Forest Ecology and Management 389 (2017) 158–166

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

On the use of stable carbon isotopes to detect the physiological impact of forest management: The case of Mediterranean coppice woodland

Giovanni Di Matteo [a,*], Pierfrancesco Nardi [a], Gianfranco Fabbio [b]

[a] Council for Agricultural Research and Economics, Research Unit for Climatology and Meteorology applied to Agriculture (CREA-CMA), I-00186 Rome, Italy
[b] Council for Agricultural Research and Economics, Forestry Research Centre (CREA-SEL), I-52100 Arezzo, Italy

A R T I C L E I N F O

Article history:
Received 13 September 2016
Received in revised form 23 December 2016
Accepted 26 December 2016

Keywords:
Stable carbon isotopes
Forest stand density reduction
Meta-analysis
Coppiced stands
Released trees
Retrospective literature-analysis
Water-use efficiency
Mediterranean forest ecosystems

A B S T R A C T

This paper reviews the use of stable carbon isotope analysis to monitor the results of forest ecosystems management. Special focus is given to Mediterranean coppice woodland. We used this due to the high sensitivity and spatial-temporal resolution of isotope analysis coupled with the complex attributes arising from the composite management options now used in the coppice system. A meta-analysis based on 1428 publications from 1996 to 2015 revealed three distinct clusters of related terms in research carried out to answer questions linked to the management of forests and terrestrial ecosystems namely, forest soil and forest carbon sequestration, the anthropogenic impact on plant and animal communities, and the physiological response to silvicultural practices. Much physiological research on the study of the impact of silvicultural practices on released trees has been carried out. A retrospective literature-analysis gave rise to three different functional hypotheses. The first hypothesis is that carbon isotope composition decreases after thinning, mainly due to the rapid increase in soil moisture availability and decreased competition for water and nutrients, i.e. decreasing intrinsic water-use efficiency (measured as the ratio of CO_2 assimilation to stomatal conductance, A/gs). Conversely, the second hypothesis is that $\delta^{13}C$ values increase due to the higher increase in *A* over *gs*, especially observed in sites where water is not a limiting factor. The third hypothesis was that there was no variation in $\delta^{13}C$ due to an equal and parallel increase in both *A* and *gs*. We found that the physiology of Mediterranean coppice stands is consistent with the first hypothesis, in accordance with other analyses already performed on permanent research monitoring plots. The main finding however is that stable isotope analysis does not overlap with any of the other investigation tools in use, but actually fills a gap by providing further, effective insights into the ongoing functioning processes. Of course monitoring these processes will take on increasing importance, especially in view of the climate shift in progress.

Contents

* Corresponding author at: Council for Agricultural Research and Economics, Research Unit for Climatology and Meteorology applied to Agriculture (CREA-CMA), Forest Acclimation lab, Via della Navicella 2-4, I-00186 Rome, Italy.

E-mail address: giovanni.dimatteo@crea.gov.it (G. Di Matteo).

http://dx.doi.org/10.1016/j.foreco.2016.12.030
0378-1127/

1. Introduction

A portion of broadleaved forests managed under the coppice system was exploited for millennia as renewable resource, providing firewood and charcoal for the daily use of domestic heating and cooking food all over Europe (Piussi, 2015). Following the first industrial revolution, coppiced forests were again the most widespread and common energy source, especially in places where coal was less available like the Mediterranean countries (Agnoletti, 2003). As a result, the forest landscape in five EU countries is still characterized by coppice system features, in an area covering about 8.5 million hectares (Morandini, 1994; Scarascia-Mugnozza et al., 2000; UN/ECE-FAO, 2000). The coppice system, based on the natural ability of broadleaved tree species to regenerate from the stool after clear-cutting (i.e., coppicing), was usually managed with short rotation cycles (10–15 to 20–25 years), in accordance with the site index, the experienced growth pattern, and the ecological traits of tree species concerned (Serrada et al., 1998a; Ciancio and Nocentini, 2002; Montes et al., 2004; Piussi, 2006; Fabbio, 2015).

There was a significant reduction in the use of the coppice system in the mid-20th century (Terradas, 1999; Agnoletti, 2002; Fonti et al., 2006; Burgi, 2015), when the use of new energy sources based on oil and gas progressively replaced wood and charcoal for both domestic and industrial uses. The concurrent migration of a large part of the rural population towards industrial urban areas and the end of traditional farming activities led to the abrupt abandonment of a portion of the coppice forests that had been regularly and intensively managed over centuries; this resulted in the creation of excessively dense forest stands over large areas (Amorini and Fabbio, 1990, 1992, 1994; Gracia et al., 1999; Terradas, 1999). The coppice woodlands were therefore exposed to high fire risk, poor aesthetics, low biodiversity and arrested regeneration (Palmberg-Lerche, 2001; Teissier Du Cros, 2001; Mairota et al., 2014; Kirby, 2015; Mullerova et al., 2015a).

The proactive option was to convert the outgrown, overstocked coppices back to high forest. As a rule, the high-forest type is considered more valuable because it provides higher-quality wood, improved protection against natural hazards such as snow avalanches or landslides, the capability of enhancing societal and ecosystem services-benefits, more attractive space for recreation and more lasting types of biodiversity (Chatziphilippidis and Grigoriadis, 1998; Cutini, 2000; Cutini and Hajny , 2006; Kopecky et al., 2013; Bruckman et al., 2016). This technique is fully based on thinning.

Reducing forest stand density by silvicultural practices is globally recognized as an approach to restore ecosystem resilience and lower wildfire risks (McDowell et al., 2006; Allen et al., 2010). Silvicultural practices may also be used for the ecological restoration of old-growth forests to trigger the regeneration phase (Covington and Moore, 1994; Mast et al., 1999), or a more proactive approach may be applied to younger forests (Skov et al., 2004). This topic is of special concern to coppice forests in the Mediterranean area where thinning is considered to be a management tool that (i) avoids heavy intra-specific competition and increases tree resistance to drought stress (Ducrey and Toth, 1992; Gracia et al., 1999); (ii) contributes to the improvement of tree water status and productivity in water-limited systems (Canellas et al., 2004; Moreno et al., 2007); (iii) addresses climate change mitigation strategy in Mediterranean forest types (Serrada et al., 1998b; Moreno and Cubera, 2008; Cotillas et al., 2009). The detrimental effect of overstocking on tree vitality, growth and survival is also highlighted (Amorini and Fabbio, 1994; Bréda et al., 1995; Terradas, 1999; Barton and Montagu, 2006). This research gap should be investigated for two reasons: firstly, in view of changing climate scenarios, it could contribute further elements of concern as drought will be a relevant issue in forestry (IPCC, 2014). It seems, therefore, reasonable to carry out thinning in coppices to increase soil moisture (Cotillas et al., 2009). In this context, the Mediterranean area hosts the most vulnerable biomes to the drought-heat shift in progress because it is in the transition zone between arid and humid regions (Sabaté et al., 2002; Ogaya et al., 2003; Peñuelas et al., 2004; Bréda et al., 2006; Hernandez-Santana et al., 2009; IPCC, 2014; Gratani et al., 2016). Secondly, in relation to the environmentally induced changes faced by released trees in the coppice turn-over or the transition from coppices to high-forest types. Here, particular attention was given to the relationship between the carbon gain and water loss in order to highlight the role of the functional "intrinsic water-use efficiency" (iWUE) trait. The iWUE may be indirectly estimated via the stable carbon isotope analyses in phytomass for this purpose. Indeed, the ratio of fixed carbon to lost water is controlled by both stomatal conductance and photosynthetic capacity. Likewise, carbon isotope composition ($\delta^{13}C$, the deviation from the unit of the ratio of carbon isotope ratios of a sample and of the standard), of photoassimilates is controlled by stomatal conductance and photosynthetic capacity (Farquhar et al., 1982; Ehleringer, 1993). Indeed, iWUE is defined as:

$$iWUE = A/gs = c_a[1 - (c_i/c_a)](0.625) \quad (1)$$

where A is the rate of CO_2 assimilation, gs is stomatal conductance of water vapor and c_i and c_a are the intercellular and atmospheric CO_2 concentrations respectively. A detailed experimental comparison of three different methods to investigate WUE is in Ripullone et al. (2004).

The study aims are twofold. We firstly performed a bibliometric analysis to answer the following questions: (i) how the topic addressing the use of stable carbon isotopes in forest management research is structured in terms of the most commonly occurring research terms and how they are intra-related? (ii) did $\delta^{13}C$ analysis have an impact on forest management issues? (iii) if yes, which were the most relevant research in terms of co-cited publications? Furthermore, based on the bibliometric analysis outcomes, we conducted a retrospective literature-analysis to find out which functional research hypotheses could explain the carbon isotope responses after forest stand density reduction, also in relation to the complementary outcomes from the mensurational surveys in coppice forests.

2. Mapping using a science mapping approach: most commonly occurring and co-cited research

2.1. Data gathering

A bibliometric approach was used here to investigate global research trends of stable carbon isotope technique applied to silvicultural research between 1996 and 2015. All bibliographic records in English were retrieved from the Elsevier's Scopus database using the following keywords in the title, abstract and keywords fields: carbon PRE/1 isotop* AND silvicultur* OR carbon PRE/1 isotop* AND forest management OR carbon PRE/1 isotop* AND thinning OR carbon PRE/1 isotop* AND wood harvest* OR carbon PRE/1 isotop* AND coppicing OR carbon PRE/1 isotop* AND coppice cut OR carbon PRE/1 isotop* AND high forest OR carbon PRE/1 isotop* AND mediterranean coppices OR carbon PRE/1 isotop* AND coppice stand* OR carbon PRE/1 isotop* AND coppice woodland OR carbon PRE/1 isotop* AND canopy OR carbon PRE/1 isotop* AND forest cover OR carbon PRE/1 isotop* AND competition OR carbon PRE/1 isotop* AND heavy thinning OR carbon PRE/1 isotop* AND adaptive management AND NOT marine sea AND NOT ocean sea.