et al., 1998, 2000). The pasture simulation model is a mechanistic ecosystem modelthat simulates dry matter production and fluxes of carbon (C), nitrogen (N), water, and energy in permanent grasslands with a high temporal resolution. PaSim consists of submodels for plant growth, microclimate, soil biology and soil physics. It is driven by hourly or daily weather data. Site-specific model parameters include the N-input from mineral and/or organic fertilizers and atmospheric deposition, the fractional clover content of the grass/clover mixture, the depth of the main rooting zone, and soil physical parameters. Different cutting and fertilization patterns as well as different grazing regimes can be specified as management options.

Dairy_sim (Fitzgerald et al., 2005; Holden et al., 2008). Dairy_sim was designed to assess theinteractions between climate and management in spring-calving milk production systems based on the grazing of grass pastures. The simulator comprises three main components: a grass herbage growth model, an intake and grazing behaviour model, and a nutrient demand model. The model has been improved to better account for soil water balance and field trafficability, but does not explicitly consider biogeochemical cycles. The level of detail was specified as appropriate for climate change impact studies, but is probably regionally constrained to the Atlantic Arc of Europe and areas with a similar climate.

CENTURY (Parton et al., 1987, 1995). The CENTURY model simulates carbon, nutrient and water dynamics for grassland and forest ecosystems. It includes a soil organic matter/decomposition submodel, a water budget submodel, grassland and forest plant production submodels, and functions for scheduling events. The model computes flows of carbon, nitrogen, phosphorus and sulphur. Initial data requirements are: monthly temperature (minimum, maximum and average in degrees C), monthly total precipitation (cm), soil texture, plant nitrogen, phosphorus, sulphur content and lignin content of plant material, atmospheric and soil nitrogen inputs, and initial concentrations of soil carbon, nitrogen, phosphorus and sulphur

EPIC (Williams et al., 1990). The Erosion Productivity Impact Calculator (also known as the Environmental Policy Integrated Climate) model was designed to assess the effect of soil erosion on productivity by considering the effects of management decisions on soil, water, nutrient and pesticide movements and their combined impact on soil loss, water quality, and crop yields for areas with homogeneous soils and management. The model has a daily timestep and can simulate up to 4 000 years; it has been used for drought assessment, soil loss tolerance assessment, growth simulation, climate change analysis, farm-level planning and water quality analysis. Examples of its application include Mearns et al. (2001) and Brown and Rosenberg (1999)

DNDC (Zhang et al., 2002). The denitrification–decomposition model is a process-oriented modelof soil carbon and nitrogen biogeochemistry. It consists of two parts, the first of which considers soil, climate, crop growth and decomposition submodels for predicting soil temperature, moisture, pH, redox potential and substrate concentration profiles driven by ecological drivers (such as climate, soil, vegetation and anthropogenic activity). The second considers nitrification, denitrification and fermentation submodels for predicting NO, N2O, N2, CH4 and NH3 fluxes based on modelled soil environmental factors.

3.8. Forest models

There are a large number of forest and related models that have been used to evaluate climatechange impacts on natural and commercial forestry. Some examples will be used to illustrate the tools available. ForClim is a simplified forest model based on the gap dynamics hypothesis (so-called “gap” models) that was designed to use a limited number of robust assumptions and to be readily parameterized so that it could be used for climate change impact assessment (Bugmann, 1996). It has a modular structure that considers environment, soil and plants separately but interactively, and was tested by evaluating whether it could simulate forest structures related to climate gradients. Examples of its use include Bugmann and Solomon (1995) and Lindner et al. (1997).

The FORSKA/FORSKA 2 models (Prentice et al., 1993) simulate the dynamics of forestlandscapes with phenomenological equations for tree growth and environmental feedbacks. Establishment and growth are modified by species-specific functions that consider winter and summer temperature, net assimilation, and sapwood respiration as functions of temperature, CO2 fertilization, and growing-season drought. All of the trees in a 0.1 ha patch interact through competition for light and nutrients. The landscape is simulated as an array of such patches. The probability of disturbance on a patch is a power function of time since disturbance. This model does not explicitly consider soil fertility but assumes uniform patch conditions and simulates the effect of nutrient limitation using maximum biomass curves. It is also used by Lindner et al. (1997). It is necessary to recognize that forest models might not simulate meaningful changes from baseline over periods of 20–40 years due to the difficulty of capturing responses in complex ecosystems over relatively short periods. The impact of climate change is more likely to be visible over periods of 75–150 years. For commercial, monoculture forestry, the impact of changes in atmospheric chemistry, drought and high winds may become detectable by simulation modelling for a shorter period because the system is more readily modelled.

3.9. Other bioresource models

While most models used by the agricultural community (in its broadest sense) to assess impacts of climate change can be directly related to production aspects, there are models available that look at wider environmental issues that overlap with agricultural activity. A good example of such a model is SPECIES: spatial evaluation of climate impacts on the envelope of species (Pearson et al., 2002). This is a scale-independent model that uses an artificial neural network model coupled to a climate–hydrology model to simulate the relationship between biota and environment and it is useful for examining the impact of climate change on the distribution of species and how this might change (Berry et al., 2002*a*). The approach requires quite intensive observations in the region being examined and thus is most useful where there is a well-established and dense meteorological observation network. The SPECIES model has also been used to evaluate forest responses to climate change (Berry et al., 2002*b*).

4. The objective of the work

The vine has been extensively studied in the context of climate change studies. These studies can be separated into two groups: first, studies on the impacts observed in recent years and related to climate change and on the other hand, studies which, through experimentation (mimicking future conditions) or modeling, try to determine the conditions of production of this crop in the future.

In this study an analysis of the potential impacts of climate change on grapevine (Vitis vinifera L.) will be presented. Namely predicting the responses of two main Sardinian varieties - Cannonau and Vermentino, in order to ascertain reliable adjustment cultural practices as well to define possible mitigation strategies.

The objectives of this research were to evaluate the effects of climate change and grapevine and phenology, at two experimental sites in Sardinia, differents for soil, climate conditions.

To achieve these main objectives, the approach used in this study was:

The application and assessment of a coupled climate scenario-crop model method, in which Atmosphere-Ocean General Circulation Models, used to generate future climate scenarios, are integrated into crop models to simulate future crop yields.

The analysis of daily meteorological variables for current climatic conditions and climate change projections. These data are used as input variables for crop simulation models in conjunction with soil parameters and agronomic and management information, to simulate the dynamics of plant growth and development.

The comparison of the results of these simulations for both current and future climatic conditions. Impacts of climate change are then expressed as changes in crop productivity and phenological phases.

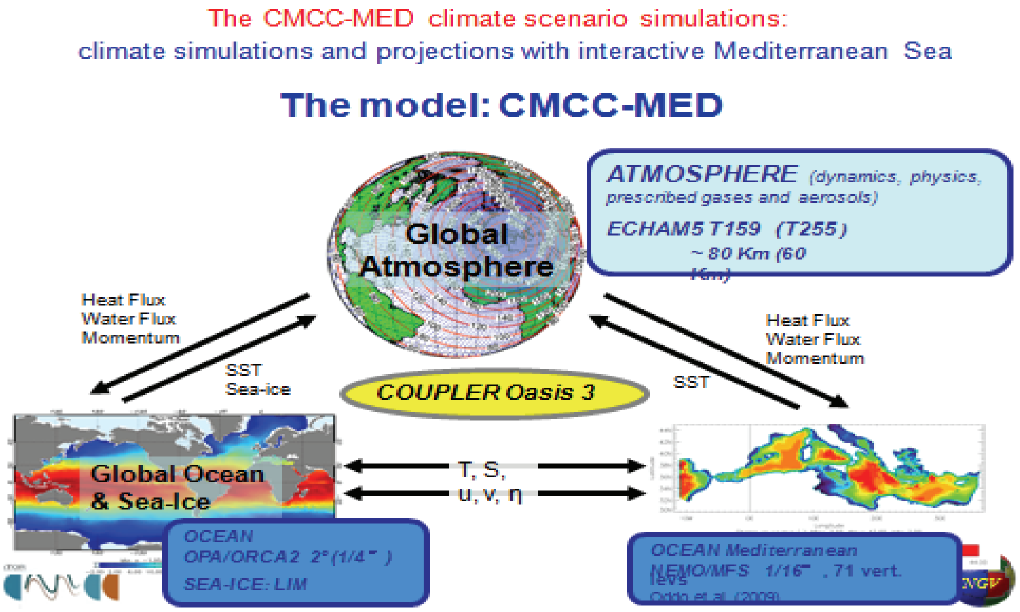
To summarize, the specific aims of the work are:

- to calibrate and validate Win-Stics model of the Cannonau and Vementino grapevin
- to assess the climate change impact on and phenological crop phases,

5. Material and methods

The global model CMCC_MED:

The global model at higher horizontal resolution is the CMCC-MED coupled atmosphere–ocean general circulation model, which has been implemented and developed in the framework of the European project CIRCE .The CMCC-MED model is an evolution of the SINTEX-G and the ECHAM-OPALIM models. The atmospheric model component is ECHAM5 with a T159 horizontal resolution, corresponding to a Gaussian grid of about 0.75° x 0.75°. This configuration has 31 hybrid sigma-pressure levels in the vertical and top at 10 hPa. The parameterization of convection is based on the mass flux concept, modified following Nordeng 9 . Moist processes are treated using a mass conserving algorithm for the transport of the different water species and potential chemical tracers. The transport is resolved on the Gaussian grid. In the CMCC_MED model the ocean component is simulated through a coarse-resolution global ocean model and a high-resolution eddy-permitting model of the Mediterranean Sea. The global ocean component is OPA 8.2 (Ocean PArallelise, in its ORCA2 global configuration. The horizontal resolution is 2o x 2o with a meridional refinement near the equator, approaching a minimum 0.5o grid spacing. The model has 31 vertical levels, 10 of which lie within the upper 100 m. ORCA2 also includes the Louvain La Neuve (LIM) model for the dynamics and thermodynamics of sea-ice. The Mediterranean Sea model 10 is a regional configuration of the NEMO (Nucleus for European Modeling of the Ocean) model with a 1/16o horizontal resolution and 71 levels along the vertical. The communication between the atmospheric model and the ocean models is carried out with the OASIS3 coupler Every 160 minutes (coupling frequency), heat, mass and momentum fluxes are computed and provided to the ocean model by the atmospheric model. Sea Surface Temperature (SST) and sea surface velocities are provided to the atmospheric model by both ocean models. The global ocean model provides also sea-ice cover and thickness to the atmospheric model. The relatively high coupling frequency adopted allows an improved representation of the interaction processes occurring at the air-sea interface. No flux corrections are applied to the coupled model.


The CMCC-MED climate scenario simulations:
climate simulations and projections with interactive Mediterranean Sea

The model: CMCC-MED

ATMOSPHERE (dynamics, physics, prescribed gases and aerosols)
ECHAM5 T159 (T255)
~ 80 Km (60 Km)

OCEAN
OPA/ORCA2 2° (1/4°)
SEA-ICE: LIM

OCEAN Mediterranean
NEMO/MFS 1/16° , 71 vert. levs
Oddo et al. (2009)

Figure 11 The CMCC-MED climate scenario simulations:

The COSMO-CLM model:

The COSMO-CLM regional model is a non-hydrostatic model for the simulation of atmospheric processes. It has been developed by the DWD–Germany and by the COSMO consortium for weather forecast services. Successively, the model has been updated by the CLM-Community, in order to develop also climatic applications. The non-hydrostatic modelling allows a good description of the convective phenomena, which are generated by vertical movement (through transport and turbulent mixing) of the properties of the fluid as energy (heat), water vapour and momentum. Convection can redistribute significant amounts of moisture, heat and mass on small temporal and spatial scales. Furthermore convection can cause severe precipitation events (as thunderstorm or cluster of thunderstorms). The mathematical formulation of COSMO-CLM is made up of the Navier-Stokes equations for a compressible flow The parameterization settings includes a Tiedtke convection scheme with a moisture convergence closure, a turbulence scheme with prognostic turbulent kinetic energy (TKE) and a Kessler scheme for grid-scale precipitation which treats cloud ice diagnostically. The model includes several other parameterizations, in order to keep into account, at least in a statistical manner, several phenomena that take place on unresolved scales, but that have significant effects on the meteorological interest scales (for example, interaction with the orography). Further parameterizations are available in order to describe some important physical phenomena for the atmospheric evolution, for example solar radiation, soil behaviour and microphysics. The discretization of the fluid dynamics equations is performed by using finite difference approximation on a computational grid defined in a rotated spherical coordinate system. The pole is tilted and can be positioned such that the equator runs through the centre of the model domain. Problems resulting from the convergence of the meridians can be minimized for any limited area model domain on the globe. Especially, for a very small domain with negligible impact of the curvature of the earth's surface, the equations become identical to those for a tangential Cartesian coordinate system. Three time integration algorithms are available: the first one is based on a second order accurate Runge-Kutta method on two time levels; the second is based on the “horizontal explicit - vertical implicit” variant of Leapfrog scheme, the third based on a semi-implicit Leapfrog scheme on three time levels. The parallelization is done by horizontal domain decomposition using a soft-coded 2-gridline halo. The Interface software MPI is used as Message Passing. The regional models consider limited domains, therefore their boundary conditions are obtained from global climate models. A Runge Kutta 2 time level HEVI scheme for the time integration Clmcmm 8km: Period 1965-2035, spatial resolution 8 km, time step 40 sec, computational grid with 207 x 211 nodes and 40 vertical levels. Boundary conditions obtained from the global model CMCC-MED, whose atmospheric component is ECHAM5 (T159 80 km spatial resolution, 6 h time resolution) and considering the IPCC A1B scenario.

A first step of evaluation the impact is defined by a description the real situation agronomic of area study, in particular.

Study area	varieties	Soil	Thickness and height; vineyard
Sella Mosca Alghero	Cannonau	1	1.30*2.00 m*2.00
Azienda Sanna Berchidda	Vermentino	1	1.30*2.00 m*2.00

This analysis allowed us to observe the impacts on the vineyard if there was no change in its current structure. We have made a parallel simulation of different variables for the years 2006 2007 and 2008 2009

The simulations were carried out as follows: for each combination x Region x Soil x structure we conducted the simulation with all the years of each series climate (Control, A1B). The option used in the model was the sequence of cultural seasons, in order to take into account root development. In each case we simulated a series of variables that describe different aspects of growth, phenology and yield. All variables were simulated using a daily time step To analyze the results, we used the average value of each variable on all years for each combination technique, in the scenarios (control, A1b), four fundamental moments of growth and plant development: flowering, veraison, the harvest and the end of the cycle.

5. The Win STics Model

In this chapter we'll make a description about the model and its main components.

STICS is a model that has been developed at INRA (France) since 1996. STICS is a crop model at a daily time scale. Its inputs relate to climate, soil and the cropping system. Its outputs relate to production (quantity and quality), the environment and variations in soil characteristics in cropping situations. STICS has been designed as a simulation tool to be operational in cultivation conditions. Its main purpose is to simulate the effects of variations in the physical environment and cropping system on the production of a farming plot. It has also been designed to be used as a tool with which to work, collaborate and transfer knowledge to other closely-related scientific fields. From a conceptual point of view, STICS is made up of a number of original parts relative to other crop models (e.g. simulation of crop temperature, simulation of many techniques) but most of the remaining parts are based on conventional formalizations or have been taken from existing models. Its strong points are the following:

- its generic quality: adaptability to a variety of crops (wheat, maize, soy, sorghum, flax, grasslands, tomatoes, beet, sunflower, peas, oil seed rape, bananas, sugar cane, carrots, lettuce, etc.),
- its robustness: its ability to simulate a range of pedoclimatic conditions without generating any major bias, to the detriment sometimes of local accuracy,
- a relative ease of access to input parameters and variables,
- its "conceptual" modularity: possibility to add new modules (e.g. volatilisation of ammonia, symbiotic fixation of nitrogen, plant mulch, stony soils, multiple organic residues, etc.).

The purpose of this modularity is to facilitate any subsequent evolutions. The context of the internal and external communication it generates and which serves as a basis for the model's development, as witnessed by the successive versions of the software. The simulated object is a cropping situation whose physical environment and management schedule can be accurately determinate and defined. The main processes simulated are crop growth and development, together with the water and nitrogen balances. The selected formalizations are based on known analogies or on the simplification of more complex formalizations. The functions used have also been selected on the basis of their being generic, which enabled us to apply them to a variety of crops.The STICS model is written in FORTRAN 90 and operates with a standard PC-compatible micro-computer in a user friendly environment using Windows. STICS simulates the behavior of the soil/crop system over one crop cycle or several crop cycles to simulate rotations. The upper boundary of the system is the atmosphere characterised by standard climatic variables (radiation, minimum and maximum temperatures, rainfall, reference evapo transpiration and possibly wind and humidity) and the lower boundary corresponds to the soil/subsoil interface Crops are generally perceived in terms of their aboveground biomass and nitrogen content, leaf area index, and the number and biomass (and nitrogen content) of harvested organs. Vegetative organs (leaves, branches or tillers) are thereby not separated in terms of their biomass. Soil is described as a sequence of horizontal layers, each of which is characterized in terms of its water content, mineral nitrogen content and organic nitrogen content. Soil and crop interact via the roots, and these roots are defined with respect to root density distribution in the soil profile.

The STICS model is structured into modules (Fig 12) with each module composed of sub-modules dealing with specific mechanisms. In particular a first set of three modules deals with the ecophysiology o aboveground plant parts (phenology, shoot growth, yield formation) whereas a second set of four modules define the generic interaction of the soil and underground plant parts. Finally the crop managements modules define the different interactions between the applied techniques and the soil/crop system. The microclimate module describe the combine effects between the climate, the water balance and the vegetative system.

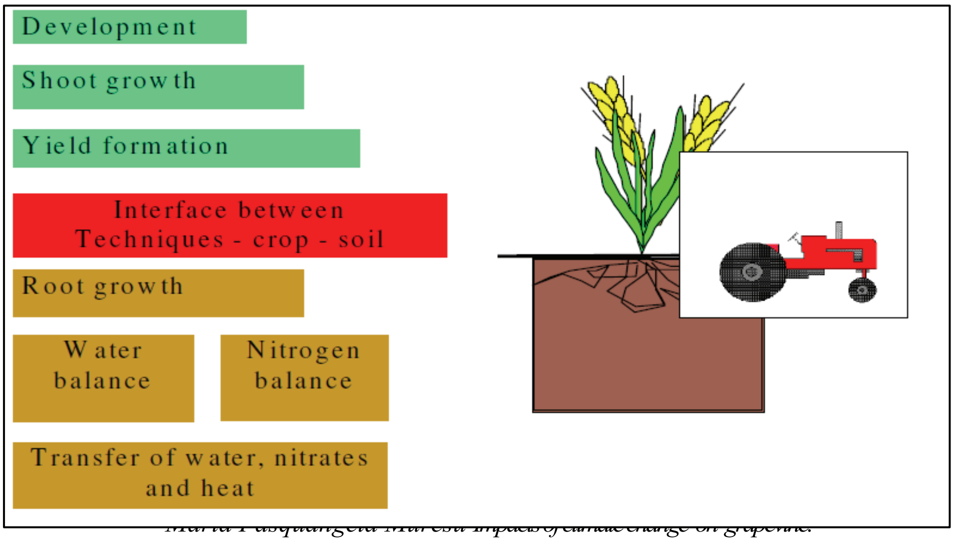


Figure 12 The various modules of the STICS model.

In general the phenological stages are used as steps for simulating vegetative dynamics (leaf area
index and roots) and harvested organ filling (grain, fruit, tuber) (see Table 1)

Development stages (leaf area index)	**Harvested organs stages**
IPLT : sowing or planting (annuals)	
GER: germination *	
DEBDORM and IFINDORM : beginning and break of dormancy (woody plants)	
LEV : emergence or budding	
LET : end of the plantlet frost sensitive stage	**LAT**: beginning of the critical phases for grain number onset**
AMF : maximum acceleration of leaf growth, e end of juvenile phase	**FLO : flowering (start of fruit sensitivity to frost**
LAX : maximum leaf area index, end of leaf leaf growth, net or gross depending on the option	**DRP : onset of filling of harvested organs**
SEN : onset of net senescence (LAI option)	**NOUd***: end of fruit setting**
LAN : nil leaf area index (LAInet option)	**DEBDES ; onset of water dynamics in fruits**
	MAT : physiological maturity
REC : harvest	

Table 1(List of phenological stages of STICS .Some stages are required as a function of the options chosen : * for sows crops,for determinate crops, ***for indeterminate crops.**

As in most crop models , the development stages simulated by STICS can differ from the stages defined in classical agronomic scales. The development stages in STICS are growth stages rather than organogenetic stages (Brisson and Delècolle, 1991). Stages correspond in fact in the trophic or morphologic strategy of the crop that the evolution of leaf area index or grain.

The periods separating the successive stages between emergence and physiological maturity are specific to each species and variety. These periods are evaluated in development units, reproducing the phonological time of the plant. In general the temperature is used in crop model as the driving variable of the phenological time. The other factors affecting the rate of development are modeled as brakes or accelerators on Thant rate per unit thermal time **(**Brisson and Delècolle, 1991). These factor in general including the photoperiod and vernalisation an sometimes water deficit. Through the use of crop temperature, the effect of the water deficit on development is linked to thermal units and not a reducing factor. Of course, what is simulated by the use of crop temperature is an acceleration of the cycle, while some authors speak of delay in the case of early stress acting upon floral induction .nitrogen nutrition can also have effect on the progress of the cycle , a well light conditions trough plant density. In particular, the sum of degree-days can be calculated on the basis of air temperature or crop temperature. When phenology is calculated on the basis of crop temperature, the duration of phases must be corrected with respect to the standard values expressed in 'air temperature' development units (Brisson et al., 2002). The use of crop temperature for crops subjected to water stress makes it possible to simulate accelerated phenology, as suggested by Idso et al. (1978). There are plants for which early plant stress has a reverse effect, i.e. delaying flowering (e.g. rice: Wopereis et al., 1996 or banana: Brisson et al., 1998b). Consequently, was introduced in STICS, just allowing to test how flowering delay is related to stress: until the DRP stage, the development unit can be multiplied by a stress factor accounting for the maximum of water and nitrogen stresses.

Radiation interception

There are a different methods of calculation tha radiation interception. In particular for row crops which takes crop geometry into account in a simple fashion (Brisson et al., 1999) in this method, the interrow is represented as 20 points equally distributed and the radiation received at each point is calculated from the critical angles below which this point receives solar radiation directly. On either side of these critical angles, radiation is reduced due to absorption by the crop; the radiation received at each point is the sum of radiation intercepted and transmitted by the crop and the non-intercepted radiation. Both of these components include a direct part and a diffuse part, taking row orientation into account and assuming that the direct radiation evolves sinusoidally during the day. The diffuse radiation/total radiation ratio is calculated according to Spitters et al. (1986). For vineyards One way of using the radiation transfer module is to simulate the effect of row orientation.

Radiation use efficiency

STICS directly calculates the daily accumulation of aboveground biomass, which is the net result of the processes of photosynthesis, respiration and root/shoot partitioning. This daily accumulation is a function of the intercepted radiation according to a parabolic law involving the maximal radiation use efficiency

(RUE). Maximal values of RUE, specific to each species and phenology-dependant, are given as input parameters. The maximal RUE **is lower during** the juvenile phase because it takes into account the preferential accumulation of assimilates in the roots at the beginning of the cycle.

Stress indices

In the STICS model the stress indices are values between 0 and 1 that reduce the vital plant functions. These indices mostly result from relationships calculated as functions of stress state variables. We can define a different variable, in particular the water stress is the soil water content while the nitrogen nutrition index is the nitrogen stress variable and the source/sink ratio is the trophic stress variable . in this case the relationships are simple bilinear functions, i.e. equal to a constant until a critical level of the state variable is reached and then linearly decreasing, using just one crop dependent parameter. For the integration the information The STICS model also includes stresses for frost and anoxia, and thermal stresses affect the RUE and filling of the harvested organ

Yield formation and quality

By definition the yield is the weight and the quality of the organs that can be reproductive organs - either grains or fruits , or vegetative storage organs either stems or roots . Yield prediction is a goal of most crop model. In STICK model thee a double approach for definition this process. In STICS model there are a double approach for simulation this process, according to difference between indeterminate plant and determinate plant, in particular the souce/sink approach for a indeterminate plant propose by Ritchie and Otter (1984) or Jones et al (2003). Or determinate crops there is a dynamic harvest index. Concerning to the simulation of the harvested product quality of the model is a original option of the STICS model. Water content is calculated independently, relying on hydration (or dehydration)dynamics based on species parameters and on the evolution of crop temperatures during filling and maturation. The quantity of nitrogen in harvested organs, both for determinate and indeterminate species , is a increasing proportion of the quantity of nitrogen in the original biomass (harvested organ N/total plant N). For sugars and lipids, it is assumed that the concentration is proportional to the dry matter in the organs.

Root growth

This simulation process is s separated from aboveground growth. The roots system absorbes only mineral nitrogen and water. For the annual species the root front begins at the sowing depth while the perennial plants the initial value of the root front can be deeper in the soil.

The second possibility is calculate he root density profile according to two methods: a first option is propose by Brisson, 1998 and it possible to calculate the root profile that is effective with respect to absorption, assuming that it always has the same sigmoidal shape established on the basis of plant parameters and of the depth of the dynamic root front. This formalization assumes that, at the surface, root density always reaches the optimal threshold for water and nitrogen absorption, set at 0.5 cm cm3. But there is a second option that makes it possible to estimate the actual root density profile using a logistic function that is in each layer of the soil profile in proportion to the roots present and as a function of the soil constraints (drought, anoxia, penetrability).

Crop management

In this module we draw attention about the irrigation practices, fertilizer practices and the microclimate. In particular according to concept that the water transfer through the canopy depending on the irrigation systems used, the supplies can be either over-the-crop, under-the crop or in the soil (drip irrigation). In the case of under-the-crop irrigation, clearly the water balance is not affected by of rain interception by the foliage system. In the case of subsurface drip irrigation the output in water balance is not subjected to soil evaporation phenomena either, while the water retained on the foliage, directly subjected to the evaporative demand of the surrounding atmosphere, can evaporate, thereby significantly reducing the saturation deficit within the canopy and crop water requirements. The maximum amount of water retained by the foliage is directly proportional to the LAI and varies from one species to another between 0.2 and 0.7 mm LAI. The general water balance is based on estimating the water requirements of the soil/leaf system on the one hand and on the water supply to the soil/root system on the other.

LAI

The STICS model includes several options for simulating this variable. A first method describes a logistic curve of development units taking on an asymptote that is characteristic for the species with an inflection point at the end of the juvenile phase (AMF). This value is then multiplied by the effective crop temperature, the planting density combined with an inter-plant competition factor that is characteristic for the variety, and the water and nitrogen stress indices. A more sophisticated option was incorporated into version 5.0 where LAI evolution results from gross growth and senescence as a result of the natural ageing of the foliage and stress-induced senescence. This method for calculating LAI is closer to the usual methods (Milroy and Goyne, 1995; Chapman et al., 1993). Growth is simulated in the same way as in the previous option and the simulation of senescence is based on the notion of lifetime applied directly to LAI. In addition there are a simple option for LAI calculation to directly soil cover rate, this options used deed in general for horticultural crops for example lettuce.

Nitrogen balance

Net nitrogen mineralisation in the soil is the sum of humus mineralisation and the mineralisation of organic residues. The former process is permanent and is always positive, whereas the second process varies in relation to the C/N ratio of the organic residues and can be either positive (net mineralisation) or negative (net immobilisation)

Data requirements

The data set consists) on three macro-areas the climatic component, the edafic one and finally the plant. In particular daily climatic variables are required: minimum and maximum temperatures, radiation and rainfall whereas the soil system is the following: organic nitrogen content, active lime content, clay content, albedo when dry, run-off coefficient, pH, soil evaporation accumulation during the potential phase. Most of these parameters are obtained from classical chemical or physical analyses. A few parameters require specific measurements. About the crop management in the model system there is some default variable tha can be used for simulation process, for example sowing (date, depth, density, variety) or planting (interrow, row orientation), mineral and organic fertilisation, irrigation, fertigation, soil tillage with ploughing-in of residues, use of plant or plastic mulching, thinning, cutting (forage) or harvesting (once or several times) using various criteria physiological maturity, water, nitrogen, sugar or lipid contents

5.2. Win Stics model calibration

Statistical analysis

The performance of model was determined using several indexes mainly based on the calculation of correlation and differences between estimated and measured dormancy , flowering and harvest values. Results obtained from data used for site Alghero were analyzed calculating the correlation coefficient (r) and its square, the coefficient of determination (R2), the root mean squared error (RMSE), general standard deviation or relative root mean squared error (GSD), modelling efficiency index (EF), coefficient of residual mass (CRM), mean bias error (MBE), mean absolute error (MAE), and Index of agreement (d-Index) for the predicted and observed values.

The Pearson correlation coefficient (r) is the correlation coefficient between measured and calculated values defined as:

$$r = \frac{\sum_{i=1}^{n}(E_i - \overline{E}) \cdot (M_i - \overline{M})}{\sqrt{\sum_{i=1}^{n}(E_i - \overline{E})^2 \cdot \sum_{i=1}^{n}(M_i - \overline{M})^2}}$$

The range of r is -1≤ r ≤1. A value of r=1 indicates that there exists a perfect linear relationship between simulated and observed values. However this does not necessarily imply that the model is perfect.

The RMSE was used to test the accuracy of the model, which is defined as the variation, expressed in the same unit as the data, between simulated and measured values (Loague and Green, 1991):

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(E_i - M_i)^2}{n}}$$

where Ei and Mi indicate the simulated and measured annual values of the year i and n the number of annual values. RMSE represents the typical size of model error, with values equalling or near zero indicating perfect or near perfect estimates. The RMSE was also expressed as a coefficient of variation (GSD) by dividing it by the mean of the measured yield or anthesis values ($\overline{M}$):

$$GDS = \sqrt{\frac{\sum_{i=1}^{n}(E_i - M_i)^2}{n}}\frac{100}{\overline{M}} = RMSE\frac{100}{\overline{M}}$$

In addition, the accuracy of the model was evaluated using another index based on squared differences, the modelling efficiency index (EF):

$$EF = 1 - \frac{\sum_{i=1}^{n}(E_i - M_i)^2}{\sum_{i=1}^{n}(M_i - \overline{M})^2}$$

EF values greater than 0 indicate that the model estimates are better predictors than the average measured value, with negative values indicating the opposite. A EF value equal or near 1 means a perfect or near perfect estimates.

To measure the tendency of the model to overestimate or underestimate the measured values three statistics were used: the coefficient of residual mass (CRM), the mean bias error (MBE) and the mean absolute error (MAE):

$$CRM = 1 - \frac{\sum_{i=1}^{n} E_i}{\sum_{i=1}^{n} M_i}$$

$$MBE = \sum_{i=1}^{n} \frac{E_i - M_i}{n}$$

$$MAE = \sum_{i=1}^{n} \frac{|E_i - M_i|}{n}$$

A negative CRM indicates a tendency of the model toward overestimation (Xevi *et al.,* 1996). A positive bias error indicates a tendency to over predict a variable while a negative bias error implies a tendency to under predict a variable. MAE values near or equal to zero indicate a better match along the 1:1 line comparison of estimated and observed values (Rasse *et al.,* 2000).

Willmott (1981) propose an Index of agreement (*d*) defined as:

$$d = 1 - \frac{\sum_{i=1}^{n} (E_i - M_i)^2}{\sum_{i=1}^{n} (|E_i - \overline{M}| + |M_i - \overline{M}|)^2}$$

If the model is perfect, then observed values are equal to simulated values and *d*=1. If the model predictions are identical in all cases and equal to the average of the observed values, d=0. These limiting values are the same as for EF, but for other cases, the two criteria will have different values.

5.4. Calibration for Cannonau variety

The model calibration for Cannonau variety was performed using data from Sella&Mosca experimental site for the period 2006-2009, was used: three years dormancy, florewing an harvest stages.

Cannonau' (syn. Grenache) is one of the most cultivated red grape varieties around the world, due to its rusticity and resistance to aridity. The leaves are light green, hairless in both sides and the plants are frequently vigorous, with high affinity to nitrogen and vertical yellow shoots. In order to prevent physiological disorders such as flower and fruit abortion, frequently caused by the high nitrogen absorption capacity, the cultural practices adopted in vineyard management, from the rootstock choice to the fertilization and irrigation, must limit plants vigour.

The first experimental site for was implemented in a 'Cannonau' vineyard from the Sella&Mosca 40° 38' N - 8° 18' E

Fourteen years old *Vitis vinifera* vines cv. 'Cannonau' grafted on 1103P rootstock were planted on rows North-South oriented. The vines were spaced 2.04 m between rows and 1.0 m along rows. Vines were trained to a mobile free cordon, developed by Sella&Mosca from the late 1990s:the foliage is supported by a single wire and is free to flutter. This training system also allows good exposure to sunlight and optimum conditions for the development of the bunches

CANNONAU				Estimated	Measured
				DORMANCY	
Maximum	Mx =	396	Mean	378	386
Minimum	Mn =	368	Standard Deviation	22.05	16.17
Mean	Mm =	48.3	Minumun	354	368.00
Number of samples	n =	3	Maximun	397	396
Pearson coefficient	r=	0.95***			
Coefficient of determination	R^2=	0.91			
Root Mean Square Error	RMSE =	10.66			
General standard Deviation	GSD =	22%			
Modelling Efficiency	EF =	1.00			
Coefficient of Residual Mass	CRM =	0.02			
Mean Bias Error	MBE =	-8.33			
Mean Absolute Error	MAE =	9.00			
Index of agreement	d-Index=	1.00			

Table 2 The statistical results for dormancy calibration in Cannonau variety

The results for dormancy calibration show perfect correspondence between mean values of observed and simulates. The Pearson's r value (r 0.95) is significant for p< 0.001. The coefficient of determination R indicates that 91% of the total variation is explained by the model.

CANNONAU				Estimated	Measured
				FLOWEWING	
Maximum	**Mx =**	**514**	**Mean**	**511**	**511**
Minimum	**Mn =**	**507**	**Standard Deviation**	**9.54**	**3.79**
Mean	**Mm =**	**511**	**Minimum**	**502**	**507**
Number of samples	**n =**	**3**	**Maximum**	**521**	**514**
Pearson coefficient	**r=**	**0.73****			
Coefficient of determination	**R^2=**	**0.53**			
Root Mean Square Error	**RMSE =**	**5.91**			
General standard Deviation	**GSD =**	**1%**			
Modelling Efficiency	**EF =**	**-2.66**			
Coefficient of Residual Mass	**CRM =**	**0.00**			
Mean Bias Error	**MBE =**	**-0.33**			
Mean Absolute Error	**MAE =**	**5.67**			
Index of agreement	**d-Index=**	**0.68**			

CANNONAU				Estimated	Measured
				HARVEST	
Maximum	**Mx =**	**631**	**Mean**	**625.**	**627**
Minumum	**Mn =**	**619**	**Standard Deviation**	**14.2**	**6.93**
Mean	**Mm =**	**627**	**Minumun**	**613**	**619**
Number of samples	**n =**	**3**	**Maximun**	**641**	**631**
Pearson coefficient	**r=**	**0.74*****			
Coefficient of determination	**R^2=**	**0.5**			
Root Mean Square Error	**RMSE =**	**8.**			
General standard Deviation	**GSD =**	**1%**			
Modeling Efficiency	**EF =**	**-1.26**			
Coefficient of Residual Mass	**CRM =**	**0.00**			
Mean Bias Error	**MBE =**	**-1.67**			
Mean Absolute Error	**MAE =**	**8.33**			
Index of agreement	**d-Index=**	**0.76**			

Table 3-4 The statistical results for flowering and harvest calibration in Cannonau variety

In this case the results for flowering ad harvest calibration show a sufficient correspondence between mean values of observed and simulates. Can you see The Pearson's r value (r 0.73) is significant for $p < 0.001$ but the coefficient of determination R indicates that 53% of the total variation is explained by the model. In according to the fact that the model in general tends to reduce the variability of simulated values, The number of samples is not many

5.5. Validation from Vermentino variety

In the literature, is often used both the term “validation” and “evaluation”. A rather common definition is that validation concerns determining whether a model is adequate for its intended purpose or not. This emphasizes the important fact that a model should be judged with reference to an objective (this definition seems to indicate that the result of a validation exercise is “yes”(the model is valid) or “not” (not valid); but it is rarely the case that one makes such a categorical decision). Rather one seeks a diversity of indications about how well the model represents crop responses. For this reason it would be preferable to use the term “evaluation” (Wallach, 2006). In this case the model evaluation, 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). Willmott (1982) has pointed out that the main problem with this analysis is that the magnitudes of r and R^2 are not consistently related to the accuracy of prediction where accuracy is defined as the degree to which model predictions approach the magnitudes of their observed counterparts. Further, as R^2 often is unrelated to the sizes of the difference between observed and predicted values, high or statistically significant R2 may be misleading.

Hence, also other different test criteria, have been used to evaluate the performance of the model, e.g., RMSE, GSD, EF, CRM, MBE, MAE, and d-Index, because it is important to use more than one measure in order to bring out different aspects of model agreementand.

The model validation for Vermentino variety was performed using data from Berchidda experimental site for the period 2005--2008, was used: three years dormancy, flowering an harvest stages

Vermentino’ is the white grape variety cultivated in Sardinia. The plants have long shoots with medium hairiness in the inferior side of the leaf, frequently suffering from shoot base infertility. C The second experimental site was installed in a ‘Vermentino’ vineyard from Sanna winery in Berchidda (OT), The ‘Vermentino’ (Vitis vinifera L.) grapevines were grafted on 1103P rootstock. The vines had North-South row orientation and were spaced 2.5 m between rows and 0.8 m along rows.

Vines were cane pruned to a single guyot and trained to vertical trellis in a single curtain.

VERMENTINO				Estimated	Measured
				DORMANCY	
Maximum	**Mx =**	370	**Mean**	367	369
Minumum	**Mn =**	368	**Standard Deviation**	3.00	1.15
Mean	**Mm =**	369	**Minumun**	364	368
Number of samples	**n =**	3	**Maximun**	370	370
Pearson coefficient	**r=**	0.86***			
Coefficient of determination	**R^2=**	0.75			
Root Mean Square Error	**RMSE =**	2.88			
General standard Deviation	**GSD =**	1%			
Modeling Efficiency	**EF =**	-8.38			
Coefficient of Residual Mass	**CRM =**	0.01			
Mean Bias Error	**MBE =**	-2.33			
Mean Absolute Error	**MAE =**	2.33			
Index of agreement	**d-Index=**	0.55			

VERMENTINO				Estimated	Measured
				FLOWERING	
Maximum	**Mx =**	499	**Mean**	502	496
Minumum	**Mn =**	492	**Standard Deviation**	12.06	4.04
Mean	**Mm =**	496	**Minumun**	491	492
Number of samples	**n =**	3	**Maximun**	515	499
Pearson coefficient	**r=**	0.81***			
Coefficient of determination	**R^2=**	0.66			
Root Mean Square Error	**RMSE =**	9.32			
General standard Deviation	**GSD =**	2%			
Modeling Efficiency	**EF =**	-6.99			
Coefficient of Residual Mass	**CRM =**	-0.01			
Mean Bias Error	**MBE =**	5.67			
Mean Absolute Error	**MAE =**	6.33			
Index of agreement	**d-Index=**	0.55			

. Table 5-6 The statistical results for dormancy and flowering evaluation in Vermentino variety

VERMENTINO				Estimated	Measured
				HARVEST	
Maximum	**Mx** =	621	**Mean**	628	608
Minimum	**Mn** =	602	**Standard Deviation**	3.21	10.69
Mean	**Mm** =	608	**Minimum**	626	602
Number of samples	**n** =	3	**Maximum**	632	621
Pearson coefficient	**r**=	0.99***			
Coefficient of determination	**R^2**=	0.98			
Root Mean Square Error	**RMSE** =	20.5			
General standard Deviation	**GSD** =	3%			
Modeling Efficiency	**EF** =	-4.57			
Coefficient of Residual Mass	**CRM** =	-0.03			
Mean Bias Error	**MBE** =	19.67			
Mean Absolute Error	**MAE** =	19.67			
Index of agreement	**d-Index**=	0.47			

Table 7 The statistical results for harvest evaluation in Vermentino variety

The results for Vermentino evaluation show a good correspondence between mean values of observed and simulated data, with a little bit lower standard deviations for simulated values.

The value of Pearson's r (r = 0.9) is significant for p <0.001. The coefficient of determination R2 indicates that 90% of the total variation is explained by the model. The RMSE index value is fairly low, moreover, the percentage of GSD (20%) indicates how the model works well in the simulation of phenological data. The CRM index value (-0.03) and MBE index values confirm the good ness of this estimate and a slightest tendency to understimate

Sensitivity analysis

A crop model is the result of a long and complex construction process, involving data at multiple stages for understanding basic processes, elaborating model structure, estimating parameters and evaluating prediction quality. In various stages of a model's life, however, there is a need to study the model on its own, with an emphasis on its behaviour rather than on its coherence with a given data set. This is where uncertainty analysis sensitivity analysis and related methods become useful for the modeller or model user. Uncertainty analysis consists of evaluating quantitatively the uncertainty or variability in the model components (parameters, input variables, equations) for a given situation, and deducing an uncertainty distribution for each output variable rather than a misleading single value. An essential consequence is that it provides methods to assess, for instance, the probability of a response to exceed some threshold. This makes uncertainty analysis a key component of risk analysis (Vose, 1996). The aim of sensitivity analysis is to determine how sensitive the output of a crop model is, with respect to the elements of the model which are subject to uncertainty or variability. This is useful as a guiding tool when the model is under development as well as to understand model behaviour when it is used for prediction or for decision support. For dynamic models, sensitivity analysis is closely related to the study of error propagation, i.e. the influence that the lack of precision on model input will have on the output. Because uncertainty and sensitivity analysis usually relies on simulations, they are also closely related to the methods associated with computer experiments. A computer experiment is a set of simulation runs designed in order to explore efficiently the model responses when the input varies within given ranges (Sacks et al., 1989; Welch et al., 1992). The goals in computer experiments identified by Koehler and Owen (1996) include optimization of the model response, visualization of the model behaviour, approximationby a simpler model or estimation of the average, variance or probability of the response to exceed some threshold. Within a given model, model equations, parameters and input variables are all subject to variability or uncertainty. First, choices have to be made on the model structure and on the functional relationships between input variables and state and output variables. These choices may sometimes be quite subjective and it is not always clear what their consequences will be. Martinez et al. (2001) thus perform a sensitivity analysis to determine the effects of the number of soil layers on the output of a land surface–atmosphere model. For spatial models, there is frequently a need to evaluate how the scale chosen for input variables affects the precision of the model output (see e.g. Salvador et al., 2001). Second, parameter values result from estimation procedures or sometimes from bibliographic reviews or expert opinion. Their precision is necessarily limited by the variability and possible lack of adequacy of the available data. Some parameters may also naturally vary from one situation to another. The uncertainty and natural variability of parameters are the central point of many sensitivity analyses. Bärlund and Tattari (2001), for example, study the influence of model parameters on the predictions of field-scale phosphorus losses, in order to get better insight into the management model ICECREAM. Ruget et al. (2002) perform sensitivity analysis on parameters of the crop simulation model STICS, in order to determine the main parameters that need to be estimated precisely. Local sensitività methods, based on model derivatives with respect to parameters, are commonly used for checking identifiability of model parameters (Brun et al., 2001). Third, additional and major sources of variability in a model output are, of course, the values of its input variables. Lack of precision when measuring or estimating input variables needs to be quantified when making predictions from a model or when using it for decision support. Aggarwal (1995) thus assesses the implications of uncertainties in crop, soil and weather inputs in the spring wheat WTGROWS crop model. Rahn et al. (2001) compare contrasted input scenarios for the HRI WELL-N model on crop fertilizer requirements through a sensitivity analysis. They identify the main factors which need to be measured precisely to provide robust recommendations on fertilization. Contrasted settings of the input variables are used for performing sensitivity or uncertainty analyses assuming different scenarios by Dubus and Brown (2002). Model structure, model parameters and input variables represent three basic sources of model uncertainty. It is often advisable to study their influence on a model simultaneously (Saltelli et al., 2000) and alternative groupings of uncertainty sources may then be more adequate. Rossing et al. (1994), for example, distinguish sources that can be controlled by more intensive data collection (model parameter estimates), and uncontrollable sources when predictions are made (daily temperature, white noise). Ruget et al. (2002), on the other hand, decompose the sensitivity analyses according to STICS sub-modules on, e.g. energy conversion, rooting or nitrogen absorption. Jansen et al. (1994) advocate to divide uncertainty sources into groups of parameters or input variables which can be considered to be mutually independent. As shown by the examples above, uncertainty and sensitivity analysis may have various objectives, such as:

- to check that the model output behaves as expected when the input varies; to identify which parameters have a small or a large influence on the output;
- to identify which parameters need to be estimated more accurately;
- to detect and quantify interaction effects between parameters, between input variates
or between parameters and input varieties;
- to determine possible simplification of the model;
- to identify input variables which need to be measured with maximum accuracy.

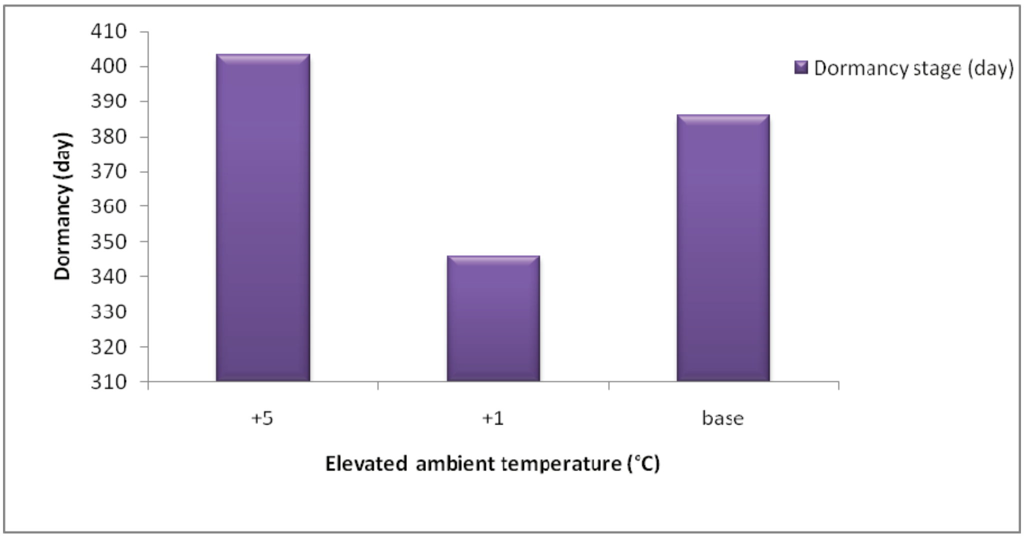
Some of these objectives have close links with other methods associated with modelling, like model construction, parameter estimation or model use for decision support. The diversity of motivations for performing sensitivity analysis is associated with a large choice of methods and techniques. In this contest a major issue with simulation modeling is the large number of model parameters (calibration values) and input data that are required. The question naturally arises: what happens if The parameter values and assumptions of any model are subject to change and error. Sensitivity analysis (SA), broadly defined, is the investigation of these potential changes and errors and their impacts on conclusions to be drawn from the model (e.g. Baird, 1989). SA can be easy to do, easy to understand, and easy to communicate. It is possibly the most useful and most widely used technique available to modellers who wish to support decision makers. The importance and usefulness of SA is widely recognised:

"A methodology for conducting a sensitivity analysis is a well established requirement of any scientific discipline. A sensitivity and stability analysis should be an integral part of any solution methodology. The status of a solution cannot be understood without such information. This has been well recognised since the inception of scientific inquiry and has been explicitly addressed from the beginning of mathematics". (Fiacco, 1983, p3).

we get some of these wrong? The correct question is: how sensitive is the model to variations in parameters or data? Especially since parameter calibration is largely a black

art, sensitivity analysis allows us to see where we should concentrate our calibration and modeling efforts, i.e., where the model is most sensitive.

The weather has a major influence on the cycle of the grapevine (Vitis vinifera L.). In particular, the temperature is the meteorological variable that acts more activity and vegetative stages phenology. Since the '60s, many studies about the exit from dormancyof latent buds, have analyzed the effects of low temperatures Whereas most of the areal wine is concentrated in regionswhere winter temperatures fall below 5 and 10 ° C. Pouget (1963) found that dehydration of the plant material, causedfrom temperatures below 5-10 ° C, is closely related to the exit fromdormancy of the buds, where the percentage of water loss issufficiently high (15-20%). In this contests the weather parameters selected for sensitivity analysis were ambient temperature (± 1 to ± 5°C), The model simulated a different phenological stages with climate series 1991 to 2009. have been compared with corresponding treatments for the year 2005-2009. This methodology have been enforced to two different area study as we described We have simulated The effects of ambient temperature on three phenological stages, in particular dormancy and flowering. the results are presented in Fig. 16 to 21 and in Table 8 to 13 respectively. Sensitivity of Winstics model showed a gradual increase about dormancy correlate with a increase the temperature. The model simulates partially this relationship because the entrance in dormancy coincides with an increase of the way of cis-ABA fig 16, 19 and table 8, 11 (Koussa et al. 1994) For the flowering stage we can see as the model simulated this process in figure 17, 20 and table o, 12 in particular the reduction in temperature from –1 to –5°C revealed an retard in flowering according to (García de Cortázar 2006) show that the increase in temperature would lead to a reduction in the duration of the vegetative cycle and the advance of all phases



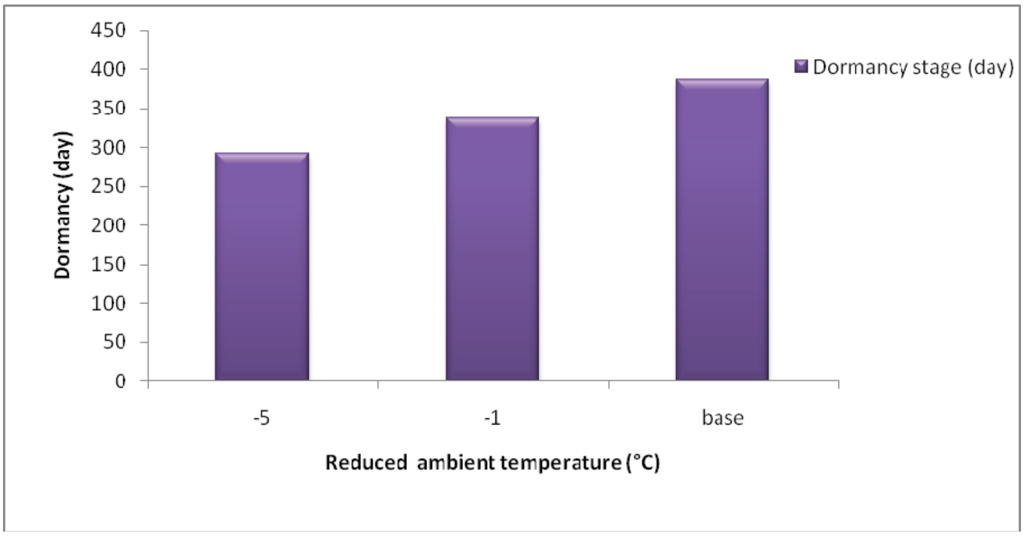
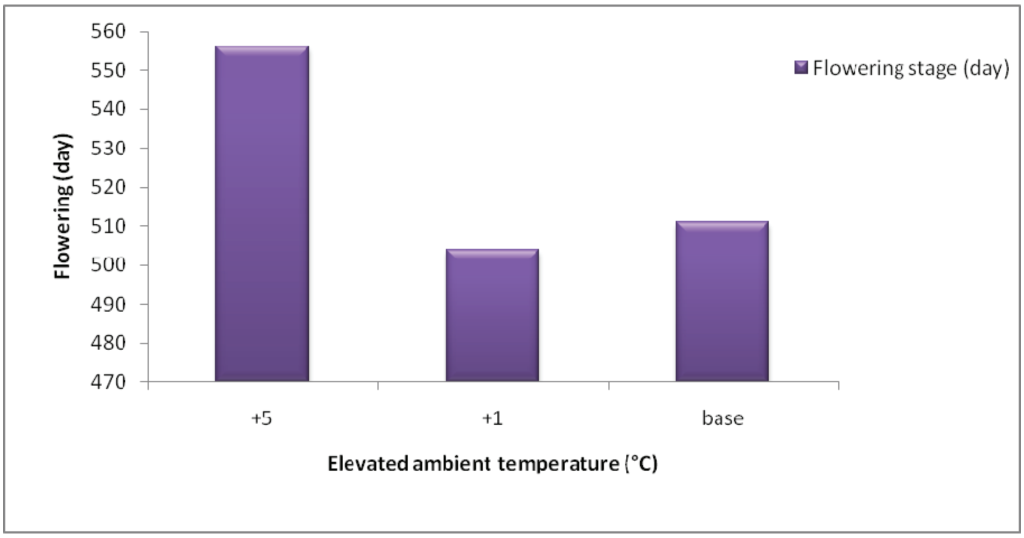


Figure 23 Effects of ambient temperature on dormancy stage in Cannonau variety as compared with base date

Mean ambient temperature (°C)	Simulated Dormancy stage (day)	% Change from base dormancy stage (386 day)
+1	346	-10%
+5	403	+4%
-1	338	-12%
-5	293	-24%

Table 8 Sensitivity of WinStics model to ambient temperature under optimal condition



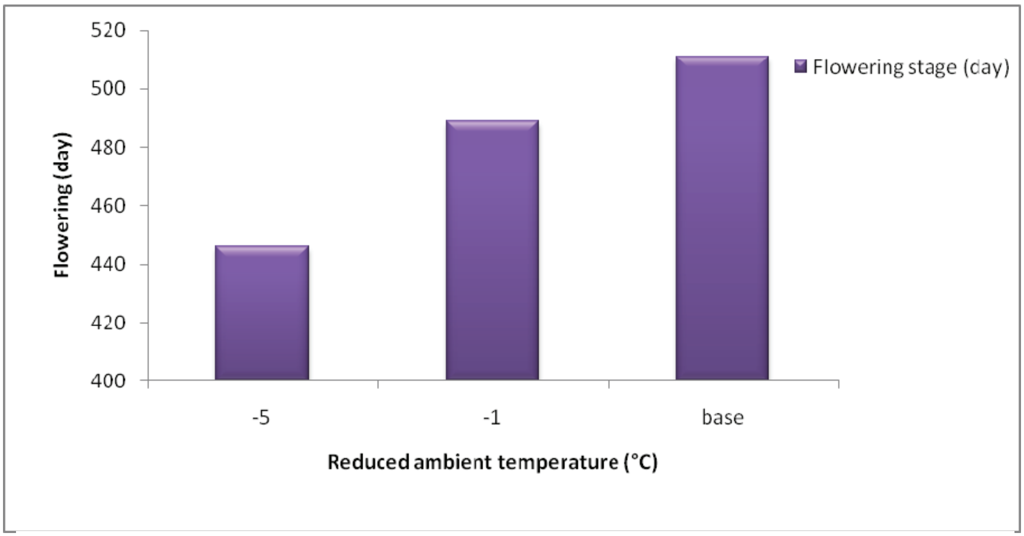
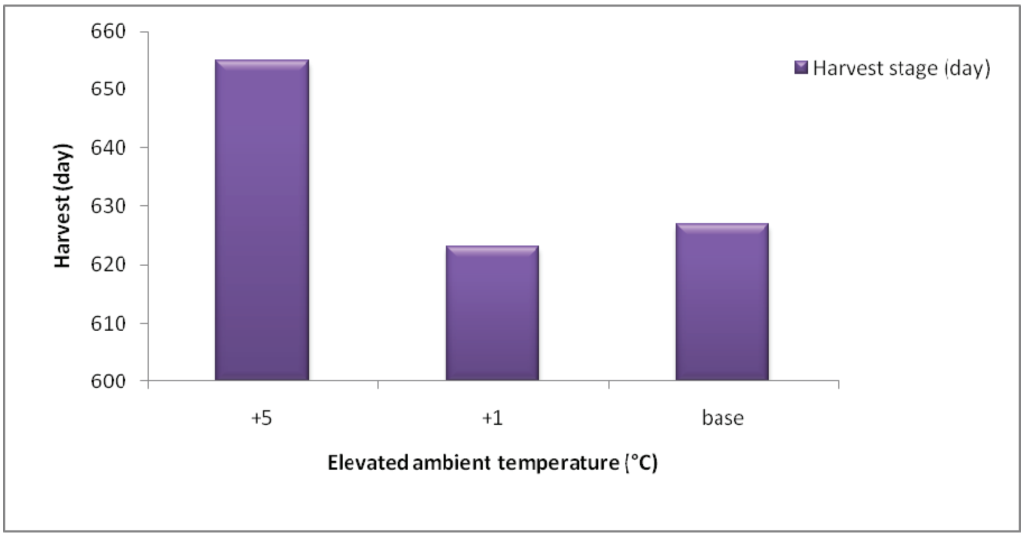


Figure 14 Effects of ambient temperature on flowering stage in Cannonau variety as compared with base date

Mean ambient temperature (°C)	Simulated Flowering stage (day)	% Change from base flowering stage (511 day)
+1	504	-1%
+5	556	+8%
-1	489	-4.3%
-5	446	-12.7%

Table 9 Sensitivity of WinStics model to ambient temperature under optimal condition



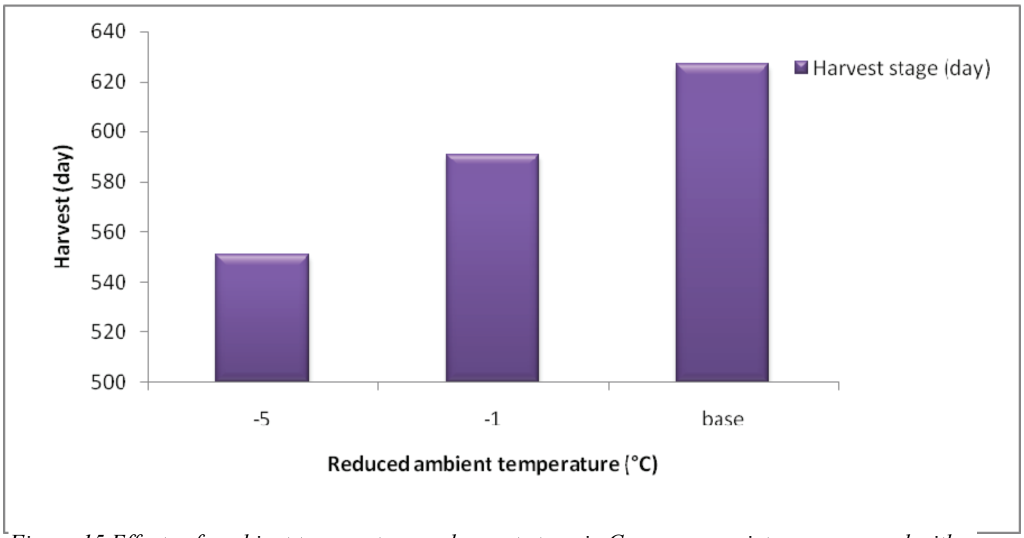
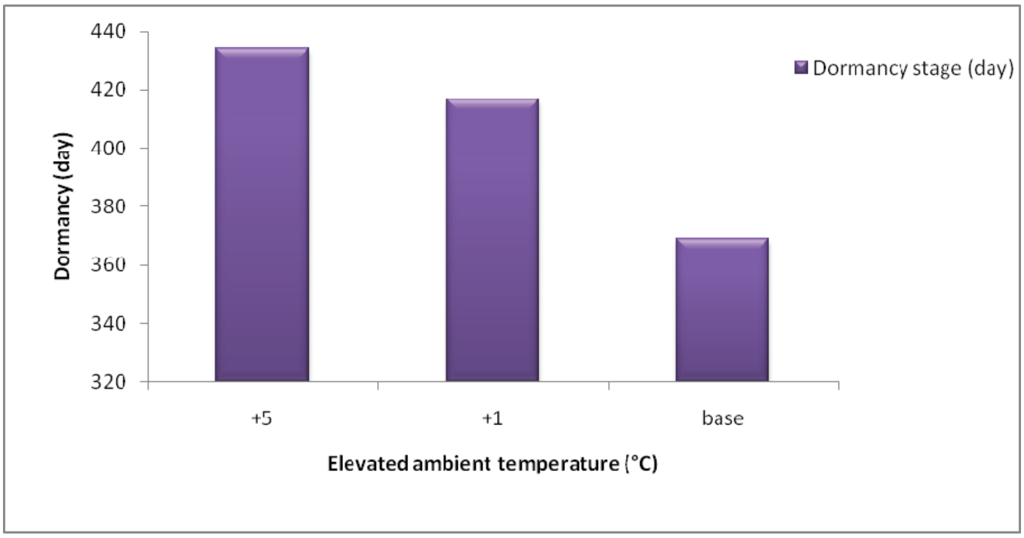


Figure 15 Effects of ambient temperature on harvest stage in Cannonau variety as compared with base date

Mean ambient temperature (°C)	Simulated Harvest stage (day)	% Change from base Harvest stage (627 day)
+1	323	+4%
+5	655	-0.6%
-1	591	-5.7%
-5	551	-12%

Table 10 Sensitivity of WinStics model to ambient temperature under optimal condition



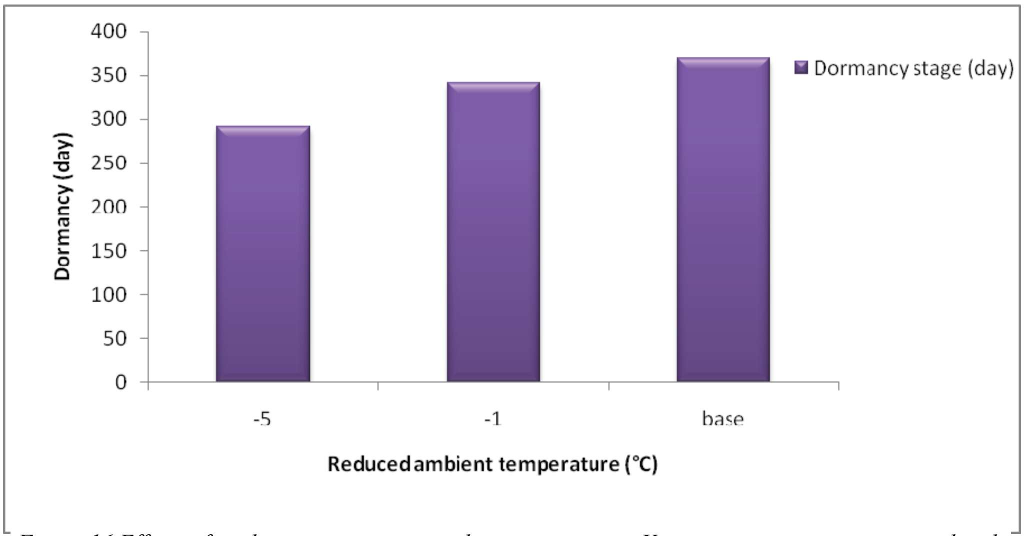


Figure 16 Effects of ambient temperature on dormancy stage in Vermentino variety as compared with base date

Mean ambient temperature (°C)	Simulated Dormancy stage (day)	% Change from base dormancy stage (369 day)
+1	417	+13%
+5	434	+17%
-1	341	-7.5%
-5	291	-21%

Table 11 Sensitivity of WinStics model to ambient temperature under optimal condition

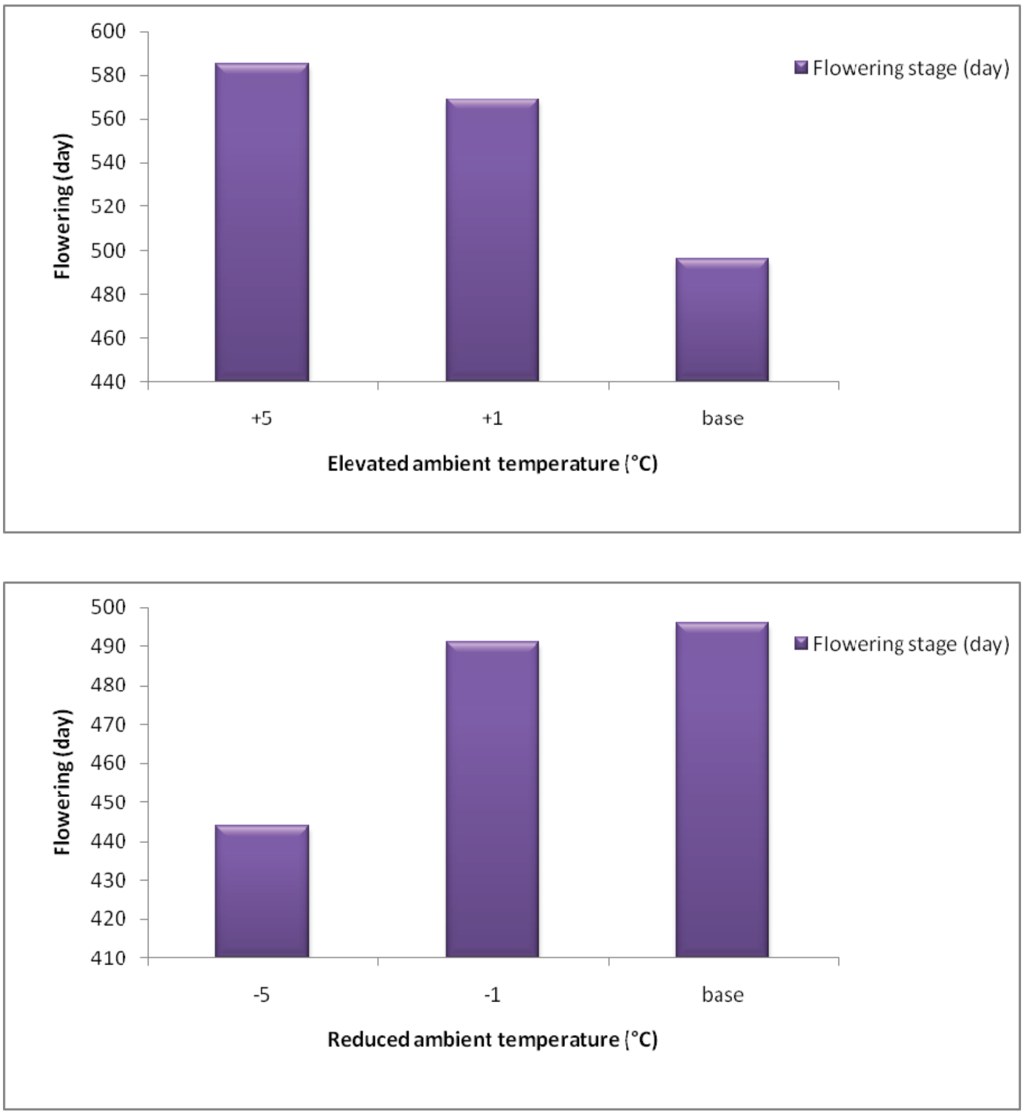


Figure 17 Effects of ambient temperature on flowering stage in Vermentino variety as compared with base date

Mean ambient temperature (°C)	Simulated Flowering stage (day)	% Change from base Flowering stage (496 day)
+1	569	+20%
+5	585	+17%
-1	491	-1%
-5	444	-10.4%

Table 12 Sensitivity of WinStics model to ambient temperature under optimal condition

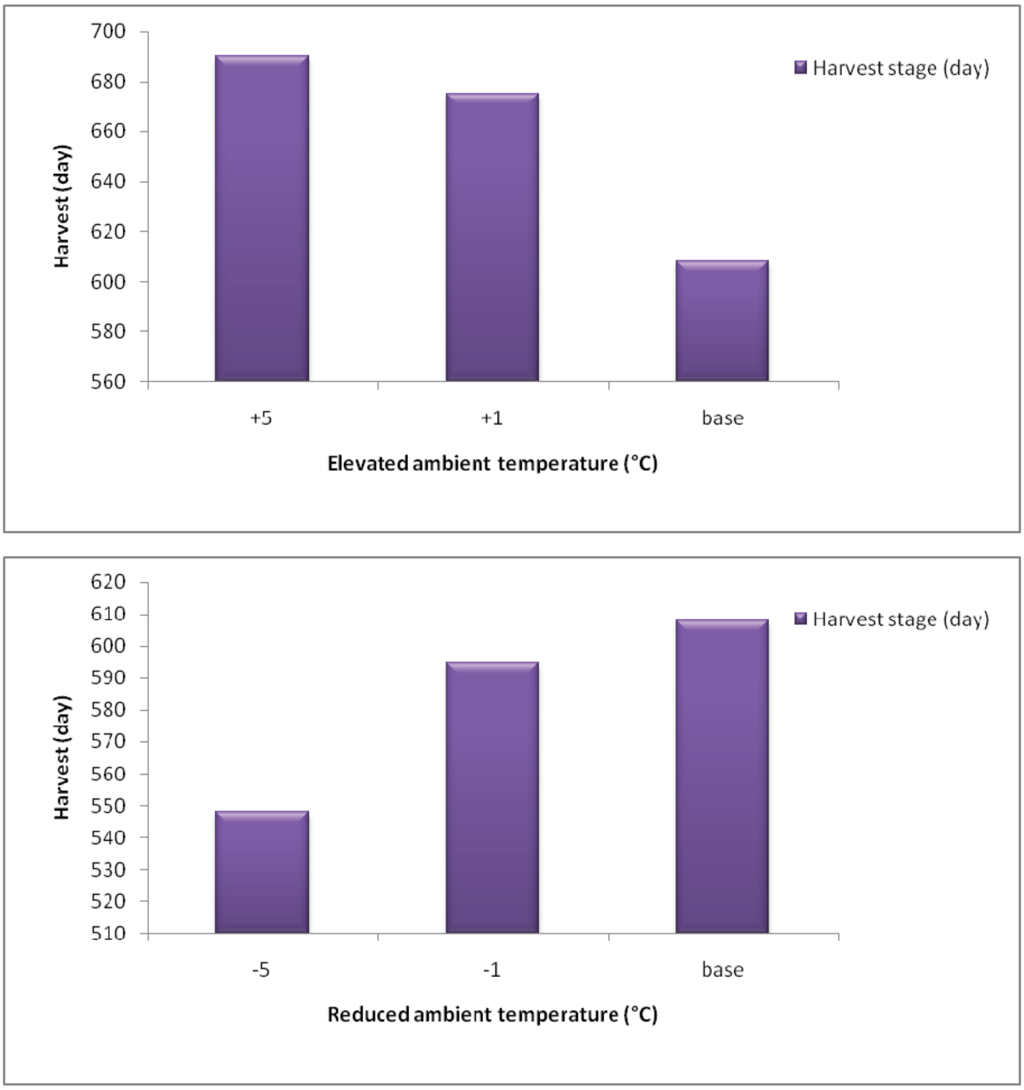


Figure 18 Effects of ambient temperature on harvest stage in Vermentino variety as compared with base date

Mean ambient temperature (°C)	Simulated Harvest stage (day)	% Change from base Harvest stage (608 day)
+1	**675**	**+11%**
+5	**690**	**+13%**
-1	**595**	**-2%**
-5	**548**	**-9%**

Table 13 Sensitivity of WinStics model to ambient temperature under optimal condition

7. Resultsand Discussion

The phenology simulations are made for the two main varieties grown in the Sardinia region 'Cannonau' (syn. Grenache) and Vermentino with climate input the scenarios IPCC A1B spatial resolution 8 km, time step 40 sec, computational grid with 207 x 211 nodes and 40 vertical levels. whose atmospheric component is ECHAM5 (T159 80 km spatial resolution, 6 h time resolution) and considering the scenario we performed the simulation with all the years of each series climate (Control, A1B). to period 1965 to 2100.In this chapter can we see a graphic representations of the phenological stages for two varieties. About the dormancy stage in all decade simulated there are a important delay of to go dormancy stage (In both the variety). This process is according to Koussa et al. (1994) depend for the significant correlation between the ability to bud and the content of ABA. In particular The inhibitory action of this growth regulator on germination seems to be exercised in particular dall'isomer cis (cis-ABA). The entrance dormancy coincides with an increased content of cis-ABA However we can register a few year with of to go dormancy is delayed respect to normal data (fig.23). In fact the model simulates partially this relationship because the entrance in dormancy coincides with an increase of the way of cis-ABA. The flowering stage is subject to anticipations on the average a week in both varietal in the simulation by scenarius A1B (fig 28 , 33)Advanced flowering occurred in all periods of the record, with relatively delayed flowering during the 25, 35, 50, 66, 78, 92 year for the Cannonau variety. (fig 20, 21) Concerning by the Vermentino variety, about the flowering is advanced on the average 5 (day fig 43) , but probably this differences is typical of the variety however there are a flowering very delayed during 8, 12, 23, 34, 48, 75, 82, 87 year. (fig 43)..But this aspect is very favorable because at germination temperature values lower than -3 ° C are ultimately detrimental. Just before flowering drops in temperature to 2.5 ° C can affect the crop and cause damage to the plants In regions with cool climates and short growing seasons, early-ripening varieties are necessary whereas in hot climates, late varieties have enough time to achieve full maturation.: The timing of these developmental stages is also related to the ability of the vine to yield fruit, with early and fully expressed phenological events (i.e., adverse weather during floraison would disrupt the event) usually resulting in larger yields . Additionally, phenological timing has been related to vintage quality with early harvests generally resulting in higher quality vintages. In this case we can see with in both varietal have a harvest stage enough late. In particular the Cannonau variety harvest occurred to average a 23 day after the normal date. Relative to Vermentino varietal the date of harvest occurred only a after week respect to date control. (fig 48) .In this contest we can affirmed in according to many study that The climate has a major influence on the life cycle of the grapevine (Vitis vinifera L.); in particular the temperature is the variable weather that acts more activity on the dynamics of emergence and vegetative stages of phenological.

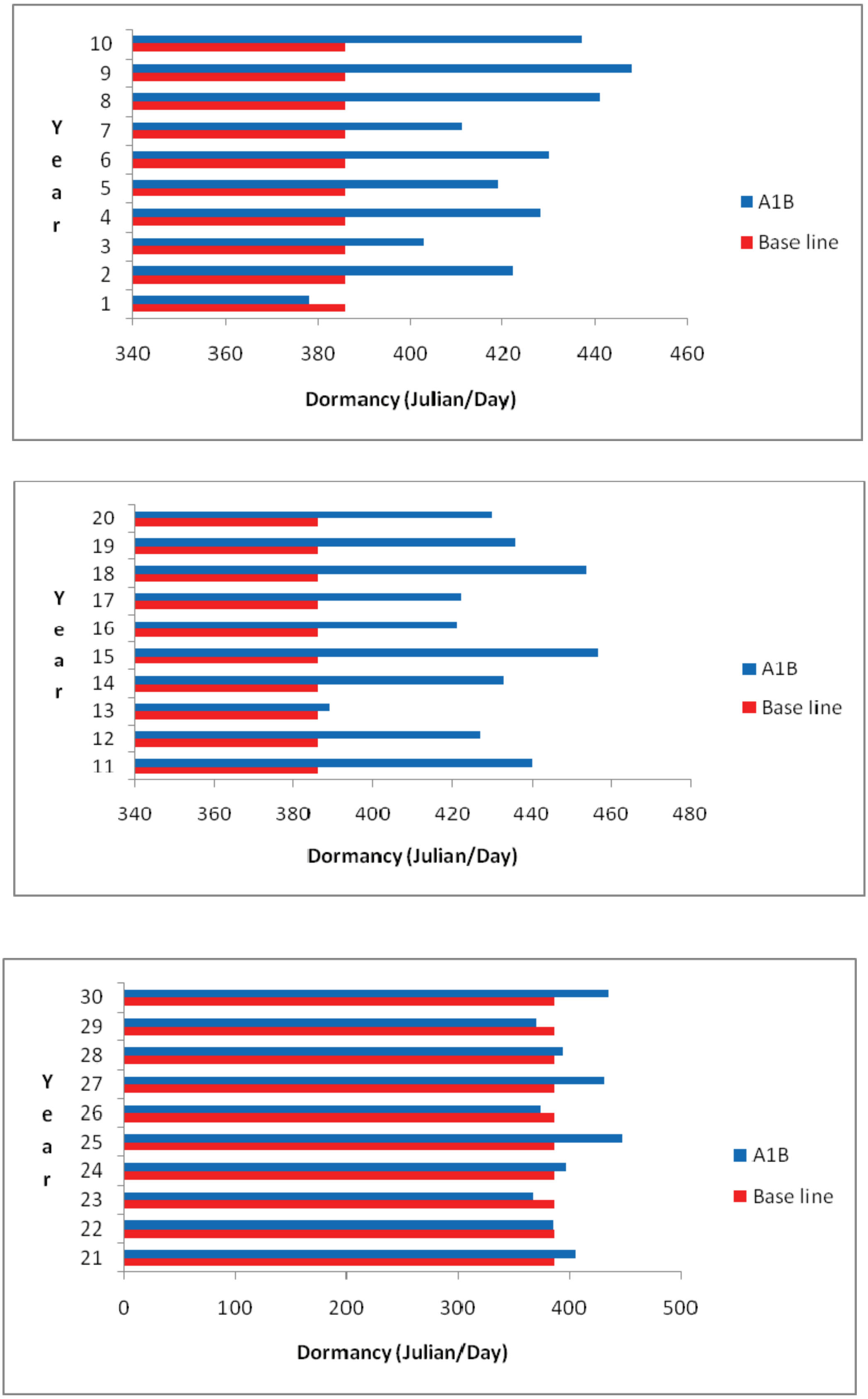


Figure 19a, b, c Simulation dormancy stage Variety Cannonau Alghero

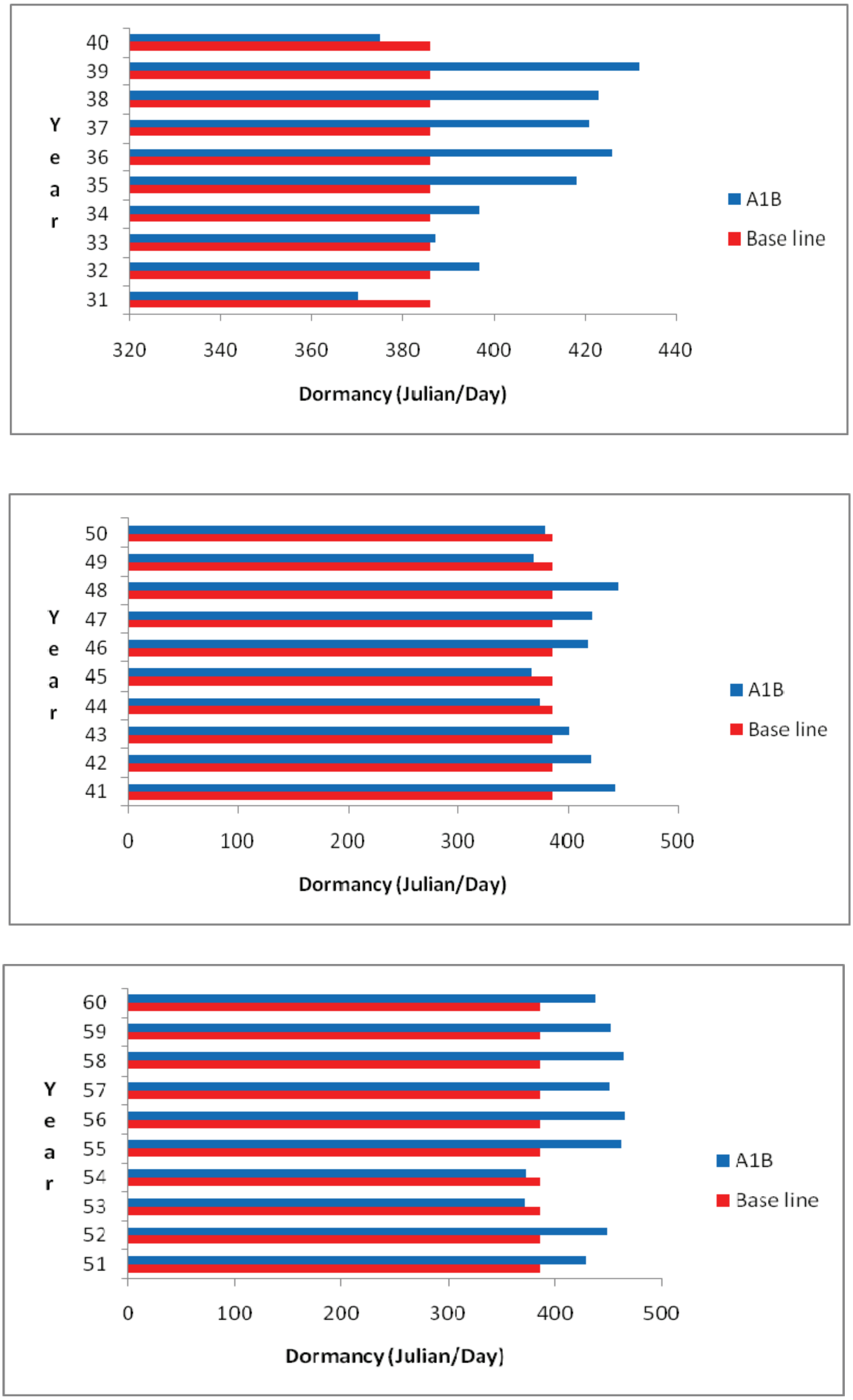
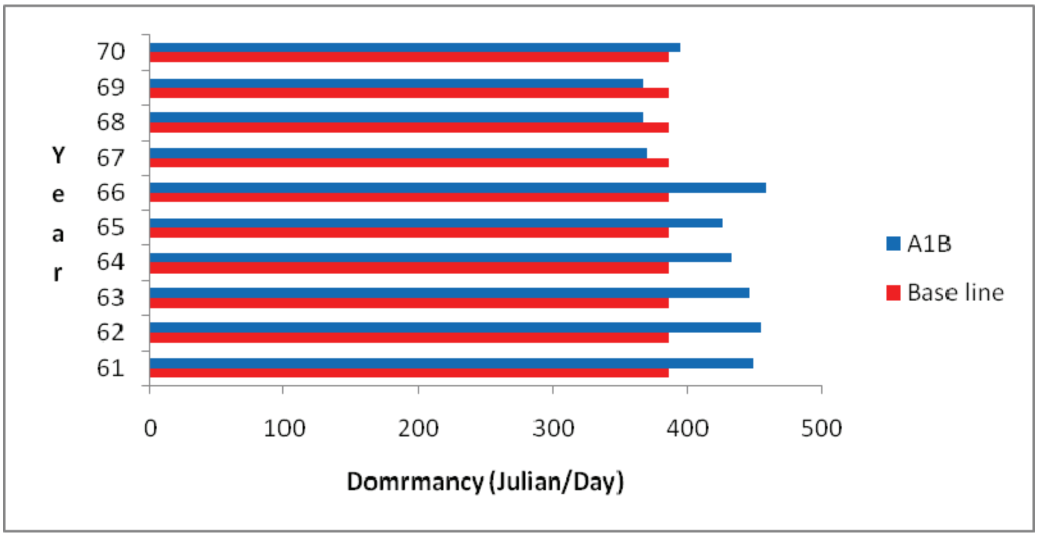
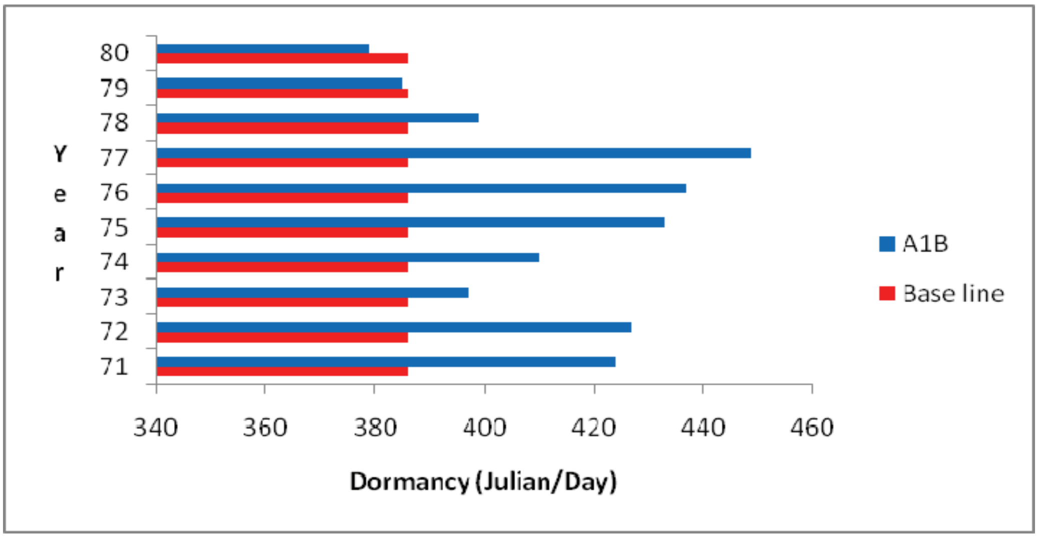


Figure 20 a, b, c Simulation dormancy stage Variety Cannonau Alghero





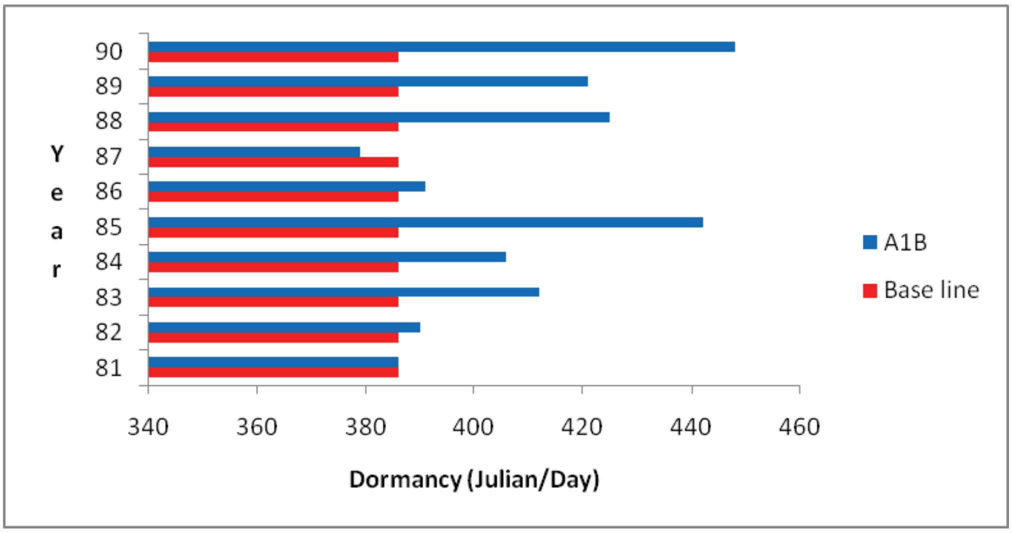
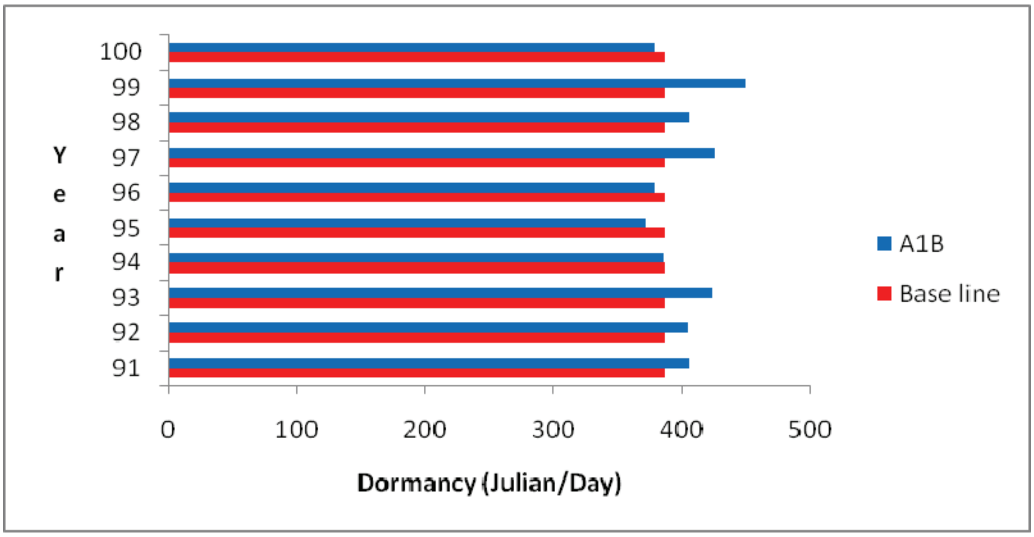


Figure 21 a, b, c Simulation dormancy stage Variety Cannonau Alghero



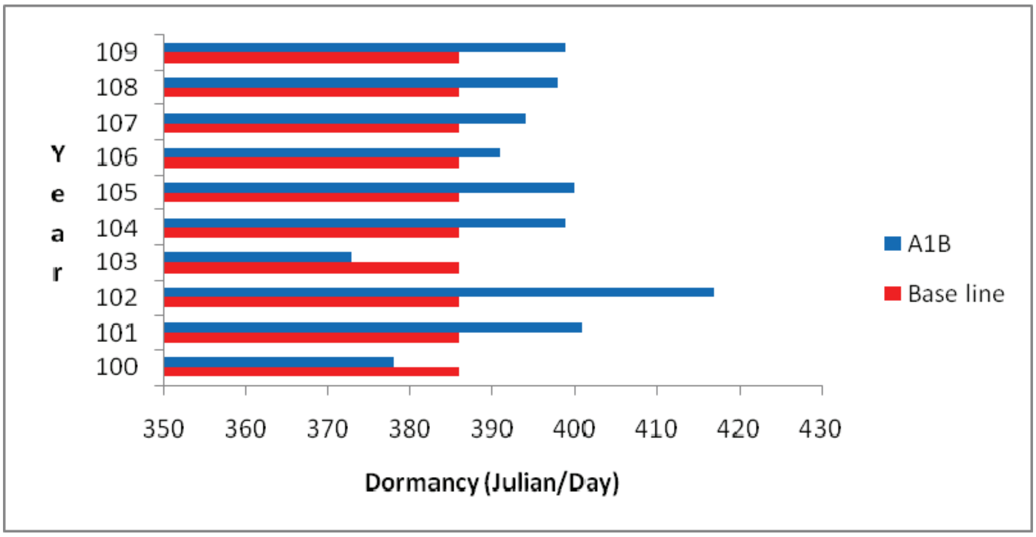


Figure 22 a, b, Simulation dormancy stage Variety Cannonau Alghero

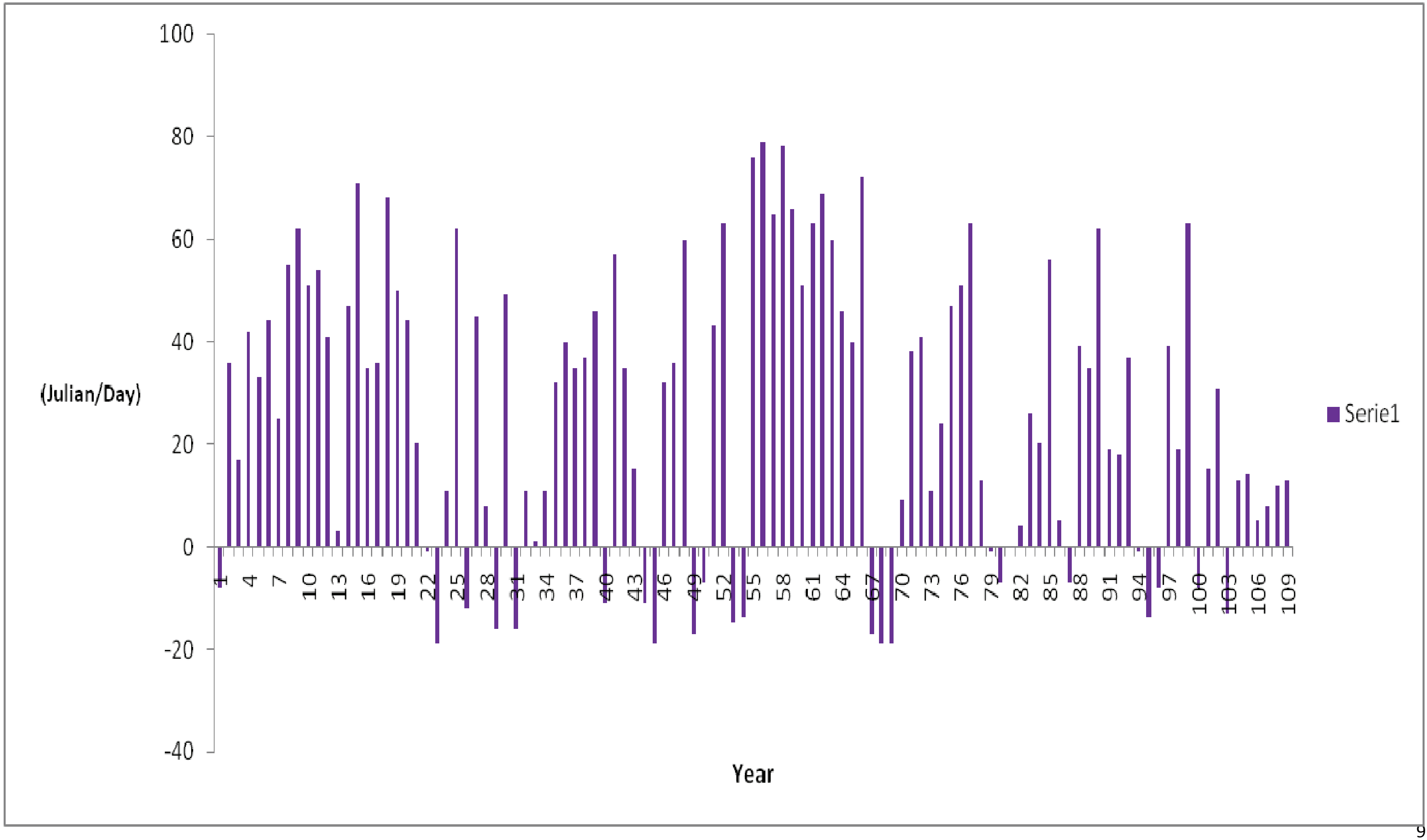
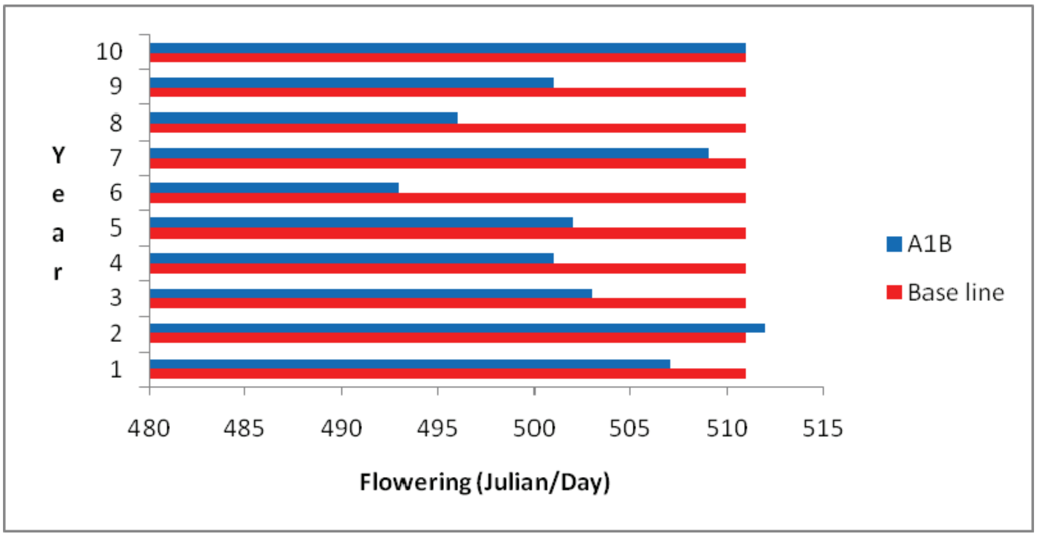
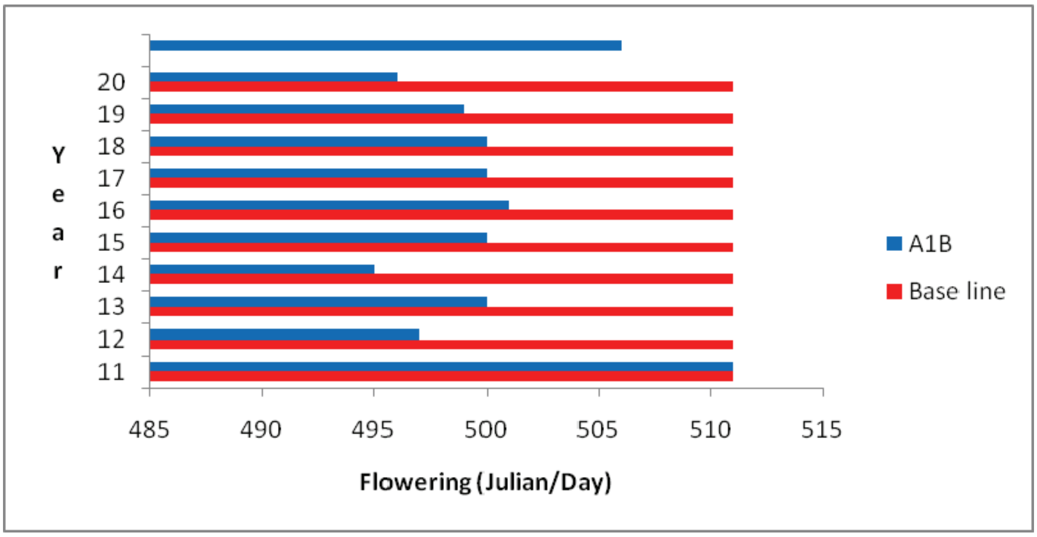


Figure 23 Difference by real value and simulation value Dormancy stage in Alghero, Cannonau Variety





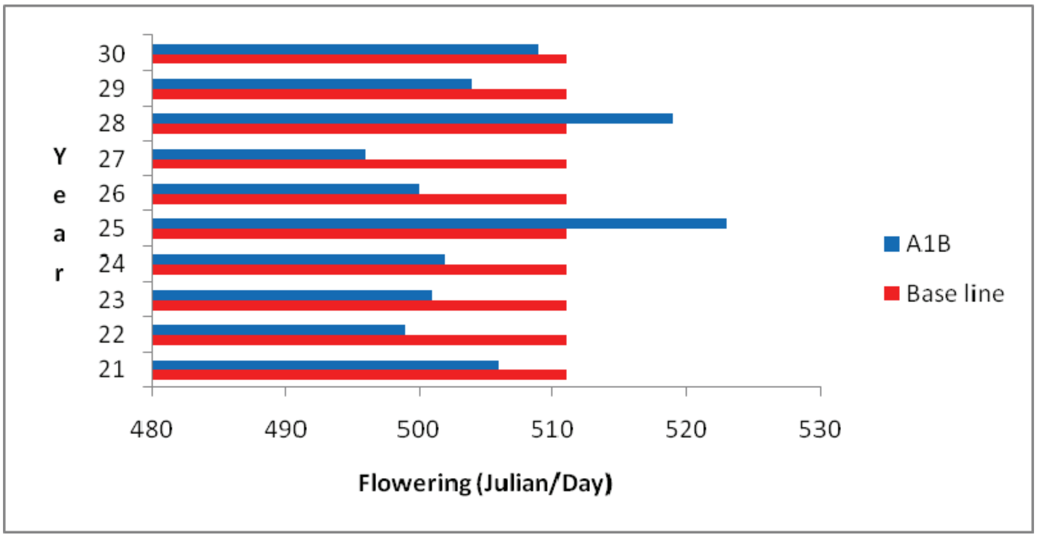


Figure 24 a, b, c Simulation Flowering stage Variety Cannonau Alghero

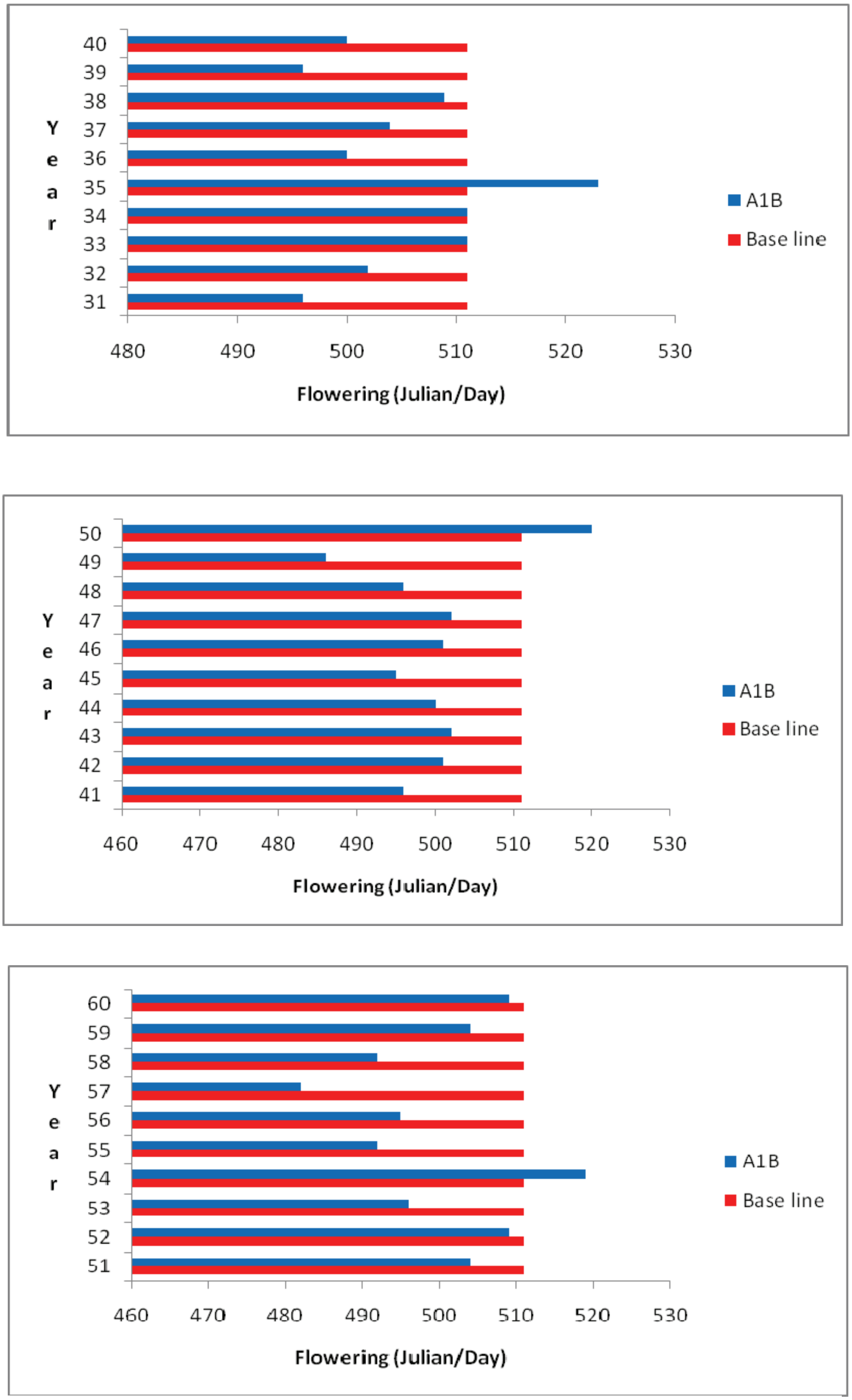


Figure 25 a, b, c Simulation Flowering stage Variety Cannonau Alghero

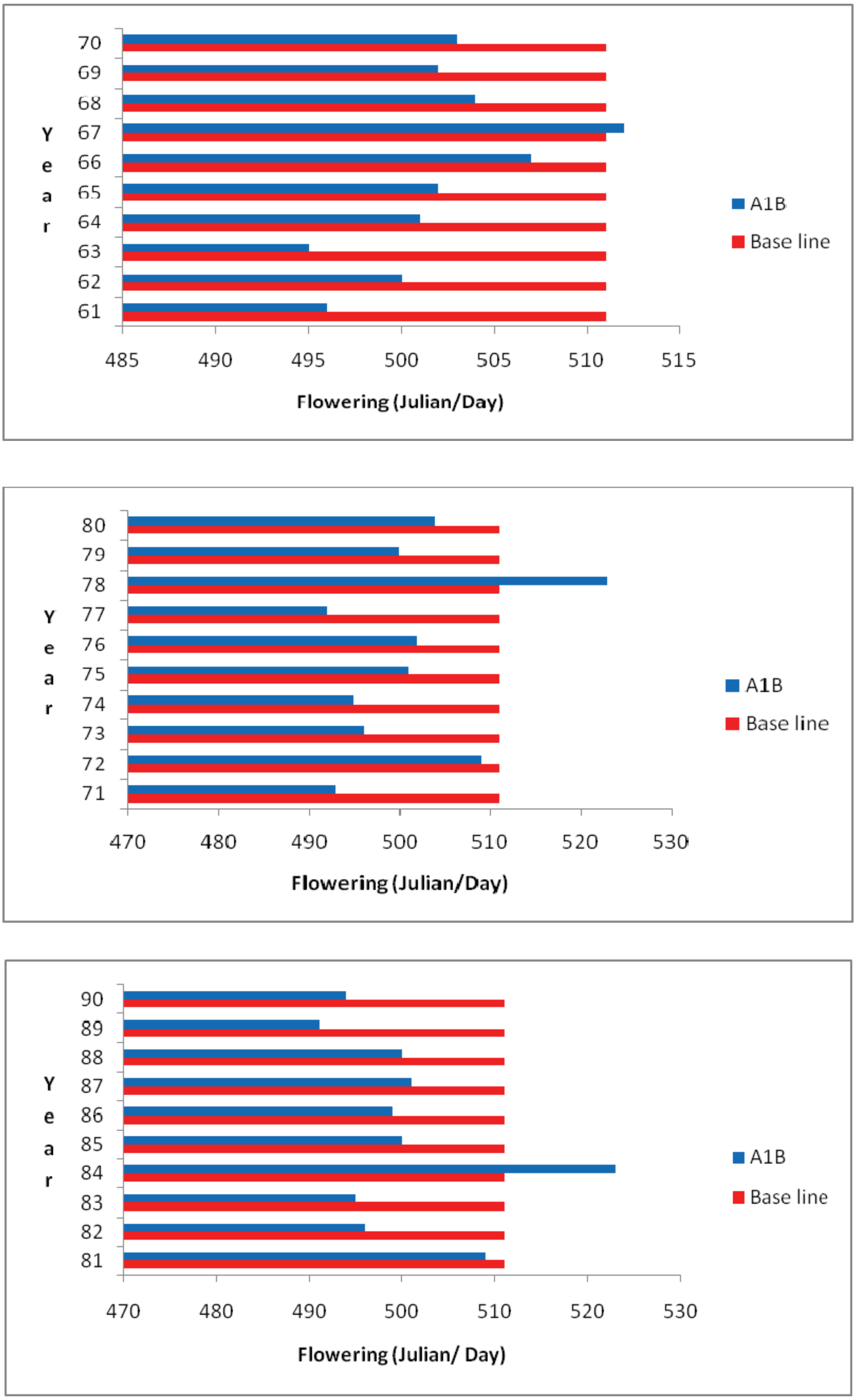
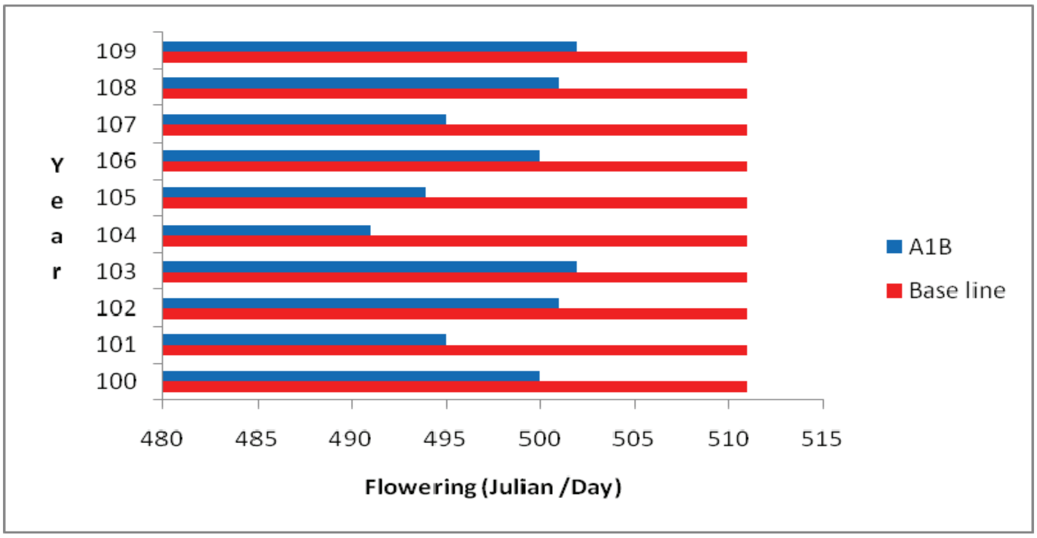


Figure 26 a, b, c Simulation Flowering stage Variety Cannonau Alghero



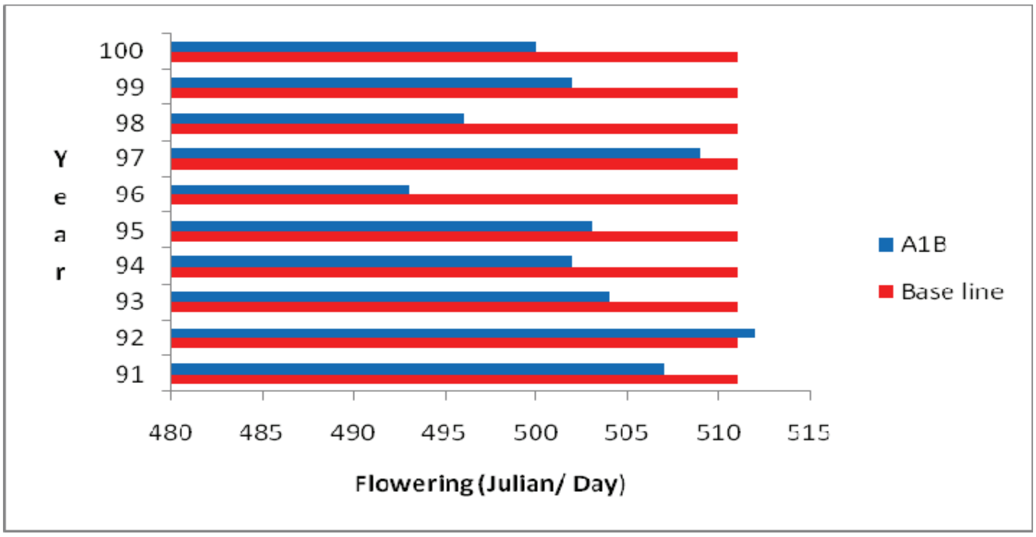


Figure 27 a, b Simulation Flowering stage Variety Cannonau Alghero

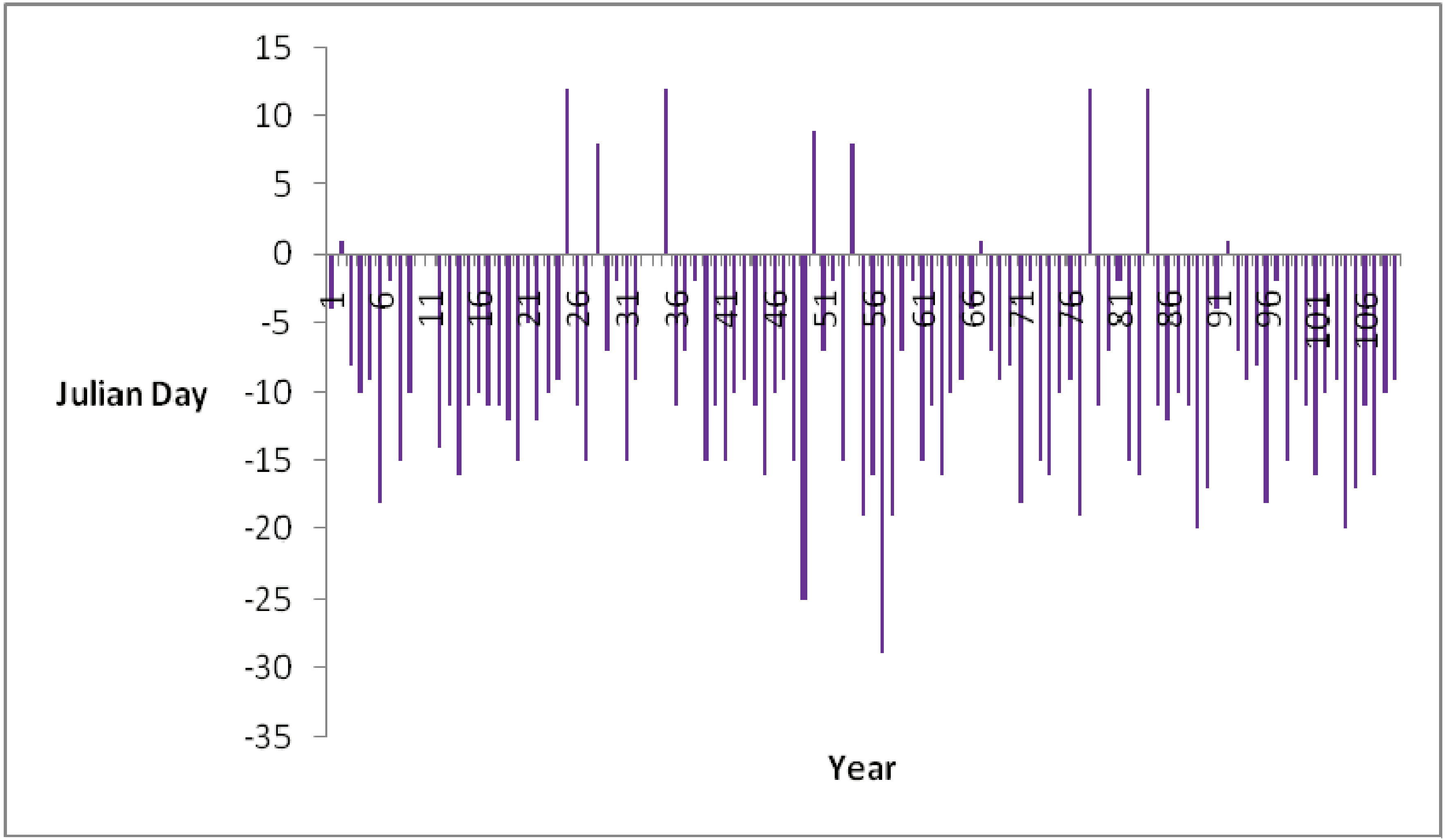
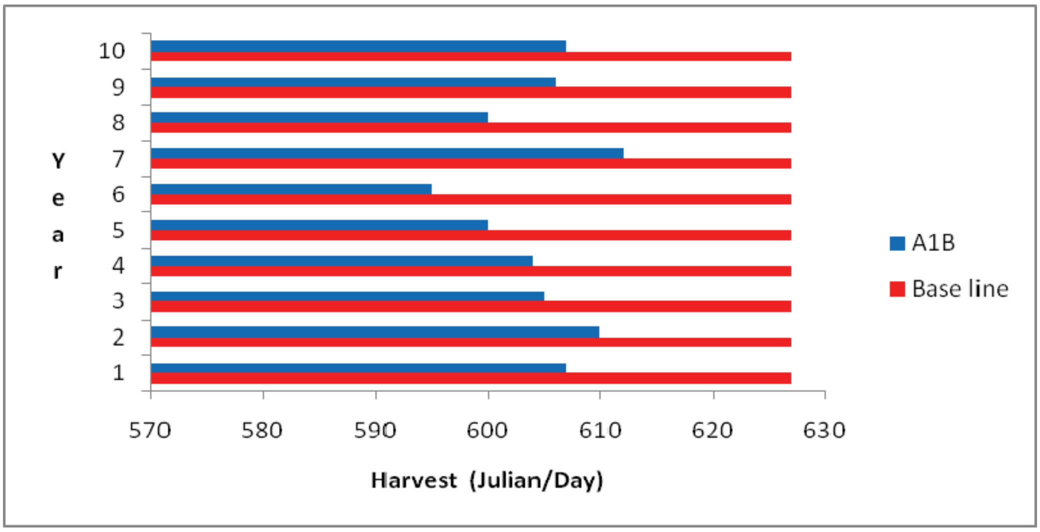
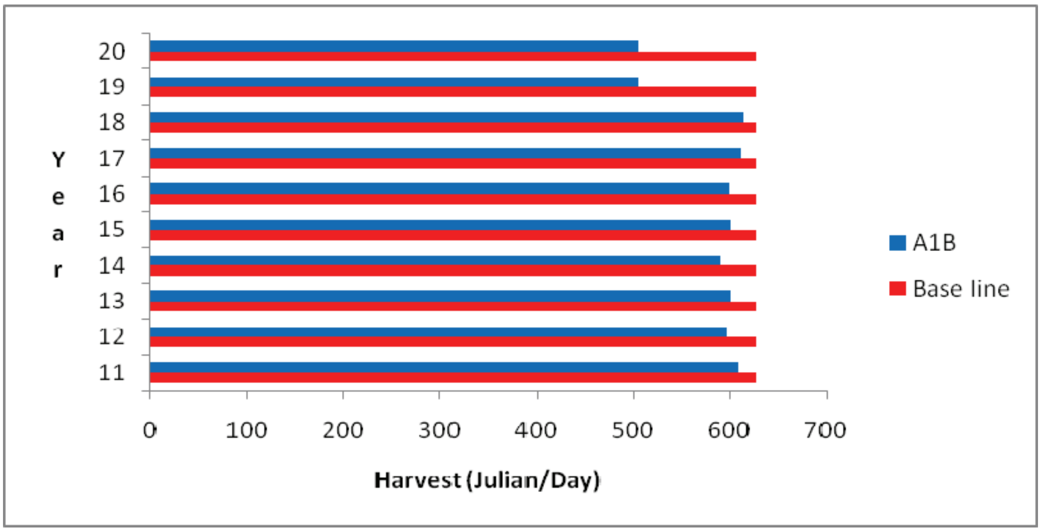


Figure 28 Difference by real value and simulation value Flowering stage in Alghero, Cannonau Variety





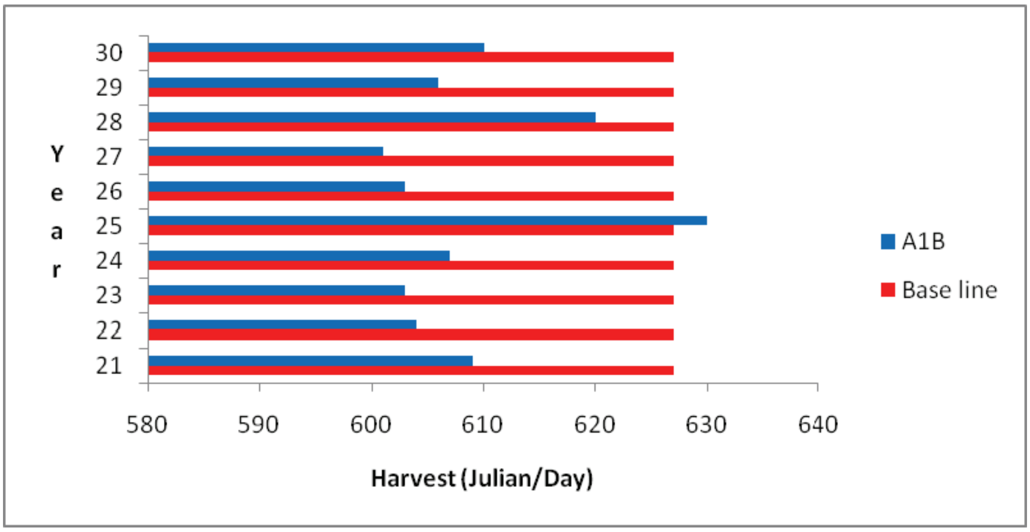


Figure 29 a, b, c Simulation Harvest stage Variety Cannonau Alghero

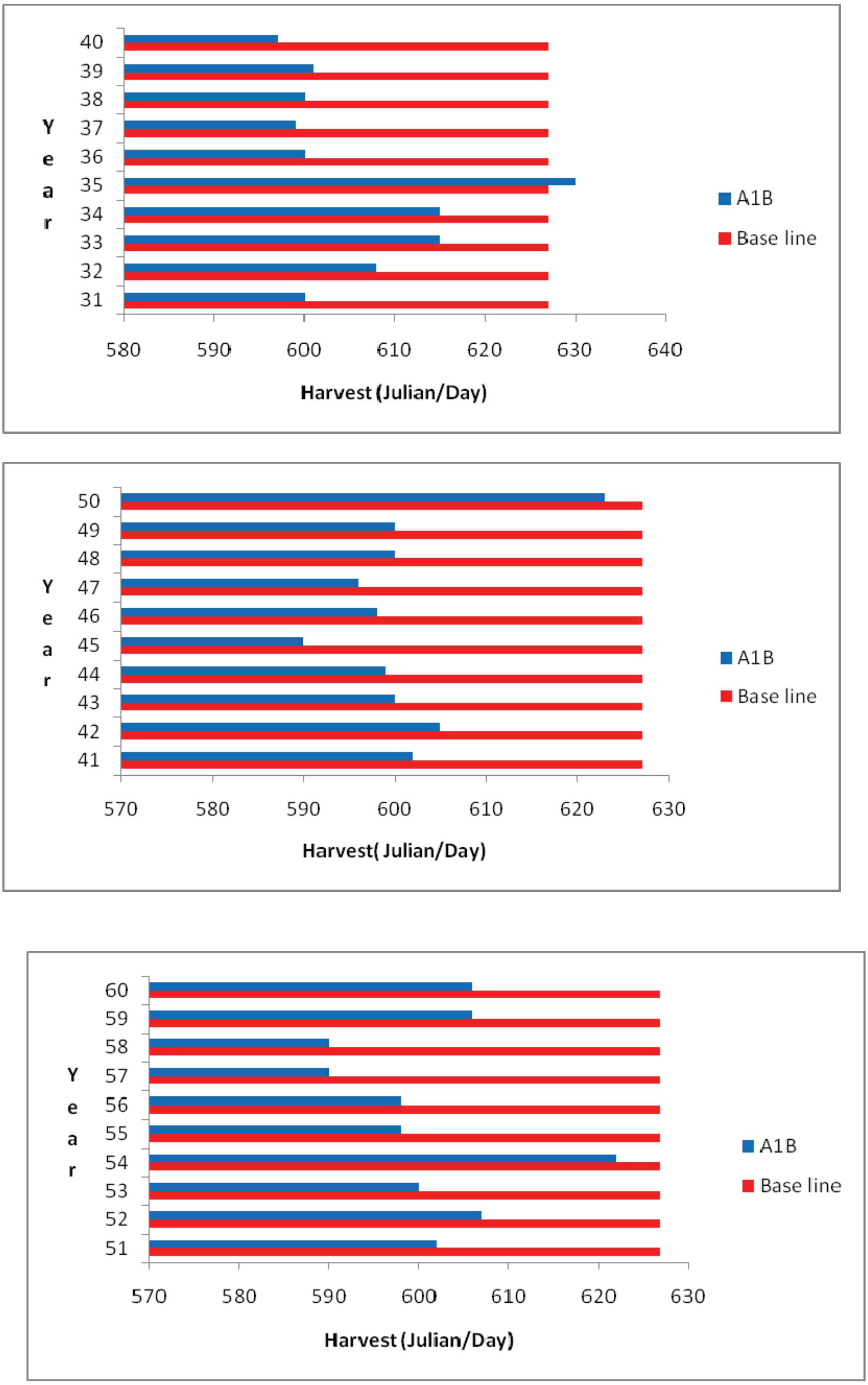


Figure 30 a, b, c Simulation Harvest stage Variety Cannonau Alghero

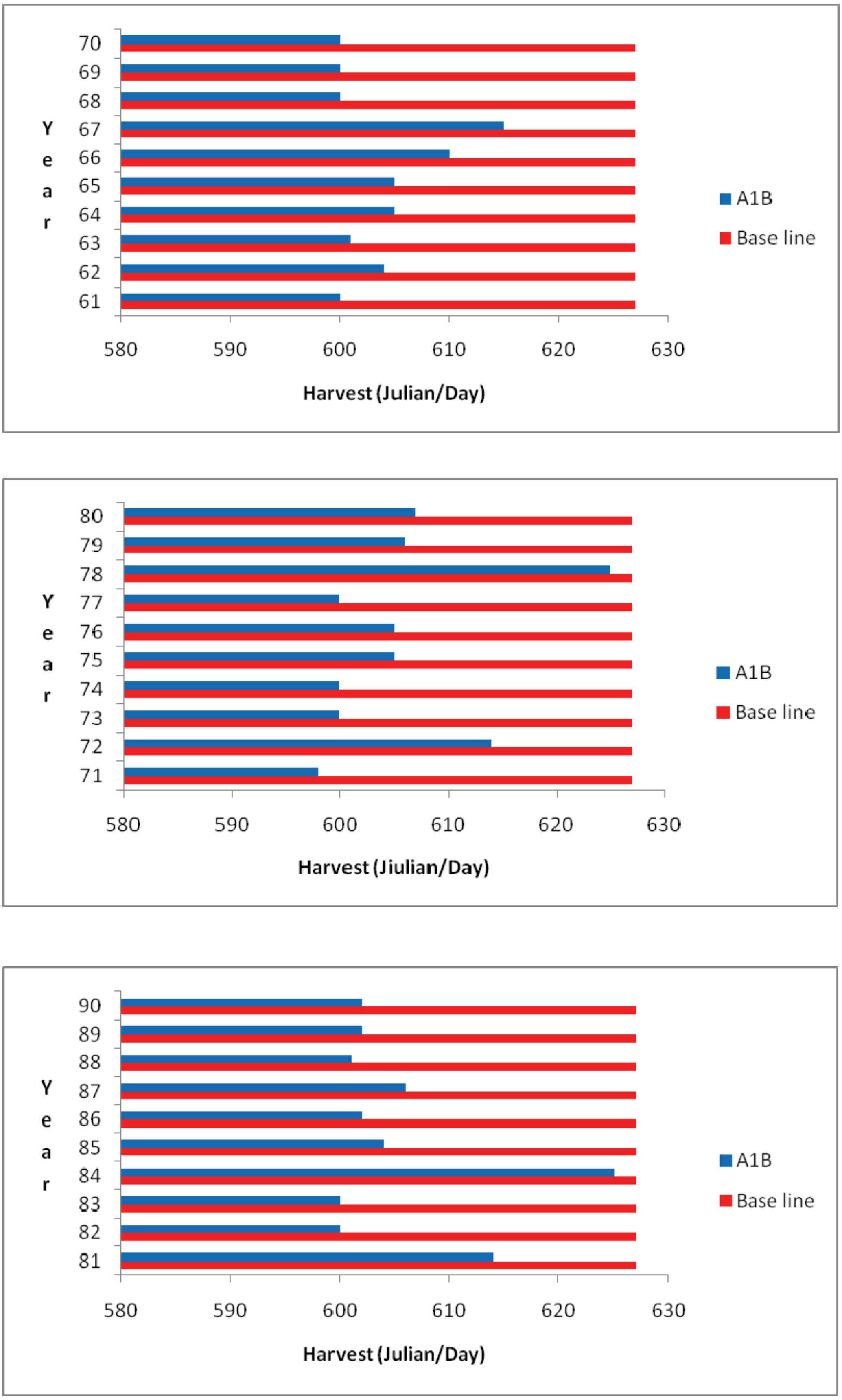
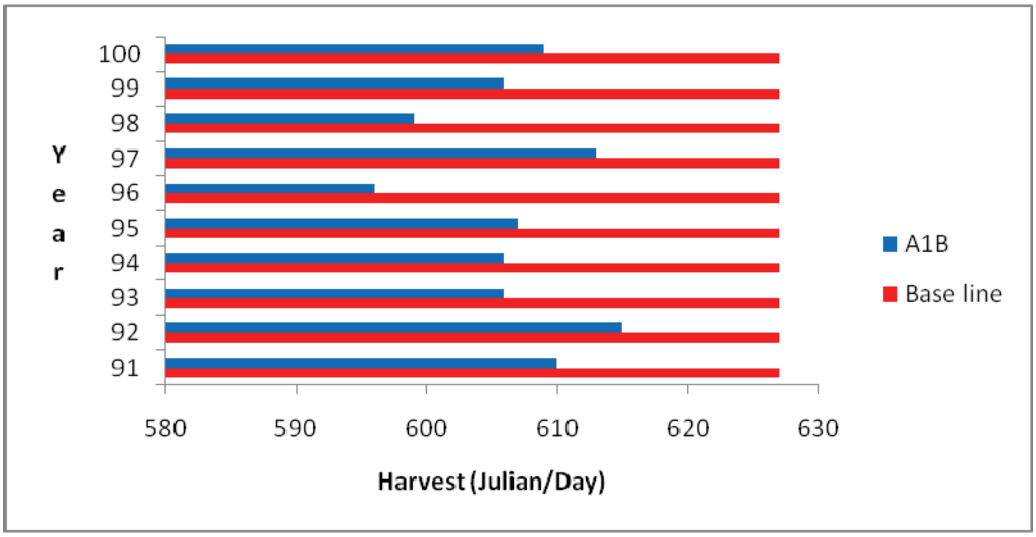


Figure 31 a, b, c Simulation Flowering stage Variety Cannonau Alghero



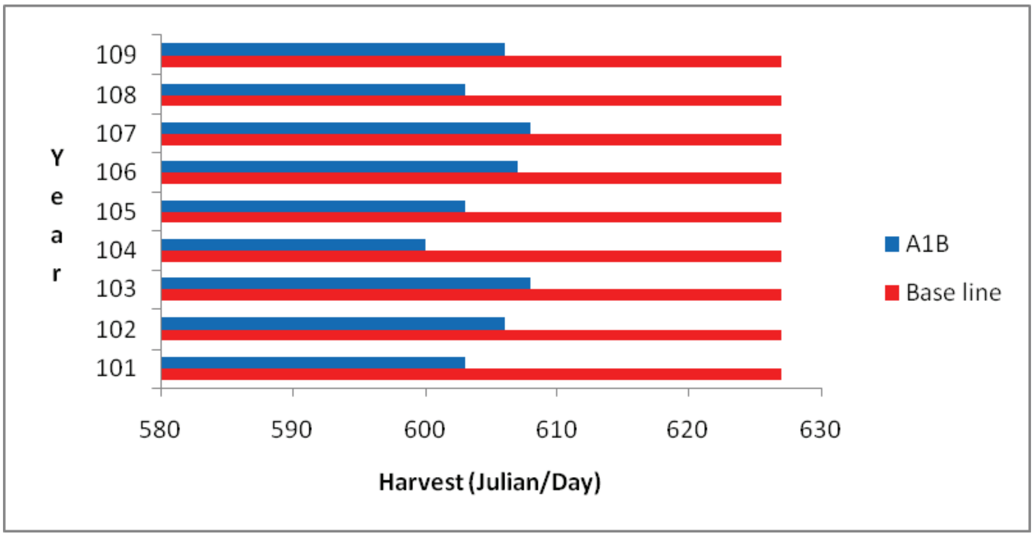


Figure 32 a, b Simulation Flowering stage Variety Cannonau Alghero

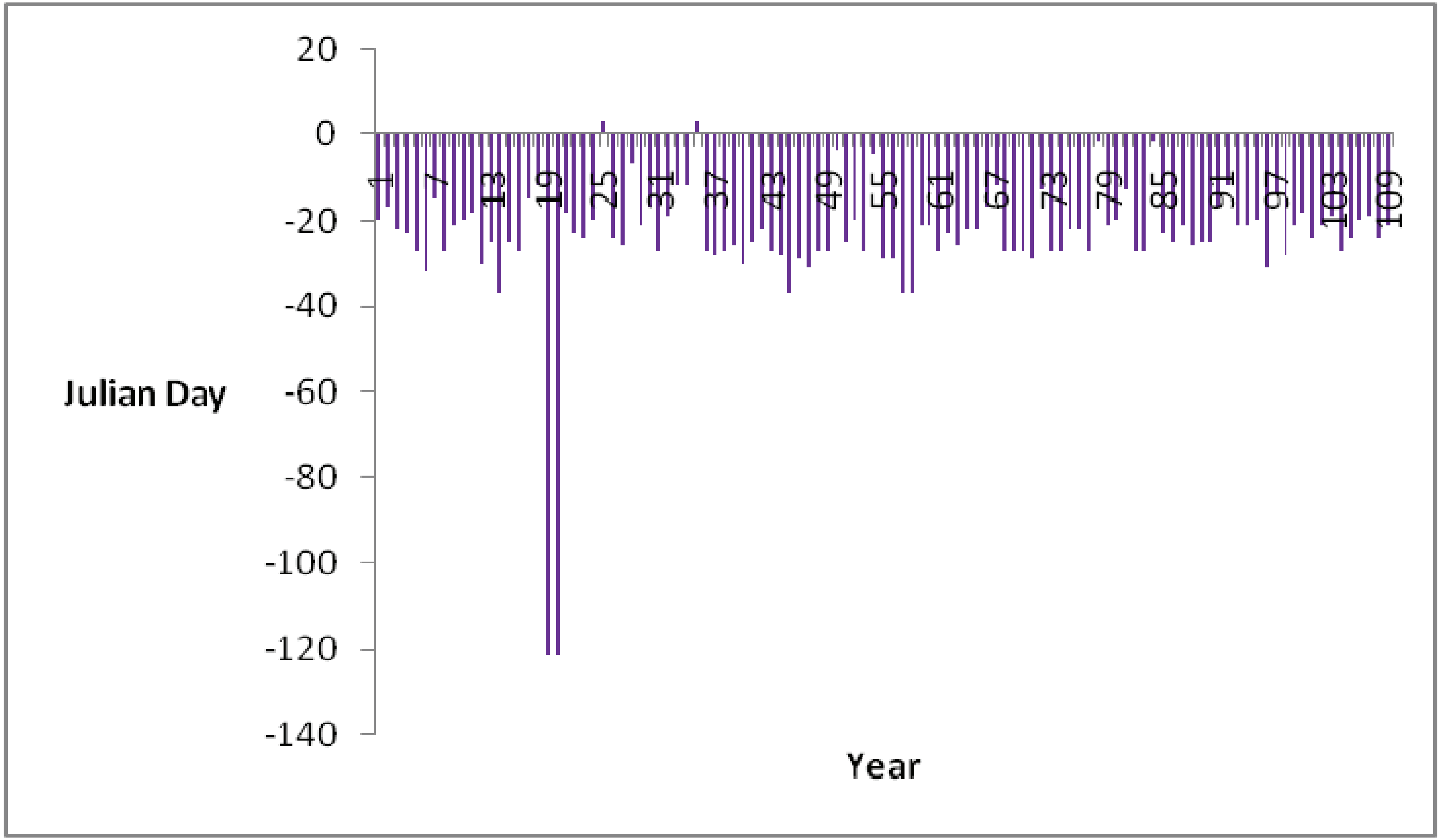
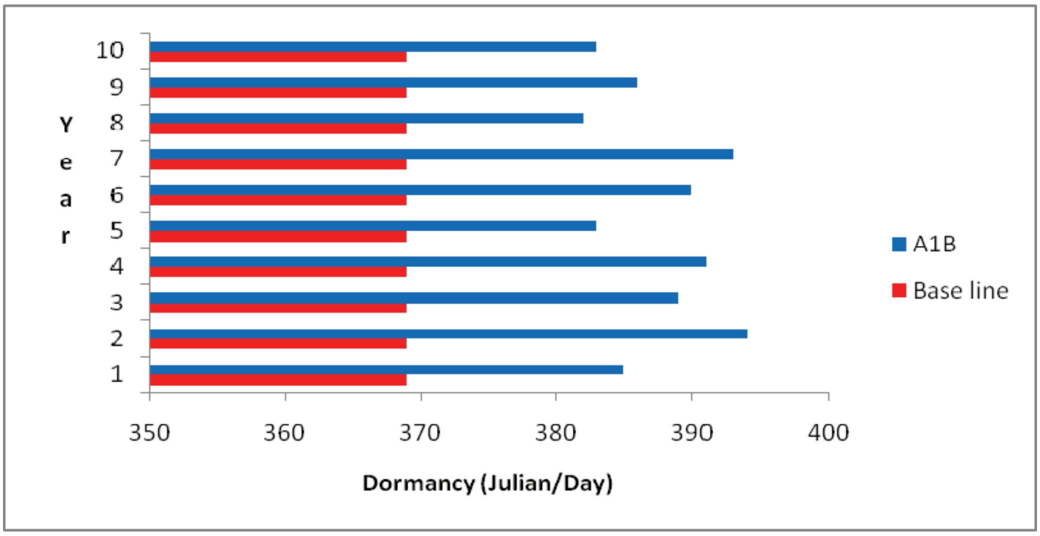
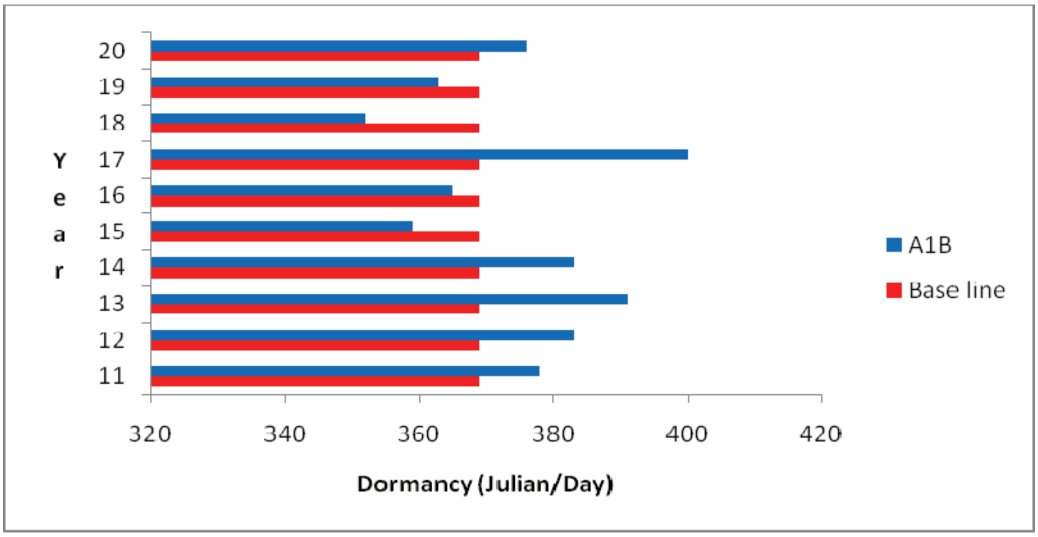


Figure 33 Difference by real value and simulation value Harvest   stage in Alghero, Cannonau Variety





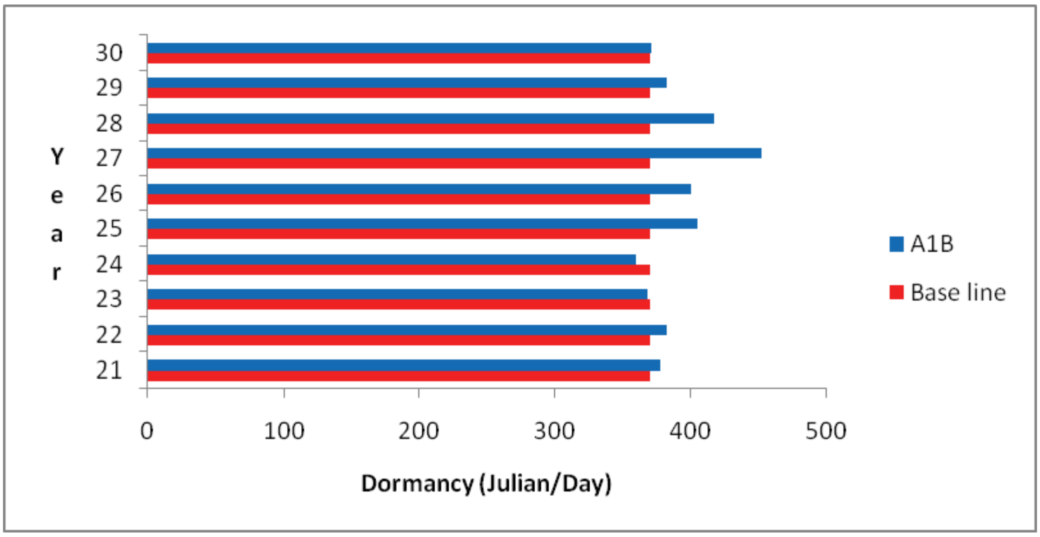


Figure 34 a, b, c Simulation Dormancy stage Variety Vermentino Berchidda

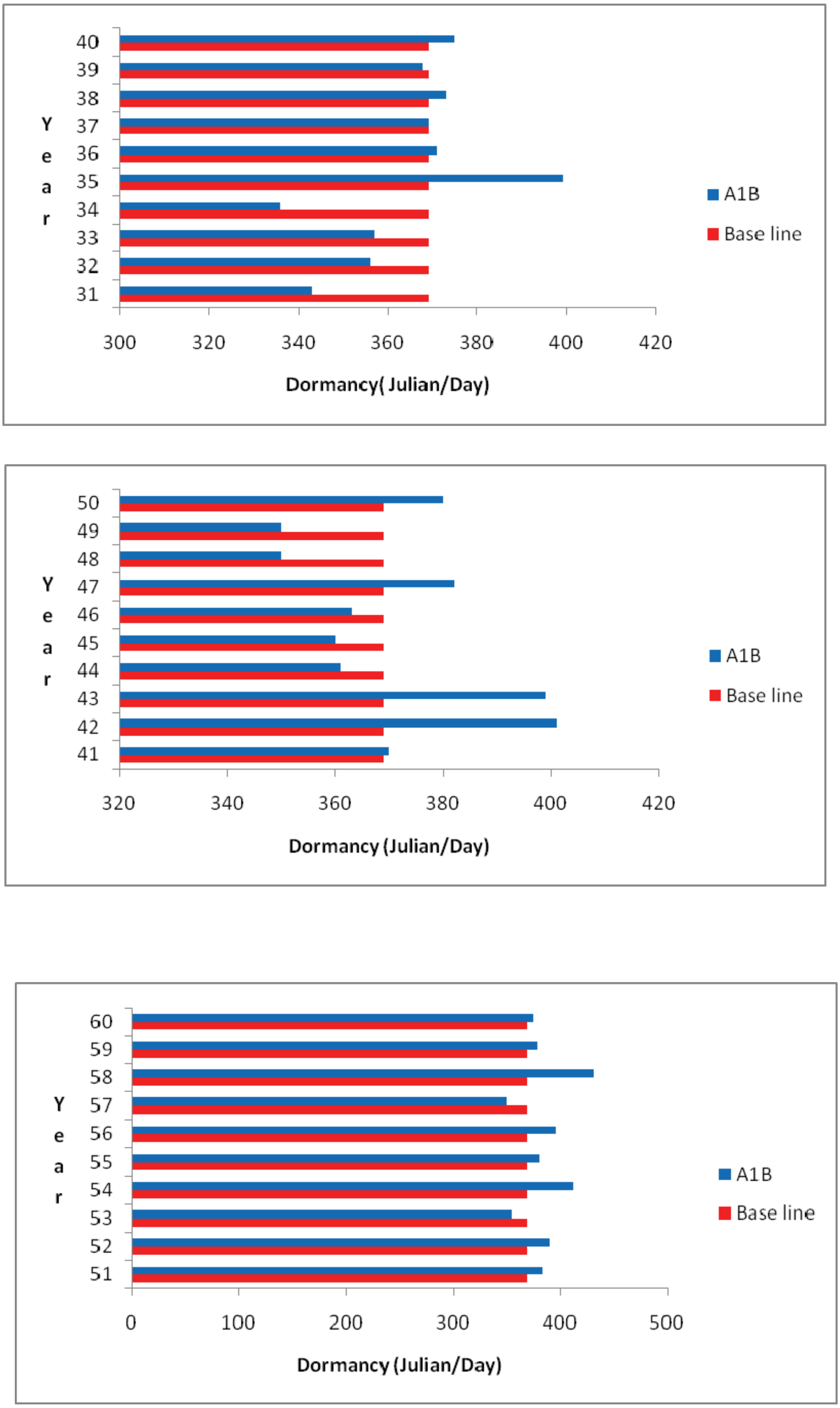
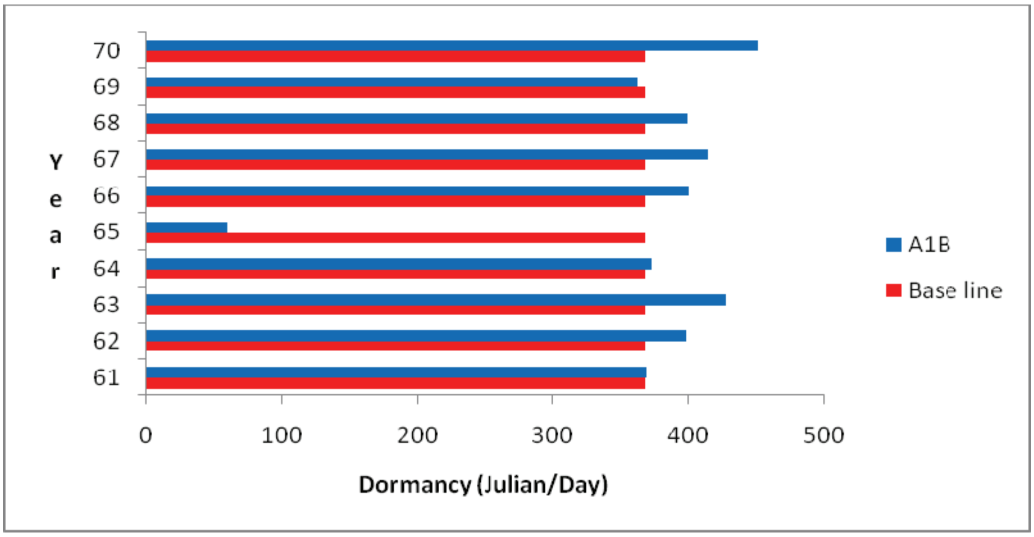
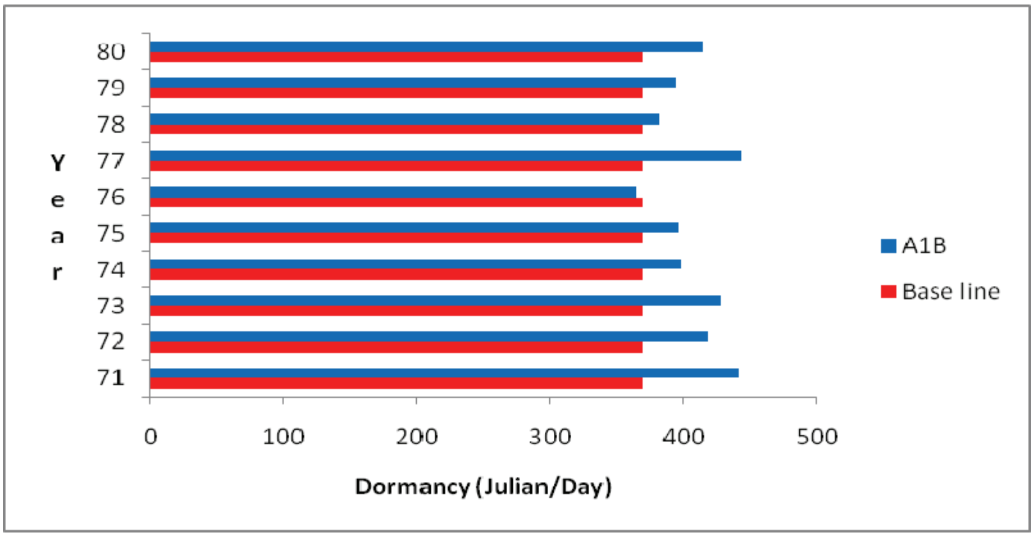


Figure 35 a, b, c Simulation Dormancy stage Variety Vermentino Berchidda





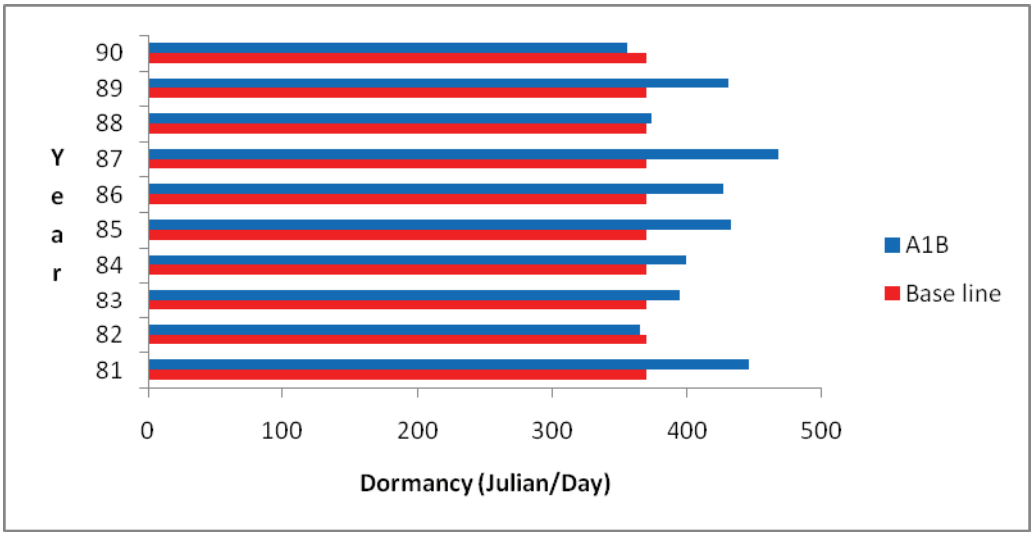
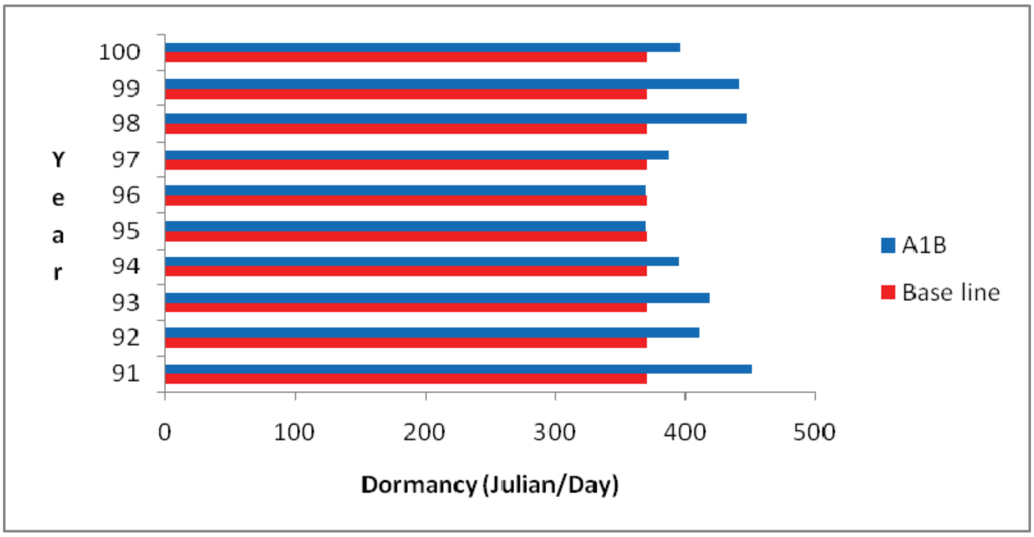


Figure 36 a, b, c Simulation Dormancy stage Variety Vermentino Berchidda



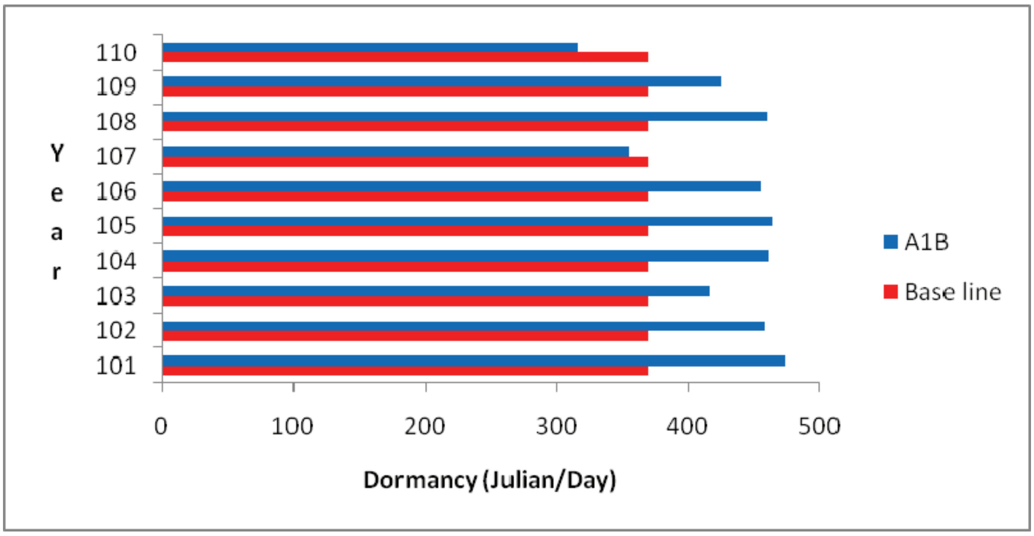


Figure 37 a, b, Simulation Dormancy stage Variety Vermentino Berchidda

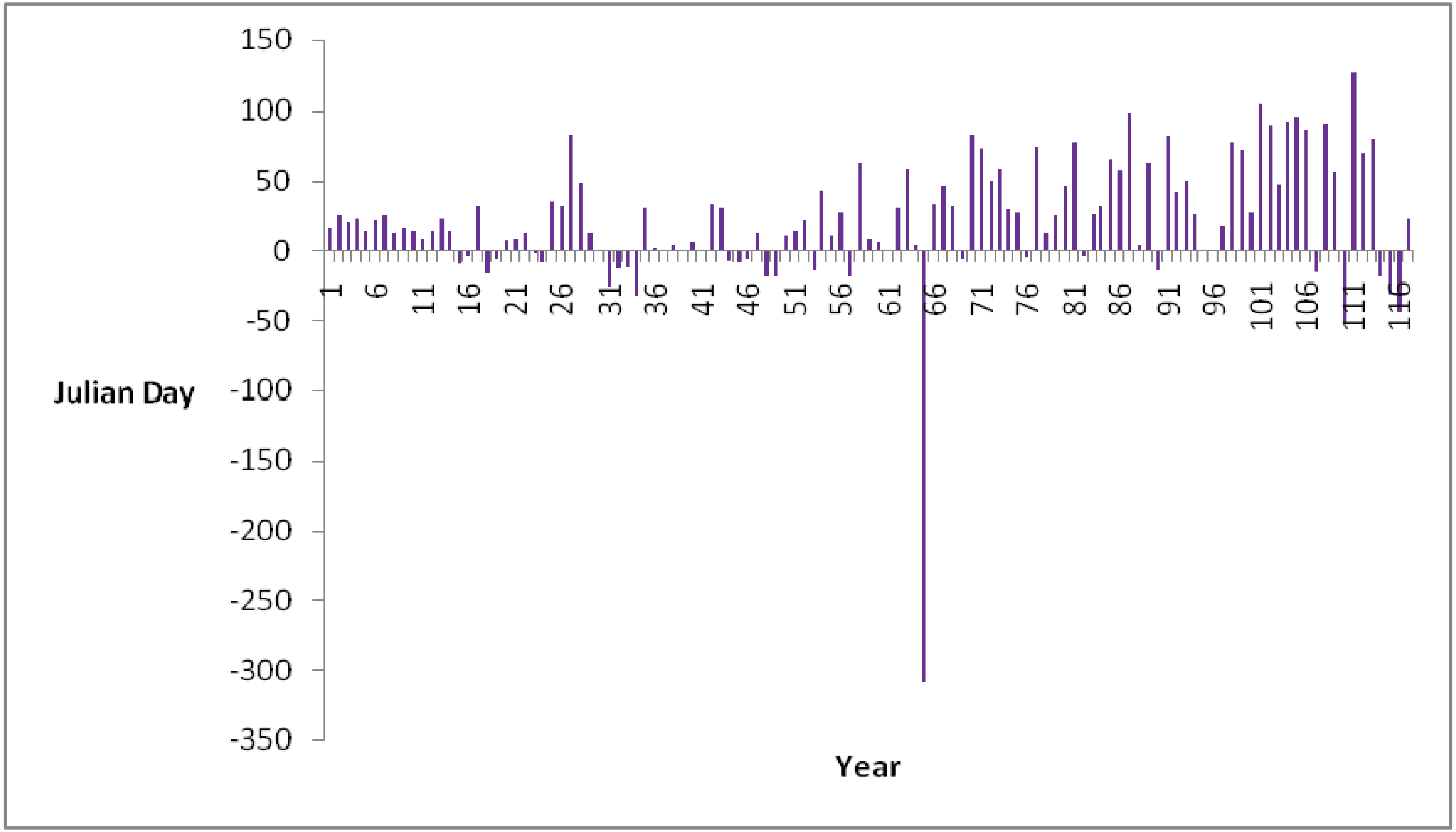


Figure 38 Difference by real value and simulation value Dormancy stage in Berchidda, Vermentino Variety

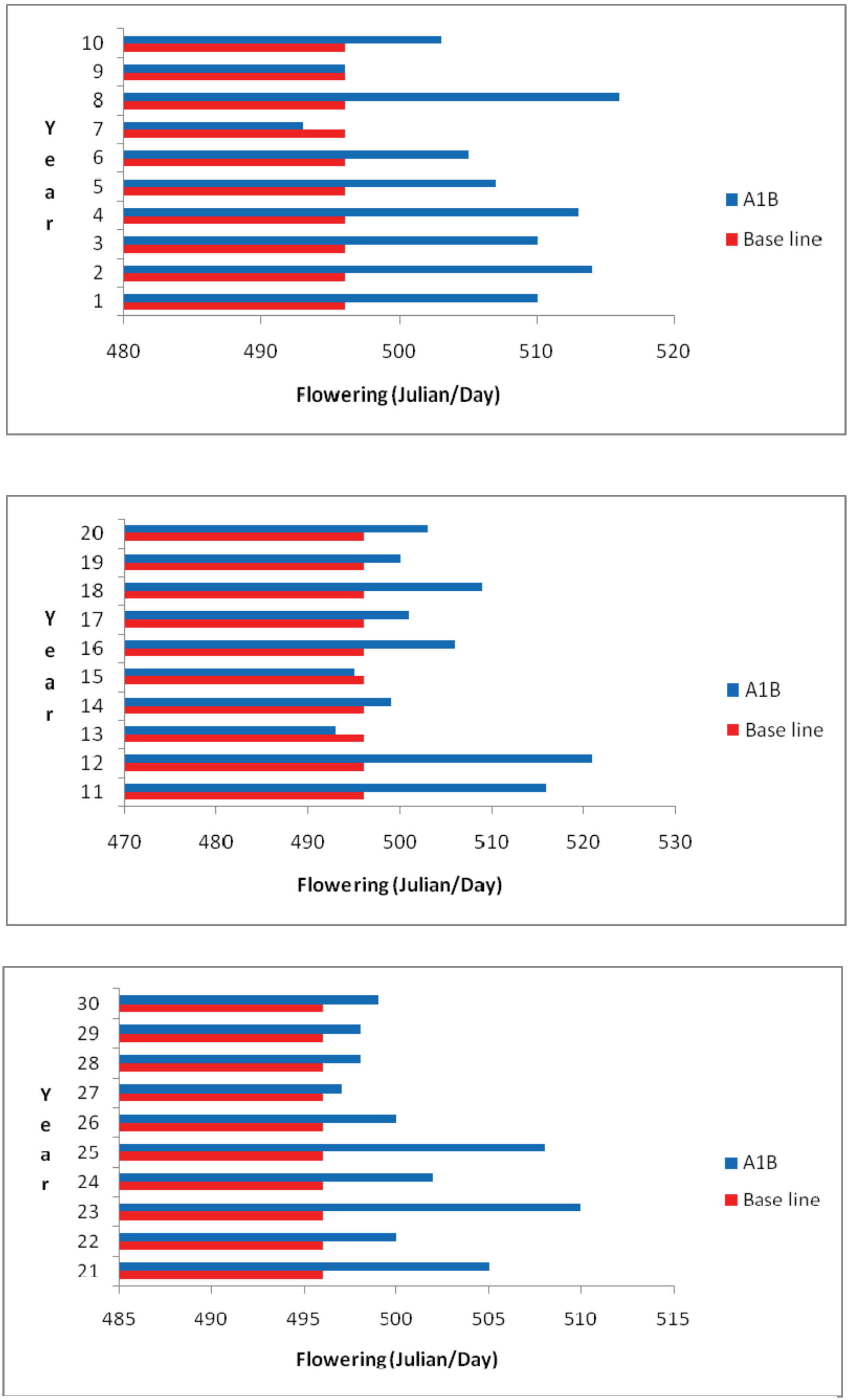


Figure 39 a, b, c Simulation Flowering stage Variety Vermentino Berchidda

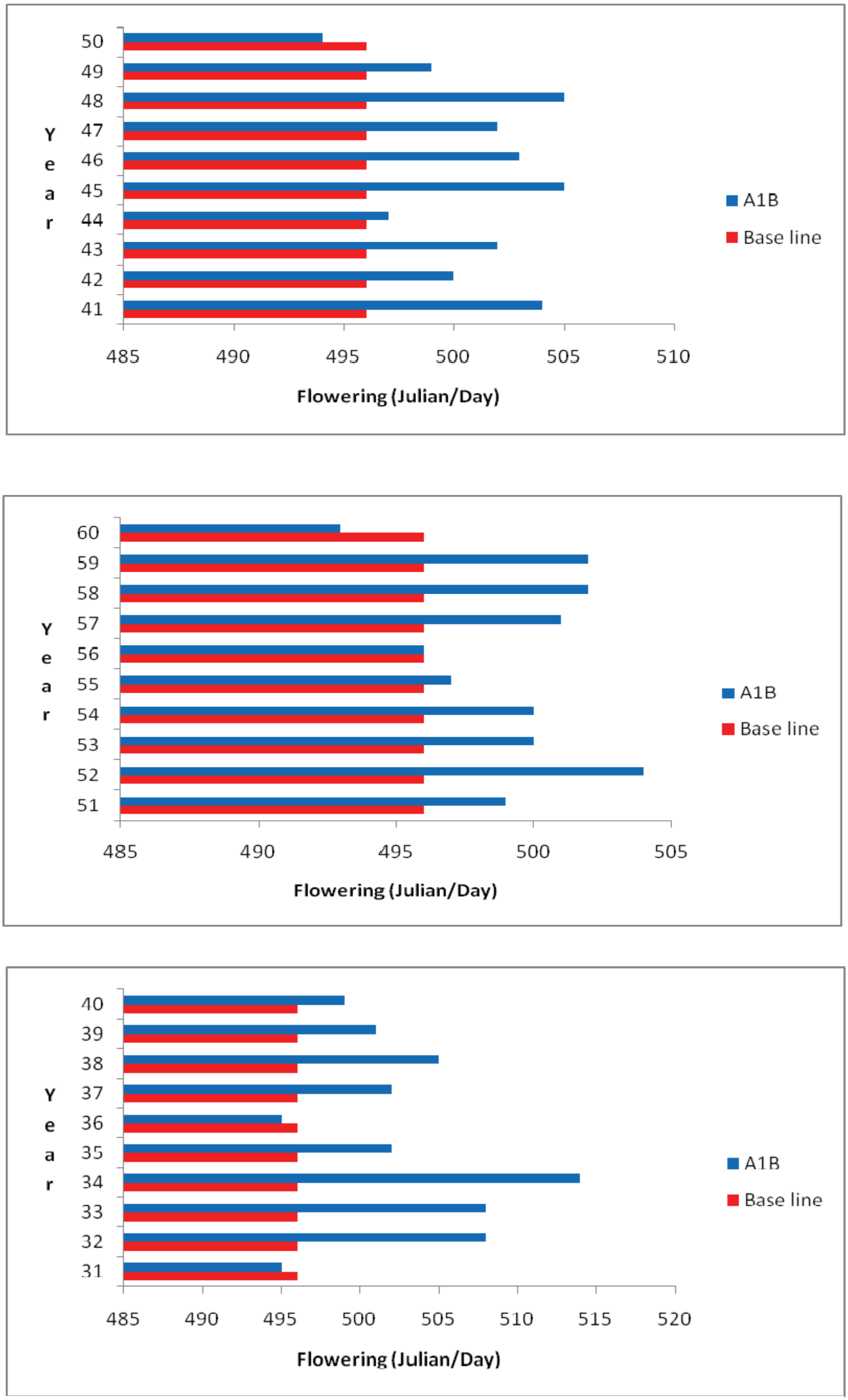


Figure 40 a, b, c Simulation Flowering stage Variety Vermentino Berchidda

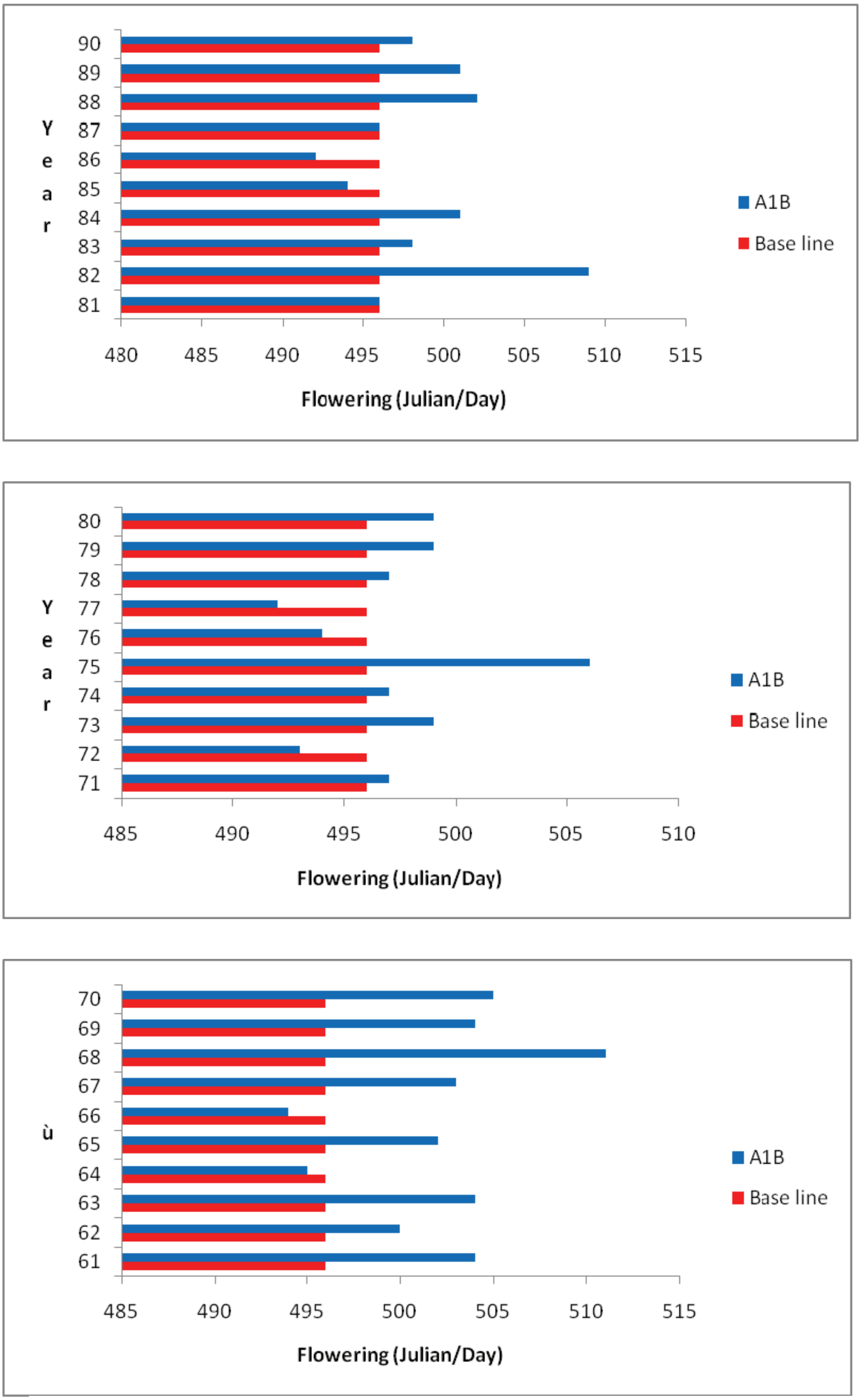


Figure 41 a, b, c Simulation Flowering stage Variety Vermentino Berchidda

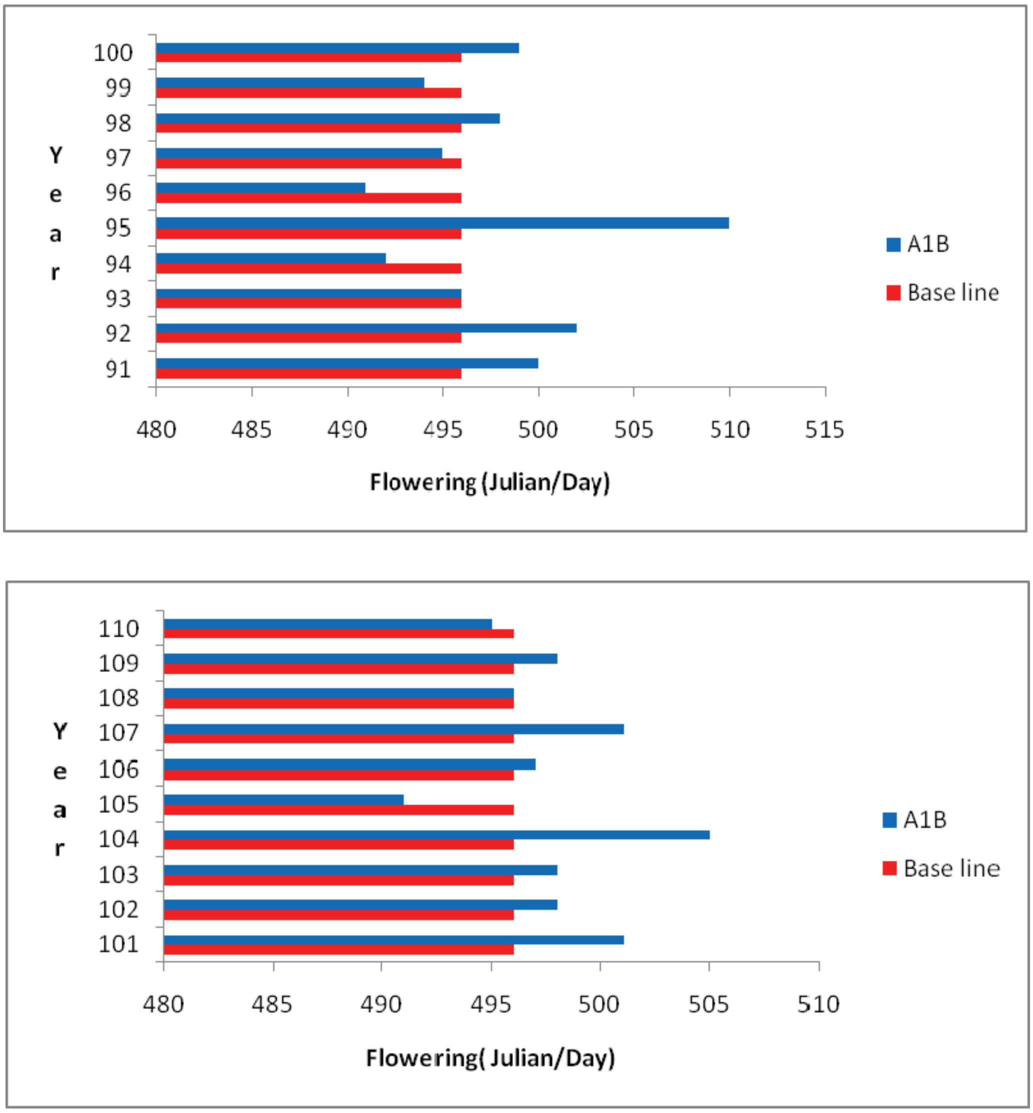


Figure 42a, b, Simulation Flowering stage Variety Vermentino Berchidda

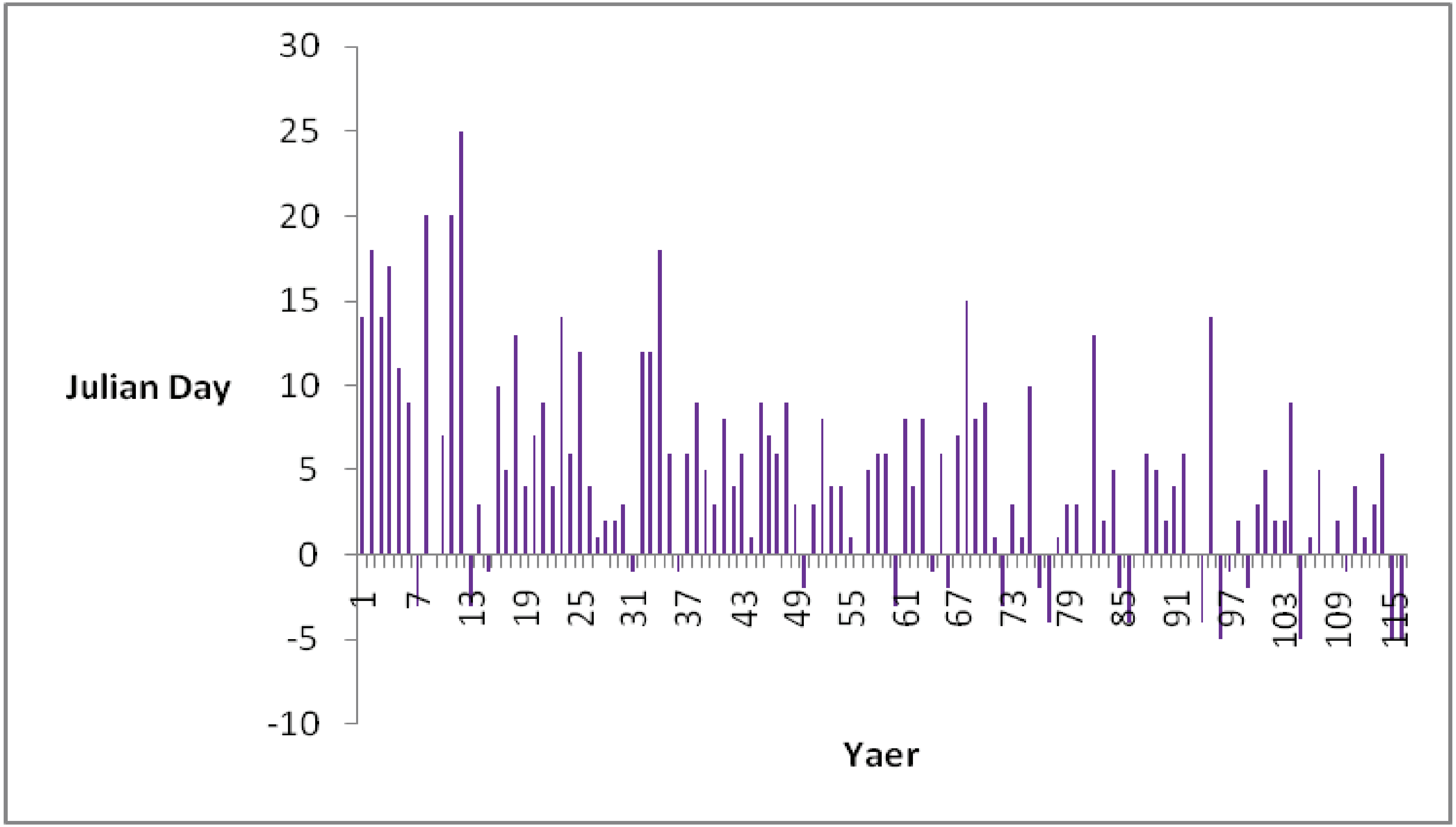


Figure 43 Difference by real value and simulation value Dormancy stage in Berchidda, Vermentino Variety

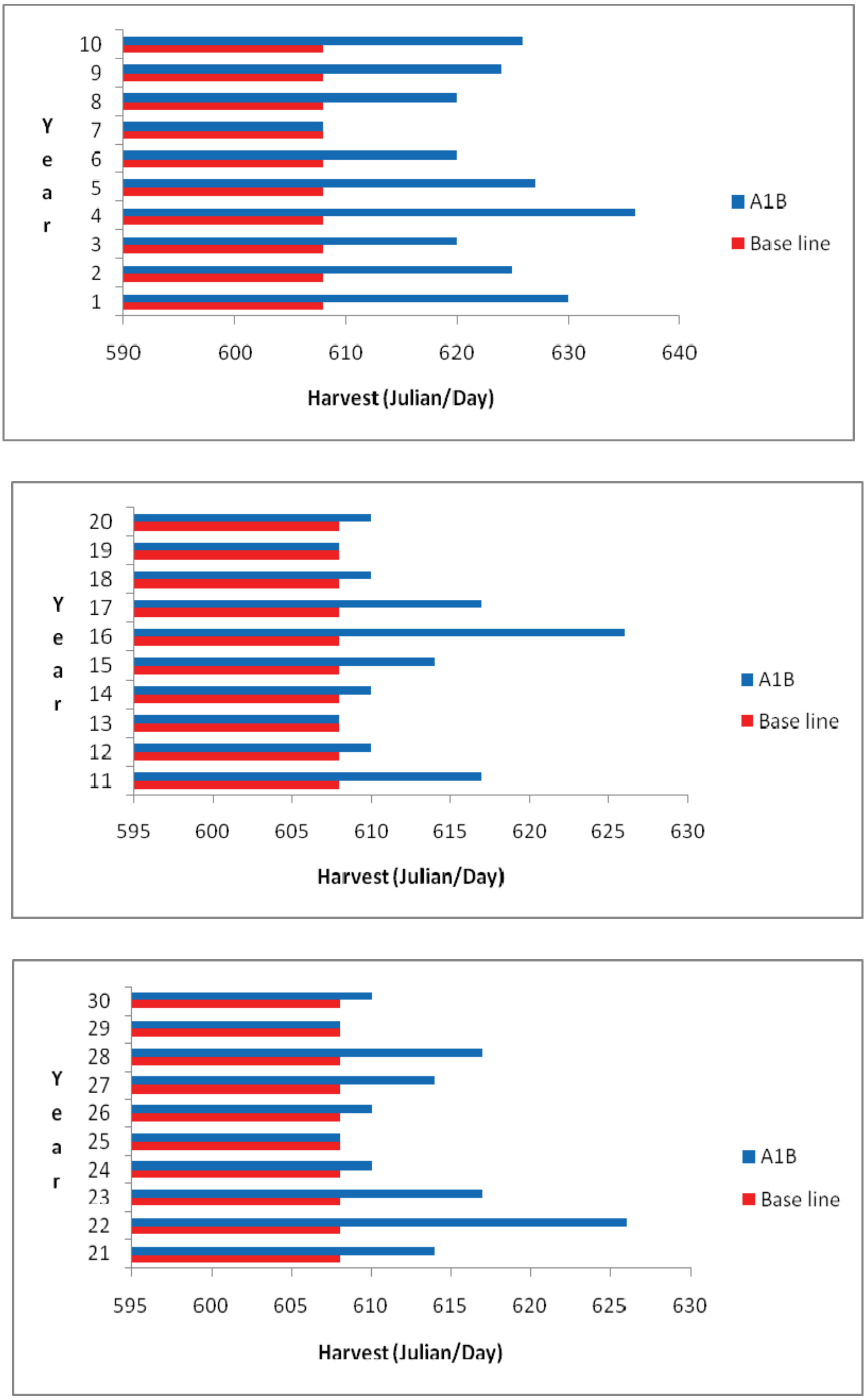


Figure 44 a, b ,c Simulation Harvest stage Variety Vermentino Berchidda

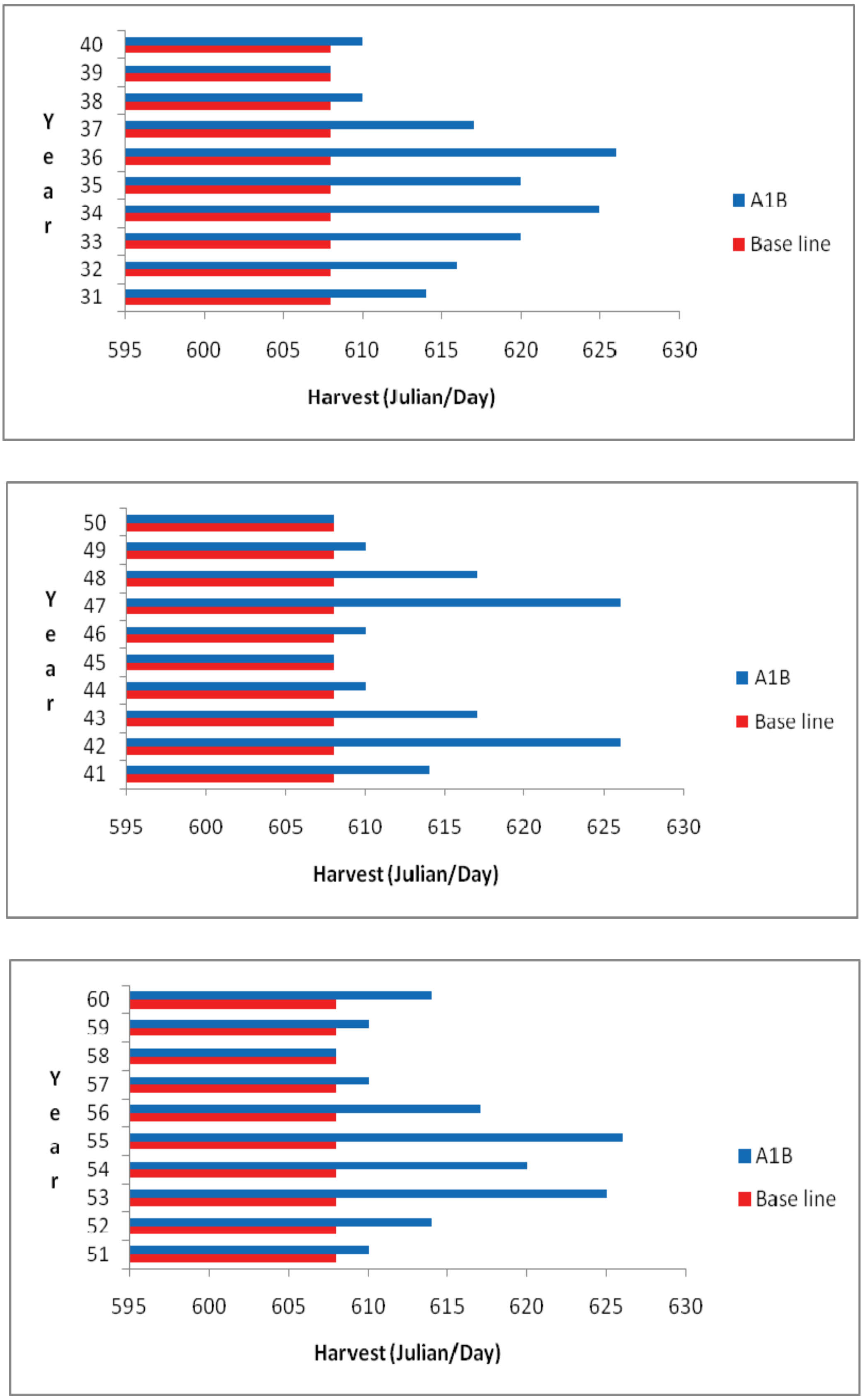


Figure 45 a, b ,c Simulation Harvest stage Variety Vermentino Berchidda

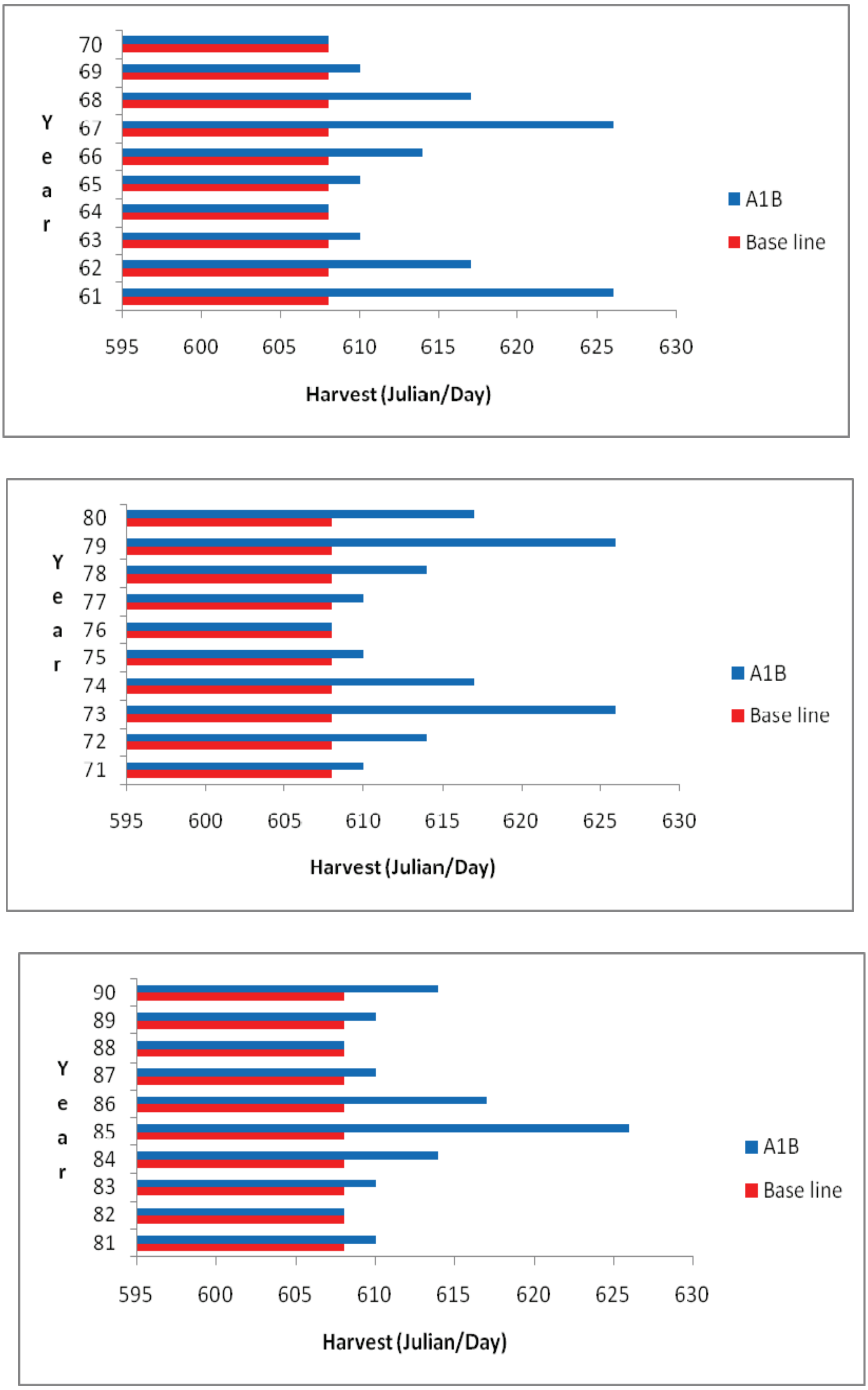
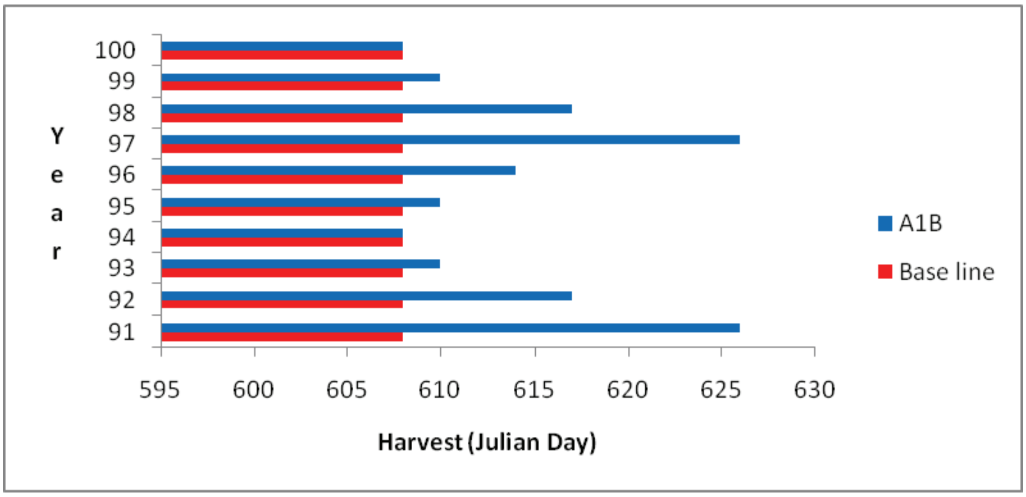


Figure 46a, b ,c Simulation Harvest stage Variety Vermentino Berchidda



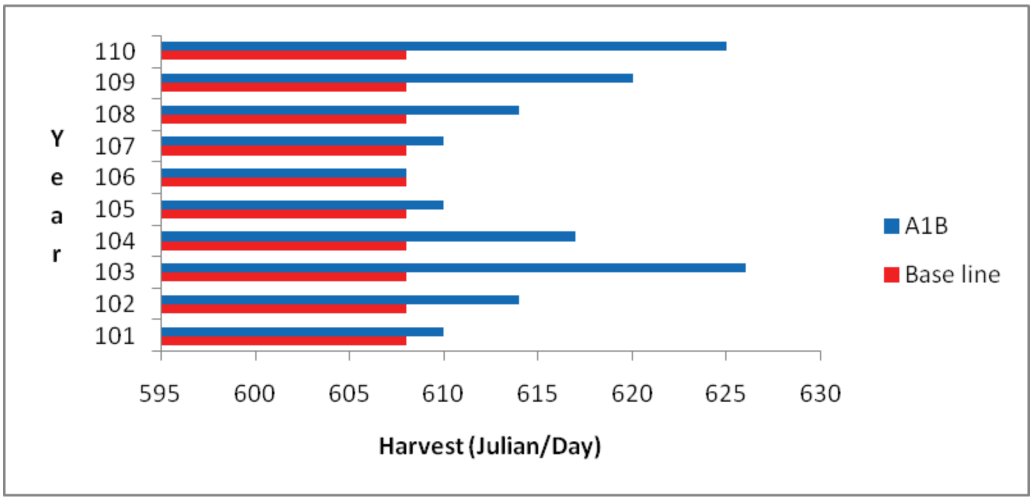


Figure 47 a, b Simulation Harvest stage Variety Vermentino Berchidda

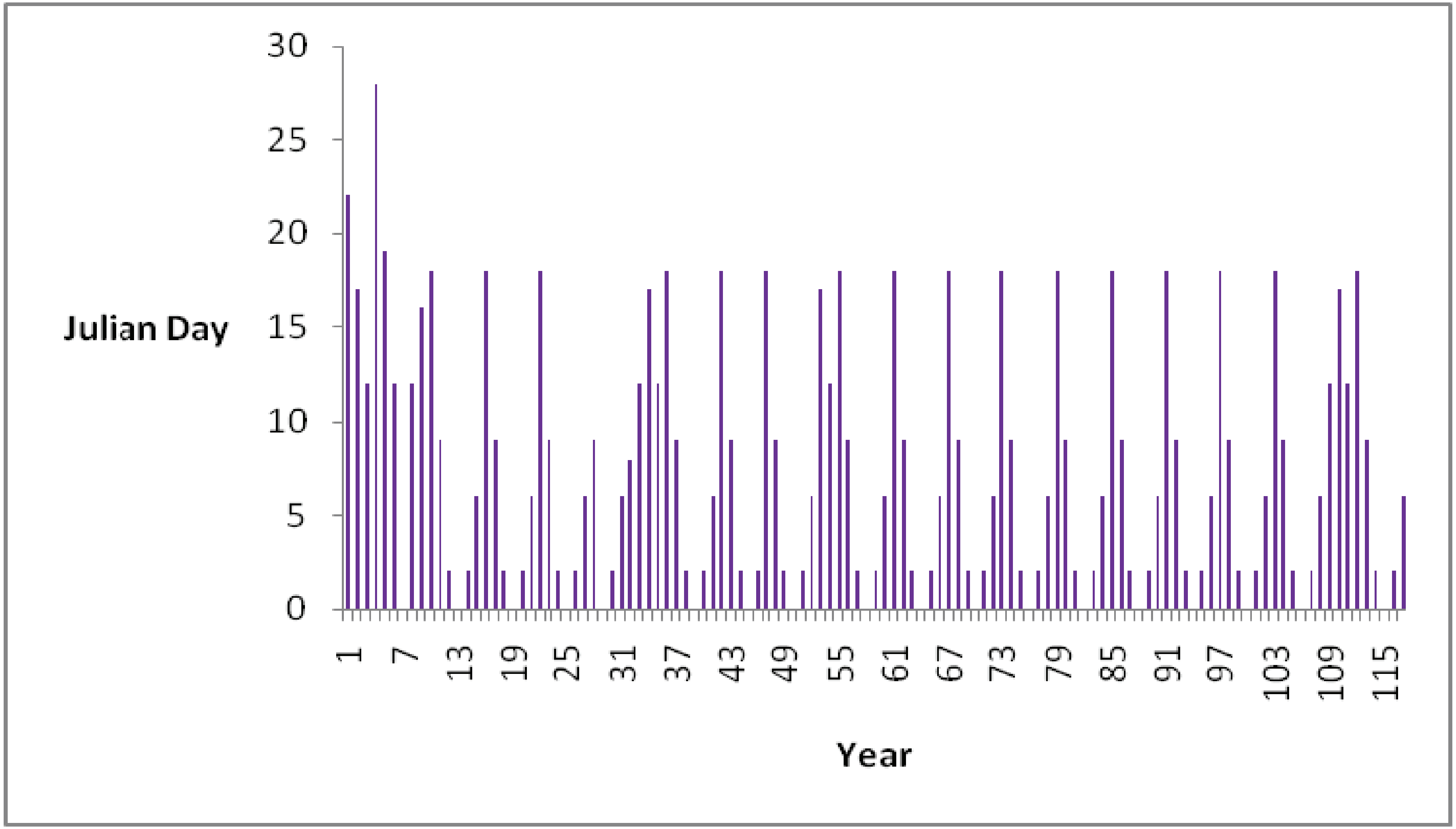


Figure 48 Difference by real value and simulation value Dormancy stage in Berchidda, Vermentino Variety

8. Conclusion

The results of the analysis performed in this study confirm the good performance of the Winstics model applied grapevine variety in Sardinia . The model was successfully calibrated and validated as far as the simulation of phenological stage dormancy, flowering and harvest As major results, the model simulates partially the dormancy stage because the entrance in dormancy coincides with an increase of the way of cis-ABA and this process is very complicated for the model. Major difficulties to obtain a satisfactory calibration of the model, and thus good performance in the validation phase, are related to the size of the datasets available for the study. In fact, the process of crop model application requires, in this case , a collection of large data sets, which must include weather, soil, and crop management data, collected over long time periods. Moreover, data set somehow do not contain the input data essentials for crop model functioning in simulation in grapevine cicle ,, with the obvious limitations that this may cause.

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