A new agro-ecosystem for a resilient fruit production

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Abstract

Modern conventional fruit production often involves mono-varietal orchard plots, with inter-row management using traditional approaches, such as tillage or permanent grass cover, which are characterized by low biodiversity and limited provision of ecosystem services. Along with climate change, small farm holdings (<5 ha), which account for about 50% of the total EU farms, face a risk of high economic instability. The project entitled: "Diversified orchards for resilient and sustainable farming systems" (DREAM) aims to test a new agroecosystem concept, adapted to local environmental, economic, and social conditions in three fruit-producing areas: Italy and Morocco for apple and Spain for pear. The DREAM system consists of a multi-varietal orchard, with the interrow managed with a selected mixture of cover crops. In 2023, the physiological pattern of the DREAM apple orchard located in Italy was tested along the growing season and compared to that of a commercial 'Pink Lady' orchard. Although still not in production, the 9 cultivars present in the DREAM system showed high variability in seasonal shoot growth, while no differences were found for stem and leaf water potential as well as for leaf gas exchanges, meaning that the cover crops did not penalize the physiological performance of the young trees. Future research will be conducted to monitor the plant responses under deficit irrigation conditions and their repercussions on fruit quality.

Keywords: apple, plant physiology, cover crops, agroecosystem, climate change

INTRODUCTION

Apple is one of the main fruit crops cultivated worldwide, primarily produced in Asia (approximately 66% of the total production), followed by Europe and the Americas (FAO, 2022). In the last few decades, apple orchards have undergone several changes toward increasingly intensive cultivation. Modern conventional fruit production often involves mono-varietal orchard plots, with inter-row management using traditional approaches, such as tillage or permanent grass cover. In addition, to increase fruit production, agrochemical inputs such as fertilizers, hormones, and pesticides are applied several times throughout the year. This management, however, has a negative long-term impact on the agroecosystem, leading to a decrease in biodiversity and the provision of ecosystem services (Cunningham et al., 2013). The effects of climate change are further exacerbating this situation, damaging part or even the entirety of the production in one or more years during the orchard's life cycle. For example, a study on apple production in Europe has demonstrated that the significant fluctuations in production volumes from 2010 to the present, with variations ranging from 17 to 24%, are primarily attributed to extremely variable climatic conditions. An example is the 2017 season, during which spring frosts caused damage to apple blossoms throughout Europe, resulting in exceptionally low production, followed by a recovery in 2018 (Muder et al., 2022). In addition, the low genetic diversity often found in conventional orchards can make the entire system susceptible to new diseases and pathogens that could become threatening in non-resistant cultivars (Evans, 2017). It is therefore evident that the most significant challenge apple producers will face is mitigating climate risks, considering the high importance of the sector to the global and national economy. Adapting to climate

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change is essential for all fruit tree growers, as even well-established commercial cultivars might behave unpredictably due to climatic anomalies (Haokip and Shankar, 2019). Additionally, anticipating and mitigating the effects of global warming is far more urgent for fruit tree growers compared to those engaged in annual crop production, which can involve changing cultivars from one season to the next and adjusting planting times based on changes during the growing season. In contrast, fruit trees in an orchard can last about 15-20 years. Considering the high initial investment required to set it up, the missed revenue for growers could seriously compromise their profitability (Luedeling, 2012). This is even more worrying for farms with less than 5 ha since their economic stability is more threatened in this scenario. For all these reasons, it is imperative to explore new potential alternatives to ensure fruit production.

The project entitled: "Diversified orchards for resilient and sustainable farming systems" (acronym: DREAM) aims to test a new agroecosystem concept, characterized by the following basic principles, which go beyond conventional agricultural systems (Figure 1):

A) Scalar multi-cultivar orchards exploiting a range of modern and old genotypes.
B) Consociation of fruit tree with a specifically designed cover crop mixture, able to prolong blooming, increase soil nutritional and water status, attract natural enemies and repel phytophagous insects, and to increase functional diversity in order to enhance biological pest control and insect pollination.
C) Adoption of Regulated Deficit Irrigation (RDI) protocols aimed at increasing the system water use efficiency as well as improving fruit quality.

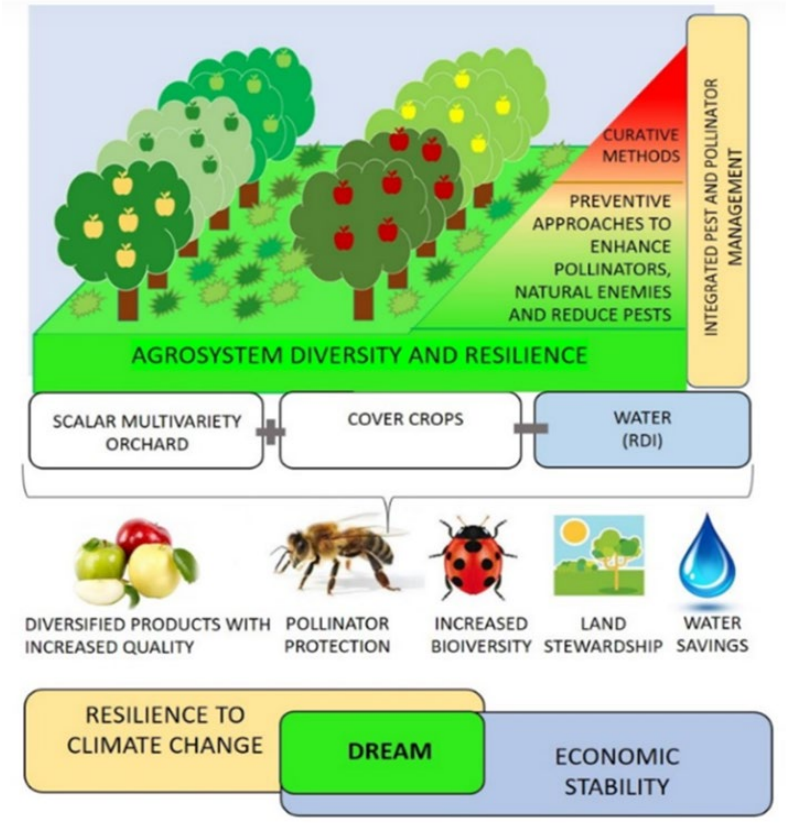


Figure 1. DREAM concept.

The DREAM agroecosystem is also managed according to low-input practices, based on integrated pest and pollinators management (IPPM) (Egan et al., 2020), integrating preventive approaches (resistant cultivars; use of biocontrol agents and natural antagonists;

bioactive natural compounds) while leaving conventional applications (curative approaches) as the last option.

Three testing sites have been implemented in important Mediterranean fruit-producing regions, on both Mediterranean shores. On each site, the new agroecosystem is tested on a fruit crop representative of the local fruit economy: apples in northern Italy and the mountain regions of Morocco, and pears in south-eastern Spain. In each site, the new agroecosystem has been designed in collaboration with local living labs developed within the project so that the DREAM basic principles will be specifically tailored to the different conditions, taking into consideration the climate, the main biotic and abiotic stressors, the type of farm holdings, and the market requirements typical of each area.

Here, we present the physiological pattern of the DREAM apple orchard in Italy in comparison to that of a commercial 'Pink Lady' orchard during the 2023 growing season (first year after planting).

MATERIALS AND METHODS

The DREAM and CONTROL agroecosystems were established in 2023, in three replicates (first plot: 44°32'41.6"N 11°22'53.3"E, second plot: 44°32'39.8"N 11°22'58.7"E, and third plot: 44°32'36.8"N 11°23'09.8" E) (Figure 2). Each plot consists of 7 rows of trees, spaced 3.5 m apart and 50 m long, covering a total area of 1250 m^2. The CONTROL plots are separated from the DREAM plots by a 12-m strip of bare ground, and the three replicates are located at least 200 m apart from each other.

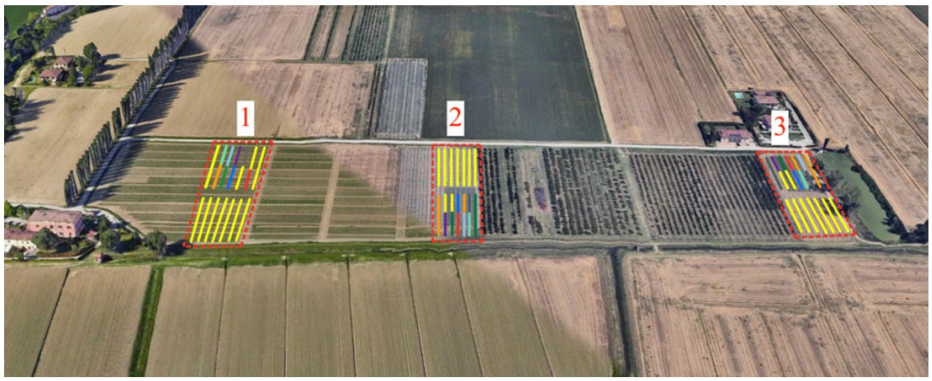


Figure 2. Spatial division of the three replicates: the study areas are outlined by the red dashed perimeter; the CONTROL plots are shown in yellow; the DREAM rows are shown in multicolor.

The DREAM agro-ecosystem tested in Bologna consists of nine different apple cultivars chosen for both their qualitative characteristics and their genetic resistance to various biotic stresses. The cultivars are the following:

- 'Pink Lady' ®: a commercial cultivar with no resistance or tolerance;
- 'Red Pulp UNIBO': developed through the UNIBO breeding program, characterized by high concentrations of nutraceutical components;
- 'Early Red UNIBO': developed through the UNIBO breeding program, resistant to aphids and scab;
- 'Red Unibo': developed through the UNIBO breeding program, resistant to aphids and scab;
- 'Gala 049': a commercial cultivar with good storage potential and resistant to scab and powdery mildew;
- 'Smeralda': characterized by high storage potential, resistant to scab and powdery mildew;
- 'Abbondanza': old local cultivar;
- 'Campanino': old local cultivar;

- ‘Renetta Grigia di Torriana’: old local cultivar resistant to scab.

The CONTROL plots are all cultivated with the ‘Pink Lady’® cultivar and managed according to standard cultural practices of the area.

In spring 2023, a mix consisting of 14 species was sown in the DREAM agroecosystem. Specifically, the cover crop mix consisted in: Dill (*Anethum graveolens*), birdsfoot trefoil (*Lotus corniculatus*), buckwheat (*Fagopyrum esculentum*), shelled sainfoin (*Onobrychis viciifolia*), black medick (*Medicago lupulina*), white melilot (*Melilotus albus*), yellow melilot (*Melilotus officinalis*), Spanish esparcet (*Hedysarum coronarium*), Crimson clover (*Trifolium incarnatum*), Persian clover (*Trifolium resupinatum*), red clover (*Trifolium pratense*), white mustard (*Sinapis alba*), alfalfa (*Medicago sativa*) and yarrow (*Achillea* spp.). The inter-rows of the CONTROL plots were managed with the natural grass cover and mowed periodically.

From April to September 2023, the vegetative growth of the shoots (36 shoots measured in each cultivar), the stem water potential and leaf gas exchanges were measured with a measuring tape, Scholander pressure chamber (Soil Moisture Equipment Corp., Santa Barbara, USA) and Li-COR 6800 (LI-COR, Lincoln, NE, USA), respectively. To measure stem water potential, 4 plants per cultivar were selected. For each plant, one leaf placed in the inner part of the canopy was covered with a foil bag at least 50 min before the measurement to allow the leaf to equilibrate with the stem. The protocol used for the measurements at 165 and 242 days of the year (DOY) was that of Turner and Long (1980), while at 206 DOY, those of Rodriguez-Domínguez et al. (2022) were employed. Leaf gas exchanges were measured on 6 plants per cultivar. The light intensity was maintained constant during all measurements by adjusting the LED light source to match the natural radiation (consistently above 1200 μmol) experienced by the leaves immediately prior to measurement, while the CO_2 concentration was set at 400 ppm.

RESULTS AND DISCUSSION

The seasonal shoot growth pattern (Figure 3) showed statistically significant differences between cultivars at all measurement points. In the first measurement (29th May 2023) ‘Campanino’ and ‘Renetta Grigia di Torriana’ stood out with higher absolute values than the other cultivars. In the second measurement day, ‘Pink Lady’ DREAM showed the highest shoot length, while ‘Early Red UNIBO’ and ‘Red UNIBO’ showed the lowest values. Finally, in the last measurement (29th August 2023), three main groups were identified, with the highest shoot lengths recorded in ‘Red UNIBO’, ‘Pink Lady’ DREAM, ‘Campanino’, ‘Pink Lady’ CONTROL, and ‘Renetta Grigia di Torriana’. The cultivar that presented the lowest shoot growth was ‘Early Red UNIBO’, while all the other cultivars presented an intermediate situation between the previous two (Figure 3).

This high diversity could be mainly attributed to the different genetic pools of each cultivar, a genetic variation that in Europe was due to the domestication process (Urrestarazu et al., 2016). However, it is also interesting to note that the trees’ vegetative growth was not negatively affected by the presence of cover crops in the DREAM system. This is further confirmed by the lack of significant difference between ‘Pink Lady’ DREAM and ‘Pink Lady’ CONTROL. Previous studies have demonstrated that cover crops can have positive effects, such as increased phosphorus bioavailability (Wang et al., 2021) and higher water retention when the cover crops are cut and used as mulch (Webber et al., 2022).

Stem water potential did not show significant differences between the different cultivars. However, ‘Pink Lady’ CONTROL reached the most negative values compared to the other cultivars, suggesting greater water availability in the DREAM agroecosystem compared to the CONTROL one (Figure 4). When the stem water potential of ‘Pink Lady’ DREAM was tested against that of ‘Pink Lady’ CONTROL with a Student’s t-test, a statistically significant difference on DOY 206 (25th July 2023) was found, with values of -3.6 MPa and -2.8 MPa in CONTROL and DREAM, respectively. It is essential to note, however, that on that measurement day, a different measurement protocol was used. The greater negative values measured on that date could be due to this variable, considering also that plants were irrigated based on the evapotranspiration estimations provided by IRRIFRAME (Irriframe), a decision support system made available by the Emilia-Romagna region.

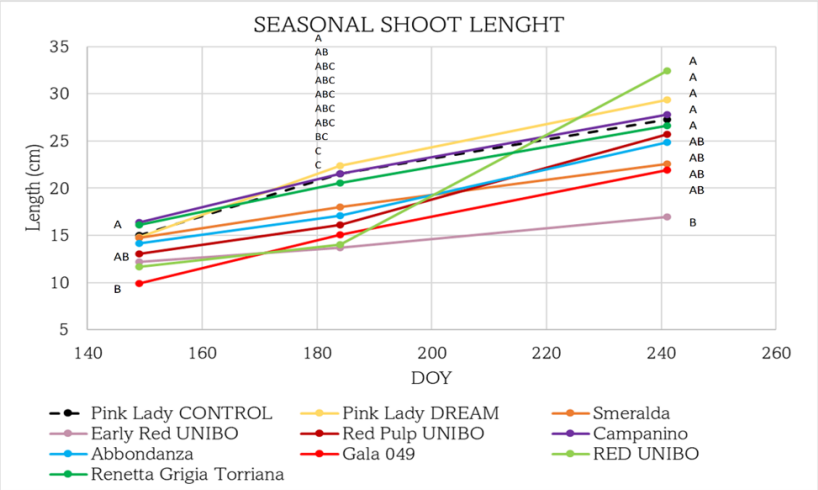


Figure 3. Shoot length measured in both the DREAM and conventional orchards during the 2023 growing season. For each cultivar considered, 36 shoots were measured. Different letters indicate statistically significant differences at $p<0.05$, tested by ANOVA.

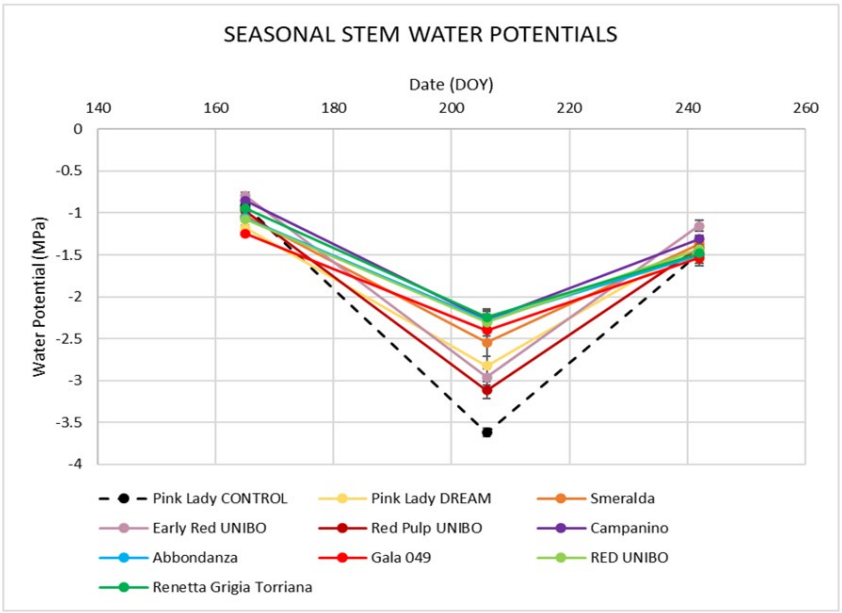


Figure 4. Stem water potentials measured at midday on 14th June, 25th July, and 29th August 2023 in different apple cultivars, both in CONTROL and DREAM systems. Each point represents the average of at least 4 leaves. No statistically significant differences are present.

Focusing thus more on the first and last measurement days, it could be seen that at the beginning of the season, the values were between -0.79 and -1.24 MPa, while at the end of August, all the values were slightly more negative, with 'Gala 049' has an average value of -1.53 MPa. According to the literature, Naor et al. (1997) proposed a stem water potential threshold of -1.2 MPa to prevent yield reductions. Considering, however, that in this case fruit was not present on the trees, the trees were able to further decrease their stem water potential without decreasing the photosynthetic rate.

Figure 5 shows the seasonal photosynthetic rate of all the cultivars considered, both in

DREAM and CONTROL agroecosystems. Most cultivars exhibited the highest photosynthesis values on July 25, 2023. This may be due to the weather conditions, as temperature and solar radiation were higher on that date than on the other two dates. Furthermore, these values demonstrate that the plants were not subjected to water stress conditions, despite Figure 4 potentially suggesting otherwise. As previously stated, it was a result of employing a different protocol. In general, however, there were no statistically significant differences between the different cultivars for any of the parameters considered. This could indicate that during the first growing season, the DREAM agro-ecosystem did not induce changes in photosynthesis parameters compared to conventional cultivation techniques, but also that under the same crop management.

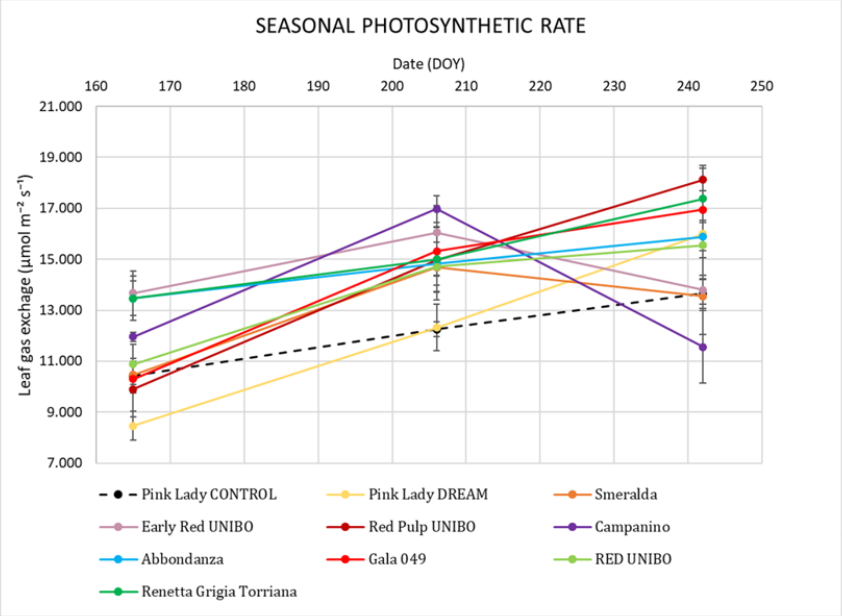


Figure 5. Net photosynthetic rates measured at midday on 14th June, 25th July, and 29th August 2023 in different apple cultivars, both in CONTROL and DREAM systems. Each point represents the average of at least 4 leaves. No statistically significant differences are present.

CONCLUSIONS

The objective of this study was to compare the physiological performance of plants cultivated in the DREAM agroecosystem with that of plants managed with conventional cultivation techniques. Seasonal vegetative growth showed differences among the various cultivars studied. However, these were primarily due to the specific characteristics of the cultivars rather than the cultural management to which they were subjected. Stem water potential, a key physiological measure in monitoring the status of fruit trees, did not differ, as did photosynthesis values measured throughout the summer season. This emphasizes that during the first year of growth, the plants were in a non-limiting condition, allowing them to perform their physiological functions to the best of their ability. In conclusion, DREAM management of the orchard did not penalise plant growth and related physiological performance, proving to be a possible alternative to conventional cultivation. However, further studies are needed to compare these preliminary results with those obtained under full production conditions and with those of prolonged DREAM management.

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