

Soil Water Availability and the Renewal of Oak Forest Stands in a Coastal Mediterranean Area: an Experimental Study

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ABSTRACT: this study was aimed to assess the causes of the structural decline in the renewal rate of a pristine oak forest close to Rome (central Italy) by analyzing long-term measurements of the water budget in open and fenced areas. Despite dry climate conditions in the area, long-term soil moisture measurements at 100 cm soil depth indicated that an enough large amount of water is available to oaks during the whole year. Moreover, while trees did not suffer from water deficit during summer, they may experience root asphyxia during rainy years. The analysis of the water budget clarified that, even during exceptionally-dry years, oak renewal was not limited by dry climate conditions. Instead, overgrazing due to the high demographic pressure determined by wild boars which eat almost exclusively oak acorns and deer which eat the leaf of young plants was one of the most important factors affecting oak renewal.

Key words: Oakwood, Tree regeneration, Water budget, Soil moisture, Mediterranean region, Italy

INTRODUCTION

The key to sustaining forests is successfully renewing all their elements after disturbance, across landscapes and through time. In the Mediterranean basin, a region characterized by long episodes of droughts, extreme climatic events, a generally low rainfall rate coupled with fragile soils susceptible to degradation processes (e.g. erosion, salinization, pollution, sealing) and human pressure due to the continuous development of both scattered and compact urban settlements, a large set of disturbance factors can be identified threatening nature forests (Juarez-Lopez *et al.*, 2008; Montserrat-Marti *et al.*, 2009; Bobiec *et al.*, 2011). Especially mesophilous oak forests adapted to dry lands constitute an important component of the Mediterranean rural landscape but are progressively threatened by climate change, soil degradation and human pressure due to forest fires and overgrazing (Drunaski and Struve, 2007). The understanding of the relationships among certain elements of forest communities in stands and forests of different ages, species compositions, and disturbance history and patterns is particularly needed in fragile and peculiar landscapes, like the Mediterranean mesophilous oak forest, undergoing increasing biotic and abiotic stresses (Campos *et al.*, 2007). By identifying the factors

that control regeneration and renewal of forest communities and the responses of these communities to disturbance, specific tools can be provided to forest managers to ensure diverse new forests, for a variety of management objectives (Hanique, 1991).

In Italy, the Presidential Estate of Castelporziano (thirty kilometers far away from Rome) represents a good example of the pristine un-fragmented and biodiversity-rich oak forest stands covering in Tyrrhenian coastal rim from Tuscany to Campania (Manes *et al.*, 1997). Castelporziano forest is an important area for the conservation of high-quality relict mesophilous forests developing on dry climate along the coasts of central Italy and acts as a barrier to contain Rome's expansion. In the last year a progressive decline in the oak renewal rate was observed in the area possibly threatening the ecosystem functioning and the ecological integrity of this typical Mediterranean landscape (Moretti *et al.*, 2006). This decline was initially attributed to the worsening climatic conditions (low precipitation and increased plant evapotranspiration). In order to inform measures preserving the ecological integrity of forest stands in this fragile ecosystem, a monitoring campaign was launched to assess over

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time changes in climate and soil possibly affecting the relict woodland ecosystem (Salvati *et al.*, 2012). The present study was aimed at verifying if the lack of natural oak renewal was caused by variations in the climatic regime insisting in Castelporziano area or by external causes including overgrazing by livestock and wild mammals.

MATERIALS & METHODS

Castelporziano estate is a protected area, mainly composed by pristine woodlands located on the fringe of Rome along the coastal rim of central Italy (Moretti *et al.*, 2014). The total protected area covers nearly 60 km² with mixed uses of land and the prevalence of pinewoods (*Pinus pinea*) and oakwoods (*Quercus frainetto* and *Quercus cerris*). Due to the closeness to the urban area of Rome (more than 3 million inhabitants), Castelporziano estate represents a key area in the network of protected land around the city with special regard to biodiversity conservation, soil preservation and containment of urban expansion (Tombolini and Salvati, 2014). The analysis of thermometric and rainfall trends in the area indicates an opposite pattern observed in the last thirty years: average temperature increases by nearly 1.5 C° while precipitation declined by 80 mm although with a high variability over time. The methodological approach to the study of the natural renewal of mature oak forest stands was based on the identification of biotic and abiotic stresses (Fares *et al.*, 2009) including the action exerted by wild animals (e.g. wild boars and deer occurring at high densities in the area) that performs a destructive action on young oak plants and consume acorns. A permanent monitoring of climatic and soil variables was carried out by investigating the inter-annual water availability regime within free and fenced areas. The study of the soil water balance in a certain area assess the water status of the soil layer which largely affects the ability of young oaks to absorb water. The permanent monitoring of water availability in the soil also allows to determine the intensity and severity of drought episodes, the duration of which may compromise the growth of the young seedlings (Schween *et al.*, 1997). The potential evapotranspiration of plants and the variation in the water balance at the local scale was studied through empirical and computational approaches, using both sensors measuring soil moisture directly and continuously over time and models estimating water availability in the soil from daily meteorological data of rainfall and temperature (Salvati *et al.*, 2012).

A network of agro-climatic stations equipped with sensors for traditional meteorological measures (Brock and Richardson, 2001) was installed throughout the woodland since the mid-1990s. In a specific location ('Campo di Rota', nearly 20 km far away from Rome) where the experiment was carried out, two adjacent research plots (200 m • 200m) were developed (Moretti *et al.*, 2006), the one open to wild animals and the other one fenced and remotely controlled. The agro-climatic station was installed under the wood canopy in the fenced plot in order to measure micro-climatic conditions possibly influencing oak renewal. Precipitation, temperature and relative humidity, solar radiation, leaf wetness and soil moisture at 10, 50, 100 cm deep were measured every hour using a Campbell CR10X gauging station and data-logger (for agrometeorological variables) and Time Domain Reflectometry (TDR) sensors provided by DeltaT Devices Ltd (United Kingdom) for soil moisture. The gauging station was activated on January, 1st, 2005 providing high-quality meteorological time-series. These information are collected and continuously updated into a dedicated database. Data collected from the station placed in Campo di Rota were compared with data recorded from a neighboring station placed in an open field (following WMO installation standards) and estimating the average climate conditions insisting on the woodland (Brunt, 2011). A descriptive analysis of climatic and agro-climatic variables (including soil moisture) was carried out using standard statistics and graphs (Holton and Hakim, 2012). The water balance was determined from soil moisture measured in the surface layer of soil (50 cm depth) which affects the ability to absorb water by oak seedlings. The water supply of the soil was determined using the following formula:

$$RI = (Au \cdot h) / 10$$

Where: RI = water available in the soil (mm), Au = the maximum available water capacity (% volume) calculated from the difference between the maximum water storage in the soil (% volume) and the wilting point determined in the laboratory at 4.2 pF, h = height of the soil layer expressed in cm (Mather, 1978).

RESULTS & DISCUSSION

The meteorological variables collected under the wood canopy ('in the plot' station) compared with the 'open field' station measurements are reported in Fig. 1. The analysis shows the impact of oak trees to intercepting rainfall (reducing rainfall, on average, by 36% in the plot compared to the open field value) and radiative energy (-80%), while air temperatures

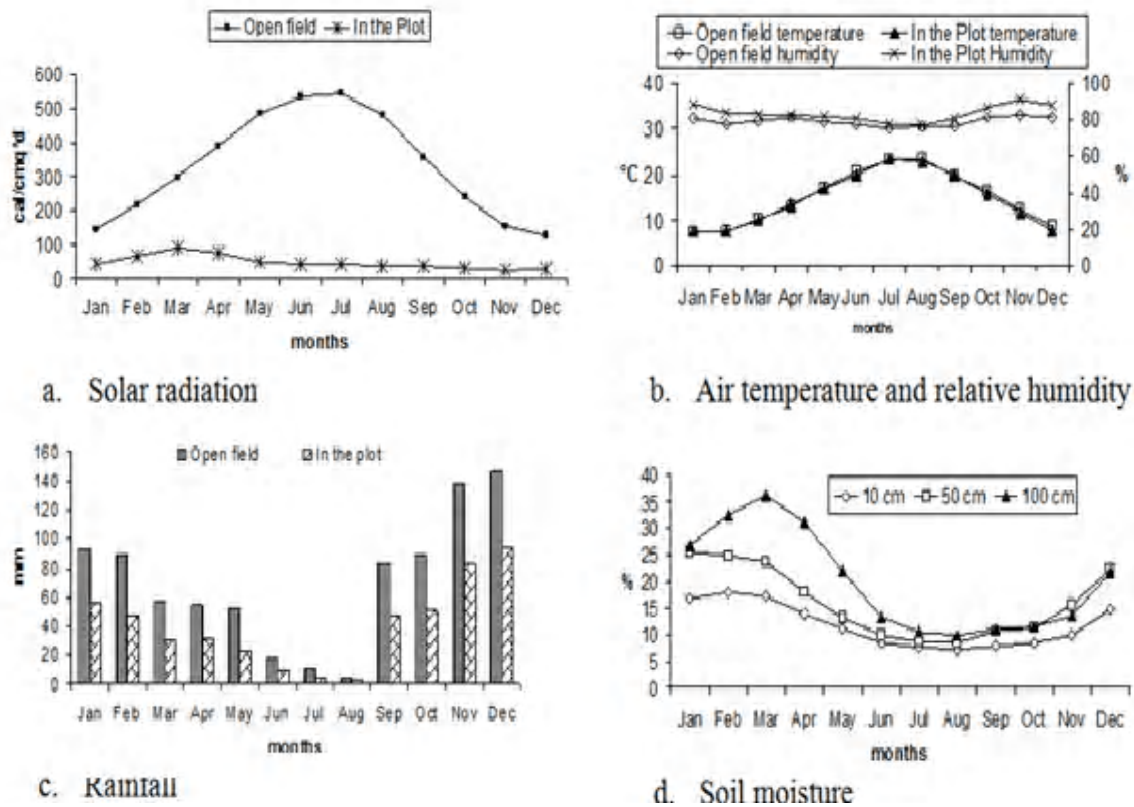


Fig. 1. Selected agro-climatic variables measured between 2005 and 2011 in the investigated area (see methods for details)

show only moderate variations among plots possibly due to the restricted air circulation found under vegetation (Manes *et al.*, 1997). As regards the relative air humidity, the values recorded under the tree canopy are, on average, higher than 10% compared to the values measured in the open field plot. The available water in the soil (Fig. 1d) shows a peculiar trend along the year among the three investigated layers. This could be due to the nature of the first layer (5-10 cm) which is rich in organic matter capable to pick up a relatively high amount of water and to offer resistance to runoff. The pattern observed in the layer up to 50-60 cm was completely different due to its characteristics (mainly sandy and slightly compacted with no resistance to the passage of water, which quickly reaches the deeper layer creating a deposit due to compaction of the sand).

On the year base, precipitation received by soil under the wood canopy ranged between 832 mm in 2010 and 271 mm in 2006, with an average value of

nearly 550 mm. Over seven observation years (2005-2011), more than 15% of the total precipitation was dispersed as a surplus percolating in the underlying soil layers while less than 85% remained in the ground layer in a form available to young seedlings. According to the water balance estimates, evapotranspiration averaged 512 mm/year (representing 66% of the water received by the soil). Interestingly, this value differed from the estimation of reference evapotranspiration (770 mm/year on average) based on thermometric data using Thornthwaite's formula (Thornthwaite and Mather, 1957). This difference may be due to different aspects: i) solar radiation measured under canopy is equal to about 30% of what observed above crown; ii) the highest rate of relative air humidity observed below the vegetation, iii) the rainfall interception by the leaf apparatus which tends to concentrate the water to the ground at certain points. Fig. 2 illustrates the observed time pattern (2005-2011) of three agro-meteorological variables (precipitation, surplus and water content of the soil). Despite the irregular rainfall distribution

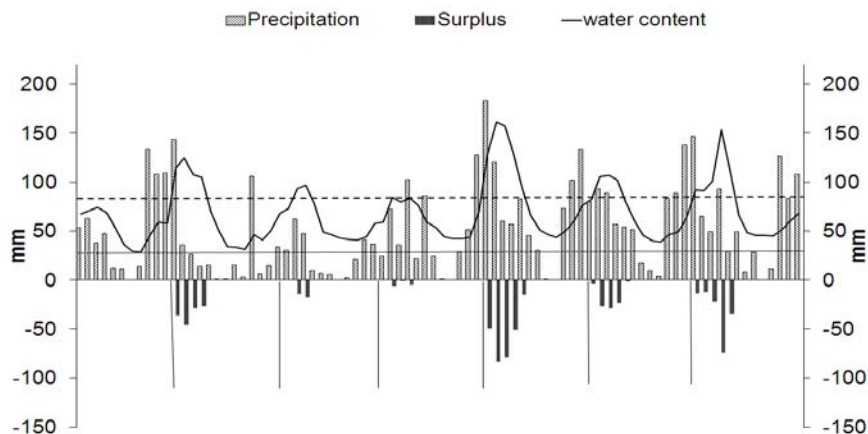


Fig. 2. Rainfall distribution along the investigated years measured in the plot station of ‘Campo di Rota’ (surplus and water content in the soil are reported together with the maximum water storage capacity (c.c.) and wilting point (p.a.) of the soil)



Fig. 3. Germination of acorns in the fenced area surrounding the meteorological station of ‘Campo di Rota’ (left) and in the adjacent open control plot in Castelporziano (the photograph was taken in the same day)

along the year, the water available in the soil is always higher than the wilting point, indicating that a sufficiently high water quantity is available to seedlings even in the driest summer periods (e.g. the 2005-2008 time interval as an example of exceptionally dry climate characteristics observed for four consecutive years).

The experimental analysis of soil characteristics in the investigated plot indicated that a compact and poorly permeable soil layer exists approximately at one meter depth, which allows creating a quite permanent surface water layer mainly extending from 50 to 100 cm depth. This water storage is used by vegetation during

periods of water scarcity in both spring and summer. Annual repeated measures in the period of maximum aridity (observed around July, 20) indicate the presence of 15% relative humidity in the soil and may explain why plants with a root system exploring soils at a certain depth (> 70 cm) are unlikely to suffer from climatic drought and soil aridity even during the most dry summer months in the study area (Manes, 1997). By a photographic analysis (example provided in Fig. 3) developed at the same day in each year from 2005 to 2011 in the fenced plot of ‘Campo di Rota’ and in the surrounding open plot, it was clear that the growth of young oaks was partially prevented by animal grazing,

especially wild boars, reaching unsustainable densities in Castelporziano estate due to the lack of natural predators.

CONCLUSION

Despite the restricted period of investigation (seven years), the present study indicates that climatic conditions and soil characteristics in the studied area may assure a normal oak renewal rate even in the driest years (Salvati *et al.*, 2012). To the contrary, renewal could be limited by short periods of intense precipitation determining the complete saturation of the water table and, possibly, triggering root asphyxia altering (or preventing) the normal vegetation renewal. Taken as an original contribution to vegetation studies in Mediterranean fragile ecosystems, soil moisture indicates the presence of a permanent water layer especially useful for plants in dry summer and possibly provoking occasional phenomena of root asphyxia due to the accumulation of free water for long periods in the winter (Moretti *et al.*, 2006). As testified by the photographic analysis, grazing is an important factor regulating oak renewal rate compared to climate and water availability in the soil. In ecologically fragile coastal Mediterranean ecosystems, the rapid increase of animal density (especially wild ungulates) due to the absence of natural predators may be dangerous for the ecosystem functioning and should be regulated using population control strategies. Taken as a measure for the sustainable land management of ecologically fragile Mediterranean environments, the control of dense mammal populations may be crucial in the maintenance of high-quality protected areas and green belts conserving pristine forest stands around the major urban centers.

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