European Journal of Agronomy 94 (2018) 36–45

Contents lists available at ScienceDirect

European Journal of Agronomy

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

Wheat performance with subclover living mulch in different agro-environmental conditions depends on crop management

E. Radicetti[a,*], J.P. Baresel[b], E.J. El-Haddoury[c,e], M.R. Finckh[d], R. Mancinelli[a], J.H. Schmidt[d], I. Thami Alami[e], S.M. Udupa[c], M.G.A. van der Heijden[f], R. Wittwer[f], E. Campiglia[a]

[a] Department of Agricultural and Forestry Sciences, Tuscia University, Via S. Camillo de Lellis snc, 01100, Viterbo, Italy
[b] Department of Plant Science, Technische Universität München, Emil-Rahmann-Str. 2, 85354, Freising, Germany
[c] International Center for Agricultural Research in the Dry Areas (ICARDA), Rue Hafiane Cherkaoui, 10112, Rabat, Morocco
[d] Organic Agricultural Sciences – Ecological Plant Protection Group, University of Kassel, Nordbahnhofstraße 1a, 37213, Witzenhausen, Germany
[e] Institut National de la Recherche Agronomique (INRA), Avennue de la Victoire, BP 415, Rabat, Morocco
[f] Agroscope, Research division Agroecology and Environment, Plant-Soil-Interactions, Reckenholzstrasse 191, 8046, Zürich, Switzerland

A R T I C L E I N F O

Keywords:
Cereal–legume intercropping
Wheat grain yield
Weeds
Cropping system
Nitrogen fertilization

A B S T R A C T

Intercropping has been proposed as a useful strategy for reducing external inputs in cereal-based cropping systems, while maintaining adequate crop yield. Intercropping of wheat and subclover, implemented as living mulch, is recommended, but there is limited experimental proof for its suitability in different environments. The main objective of this study was to provide an overview and evaluation of wheat-subclover intercropping under different agro-environmental conditions. Coordinated field experiments were conducted over a two-year period in six sites located in four agro-environmental zones [Atlantic North (Neu-Eichenberg, Germany), Continental (Freising, Germany – Tänikon, Switzerland), Mediterranean North (Viterbo, Italy), Mediterranean South (Sidi Alla Tazi and Sidi El Aidi, Morocco)]. Wheat–subclover intercropping was compared with a pure wheat. Additionally, other treatments adopted in specific sites were: soil tillage (conventional and minimum tillage); fertilization input (high and low level); cropping system (conventional and organic). The measurements recorded were: soil coverage, wheat and subclover phenological stages, wheat grain yield and yield components, subclover and weed biomass. The data of each site were analyzed separately and were also used for a meta-analysis to obtain an overview of how pedo-climatic conditions affect the interactions of subclover living mulch with wheat and weeds. Subclover biomass was the highest at Viterbo (228 g m^{-2} of DM) proving its adaptability to the climatic conditions of Mediterranean North characterized by mild temperature and abundant rainfall. Wheat-subclover intercropping reduced weed infestation (from 22 to 75% in Mediterranean South and North, respectively). Intercropping also resulted in grain yield losses compared to pure wheat in Mediterranean North and Continental (on average −16 and −14%, respectively), probably because of the competition between the intercropped species. In the agro-environmental zones where subclover growth was limited by cold temperatures (Atlantic North) or dry conditions (Mediterranean South), hardly any grain yield reduction of intercropped wheat was observed. Subclover biomass and wheat grain yield were also negatively correlated and yield reductions were generally due to a reduced number of fertile spikes. The yield gap between intercropped and pure wheat was reduced when: (i) there was a proper spatial arrangement of subclover and wheat; (ii) the amount of added mineral nitrogen fertilizer was reduced, while compost application did not influence the cropping systems. The use of subclover living mulch in wheat appears to be most suitable for low input systems. Future research should focus on the development of appropriate crop management practices for intercropping in order to avoid wheat yield loss.

1. Introduction

The simplification of cropping systems over the last decades has been accompanied worldwide by an increased use of chemical fertilizers, pesticides, and heavier mechanization. These practices have produced higher crop yields, yet they have simultaneously contributed to an increase of environmental issues, such as soil erosion and water contamination (Nazari et al., 2015). Consequently, it is necessary to

* Corresponding author.
E-mail address: radicetti@unitus.it (E. Radicetti).

https://doi.org/10.1016/j.eja.2018.01.011
Received 26 February 2017; Received in revised form 15 January 2018; Accepted 17 January 2018

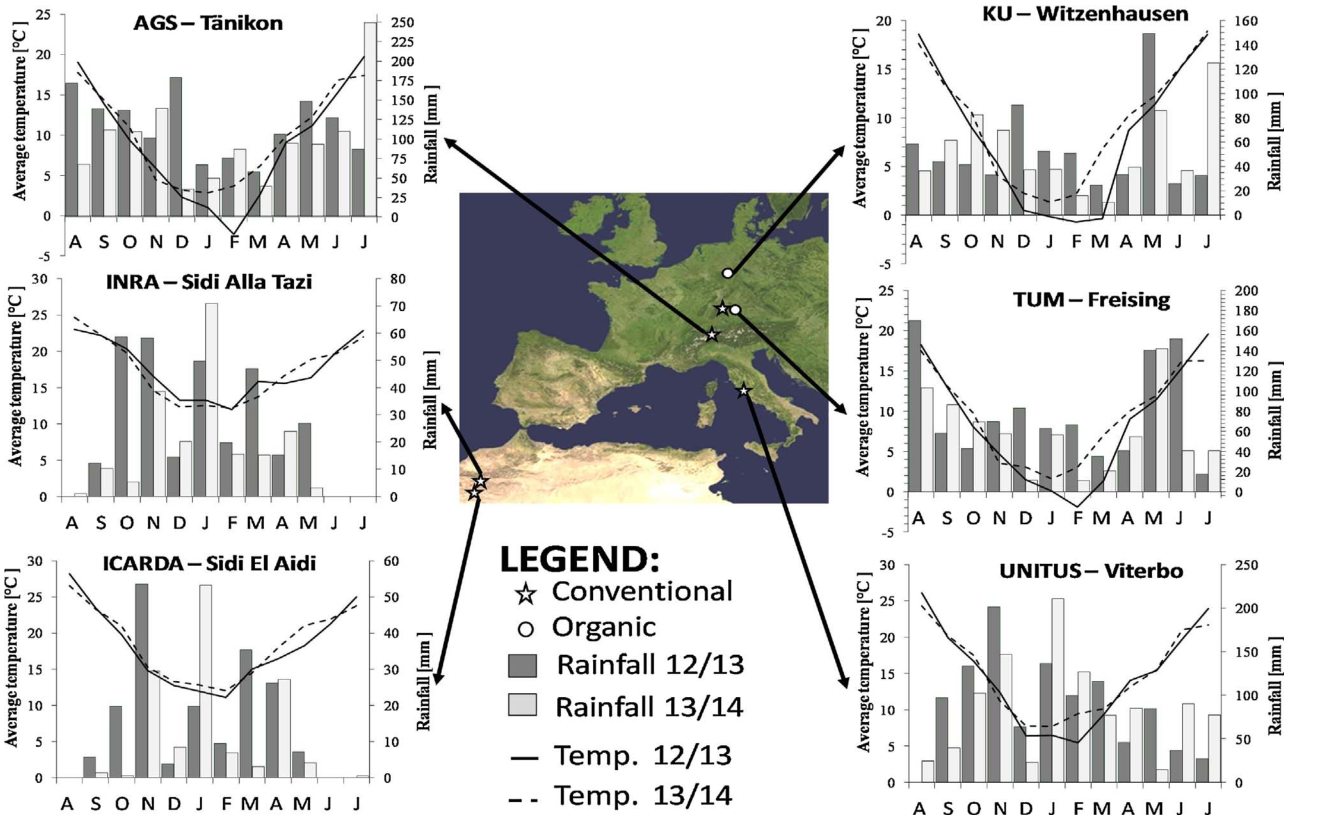

Fig. 1. Weather conditions (monthly average of the daily temperatures and monthly total amount of rainfall) during the field experiments in 2012/2013 and 2013/2014 experimental years at the sites described in Table 1. Only one climate chart provided for the two sites at TUM as they were located near each other.

design innovative cropping systems for greater nutrient use efficiency and resource conservation, which are more sustainable from an environmental point of view. Importantly, agro-ecosystems should be more diversified by increasing the number of species grown and using more leguminous crops (Bedoussac and Justes, 2011) or including cover crops (Wittwer et al., 2017). The adoption of intercropping could be a useful strategy for reducing external inputs while maintaining adequate levels of crop yield (Tilman et al., 2002).

Intercropping is defined as the co-cultivation of two or more species in the same space and for a significant part of their growing season, without necessarily being sown and harvested together. An established cover crop intercropped and grown simultaneously with an annual cash crop is known as living mulch (Hartwig and Ammon, 2002). The benefits of using living mulch as cropping systems include a reduction of water runoff and soil erosion, and the suppression of weed germination and weed establishment through competition for limited resources and/or the production of allelochemicals (Costanzo and Barberi, 2014). However, competition with the main crop for limited resources such as water, light and nutrients should be minimal (Hiltbrunner et al., 2007a). This can be achieved when the intercropped species occupy different niches in time and space (Malézieux et al., 2009) using complementary resources (Bedoussac and Justes, 2010). Using a legume living mulch in an intercropped cereal system increases biodiversity and could reduce the need of external inputs such as nitrogen (N) fertilizers, herbicides and pesticides, thus improving the sustainability of the cropping system (Bedoussac and Justes, 2010). The adoption of a legume living mulch, as an environmental-friendly strategy, could be performed in different ways. One of these is the undersowing of forage legume cover crop in growing winter wheat, also called as relay intercropping. Despite a positive effect of enriching the soil-crop system with nitrogen and weed control (Amossé et al., 2013a), relay intercropping systems could cause a competition for resources determining a low wheat performances depending on soil, climate conditions and wheat development (Amossé et al., 2013b; Bergkvist et al., 2011). Another possible solution could be the contemporary sowing of the winter wheat with a self-reseeding legume, such as subclover (*Trifolium subterraneum* L.). Subclover is an annual legume with prostrate and non-rooting stems that adapts well to mild winters during which its vegetative growth and part of the reproductive phenophase occurs. Seeds buried naturally in the soil in the spring remain dormant until high summer temperatures drop and rainfall or irrigation occurs in the autumn. Since the plants die due to the increase in temperatures in late spring, it is not necessary to suppress subclover mechanically or chemically. Therefore, due to its particular life-cycle subclover seems to meet the requirements of a successful living mulch during the cereal crop cycle and an efficient dead mulch after wheat grain harvest during the summer period (Campiglia et al., 2014). Furthermore, its natural re-establishment ensures a new legume cover crop free of charge in the following period which can be used as cover crop or dead mulch for cultivating vegetable crops, such as tomato, pepper and eggplant under no-tillage conditions (Campiglia et al., 2014, 2010). Therefore, using subclover as living mulch in wheat appears to be a suitable option for reducing the external inputs and costs of agricultural production. Moreover, living mulches are compatible with both organic and conservation agricultural systems (Canali et al., 2017). However, as yet few studies have evaluated the effects of subclover–wheat intercropping systems. Hence, it is necessary to determine if the wheat-subclover intercropping system works in selected agro-environmental conditions to provide benefits, before it can be recommended as an agricultural practice. We hypothesized that using subclover as living mulch in a wheat–subclover intercropping systems is feasible in several agro-environmental conditions and could be an environment-friendly management practice that has beneficial effects on the agro-ecosystem. The main objective of this study was to provide an overview and evaluation of subclover used as living mulch in wheat under a wide range of pedo-climatic conditions spanning from the Atlantic North to the