Invited lecture

INNOVATIONS IN STRAWBERRY CULTIVATION TECHNIQUES AND EXPERIENCES WITH RECENTLY OBTAINED CULTIVARS IN ITALY

Pierluigi Lucchi, Gianluca Baruzzi, Walther Faedi

Consiglio per la Ricerca e la Sperimentazione in Agricoltura
Unità di Ricerca per la Frutticoltura, Forlì (CRA-FRF)
E-mail: pierluigi.lucchi@entecra.it
E-mail: gianluca.baruzzi@entecra.it
E-mail: walther.faedi@entecra.it

Abstract. In the last three years, the Italian strawberry industry has settled on a surface of about 3,700 ha. The negative trend starting at the end of the 80s seems to have ended. More than 80% of the cultures are plastic tunnel protected. The open field culture is still of interest in the North, especially in Romagna area, while it is almost absent in the South. The main strawberry regions are: Campania (824 ha) and Basilicata (631 ha) in the South and Veneto (614 ha) in the North. Cultivated surfaces have been reduced in Piemonte and Emilia-Romagna, the latter being once the main Italian strawberry region.

Southern varieties composition is dominated by two Spanish-origin varieties: ‘Sabrina’ in Campania region (58% of surface) and ‘Candonga®Sabrosa’ in Basilicata region (80%). In Northern cultivated areas, the variety standard is quite various depending on the area and on the cultural technique: ‘Eva’ dominates “Verona fall cultures” in Veneto; ‘Alba’ continues to be the dominant variety in Romagna area (both in protected culture and in the open field culture), followed by ‘Roxana’, ‘Tecla’, ‘Clery’, ‘Joly’ and ‘Asia’; ‘Elsanta’ is still grown in the “programmed cultures” of Trentino Alto-Adige region. In Trentino and Piemonte (Cuneo province) mountain areas, the everbearing varieties ‘Portola’, ‘Monterey’, ‘Irma’ and ‘Murano’ are becoming popular.

The end of the surface negative trend could be explained by two aspects – variety innovation and improvement of cultural techniques – that together can allow a more-than-ever necessary extension of the harvest time: producing for a period as long as possible could probably be the winning feature of the strawberry culture, and not only the Italian one. As a further proof of this fact, the areas which underwent more limited reductions in investments in Italy in the past are the ones having the most extended ripening calendar. In Southern areas, harvest starts in November with the “plug plants” of the earliest varieties and ends in late-May with the fresh bare-root plants. In the North, with “Trento programmed cultures”, “Verona fall cultures” and everbearing varieties it is possible to harvest strawberries for all spring-summer-autumn months; in particular, the everbearing varieties allow to extend the calendar in the North from spring to late-autumn. On the contrary, the areas cultivated with June-bearing cultivars and traditional techniques for the spring production concentrated in a period of 20-25 days seem to be destined to an uncontrollable decline.

Key words: *Fragaria x ananassa*, bare-root plants, plug plants, cold-stored frigo plants, variety.

Introduction

In the last three years, the Italian strawberry industry has settled on a surface of about 3,700 ha (CSO-Ferrara, 2014). The negative trend starting at the end of the 80s seems to have ended. This decrease comes from an increase of production costs not corresponded by an equal increase of selling prize. For example, in Romagna area, the production costs of the open-field culture are about 50,000.00 Euros, while the trend of the selling prices to the grower shows to be quite static, if not even decreased in some of the latest years. Being the yield per hectare quite constant or slightly lower, particularly if sweet fruit varieties are grown – having better taste but generally less productive because of the smaller size of the fruits – the lack of profitability of strawberry cultivated fields is clear.

At the moment, the negative trend seems to have ended. This could be caused by variety innovation and improvement of cultural techniques that together can allow a more-than-ever necessary extension of the harvest time. Nowadays it is possible to harvest strawberries for 12 months in Italy, a longer period than in the past (Fig. 1). It is possible to extending the ripening calendar in Southern areas thanks to the winter planting system (bare-root plants or “plug” plants) and in Northern areas thanks to “Programmed cultures”, “Verona fall cultures” and everbearing varieties.

The main strawberry cultivated areas

In Italy there are two distinct strawberry production areas: the South and the North. Southern regions account for 60% of the production on 55% of the surface. Compared to the North, the higher production per hectare is due to a longer harvest period (3 months against 25-30 days) combined with varieties adapted to mild winter environmental conditions enhanced by tunnel-protection.

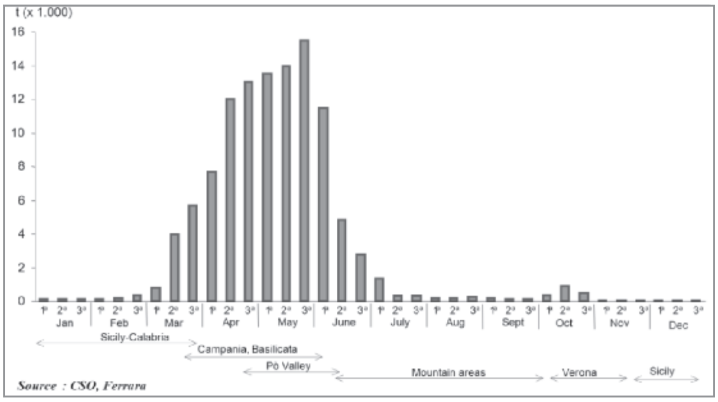


Figure 1. Italian strawberry production per decade in 2013.

In the South, strawberries are cultivated with very intensive annual cultural techniques, including preplant soil fumigation, drip irrigation, and high-density planting - 70,000 to 90,000 plants per hectare - with twin hill-rows on raised beds. The main strawberry regions are: Campania (824 ha), Basilicata (631 ha), Calabria (215 ha) and Sicilia (348 ha) in the South, Lazio (120) in the Centre and Veneto (614 ha), Emilia Romagna (268 ha), Trentino Alto Adige (245) and Piemonte (123) in the North.

In the last ten years, in Southern areas, a total change of the cultural technique from cold-stored plants to bare-root plants produced in nurseries localized in Poland or in Spain (high altitude) has been taking place. Compared to cold-stored plants, fresh plants allow a one-month delay of plantation, an important advance of the fruit harvest calendar and its extension in time avoiding production peaks and so favoring better fruit quality characteristics. Moreover, a better management of farm labor is possible due to the fact that production is not concentrated in a sole period. On the other hand, the risks are mainly linked to negative weather trend that, together with too late plantations (late October – early November) often caused by late availability of nursery plant material, could determine a reduced development of the plant before winter time with consequent limited productive levels. Recently, a fresh “plug” plant has been diffused allowing a further advance in ripening compared to fresh bare-root plant (Lucchi, 2010).

Cold stored plants are very common in the North of Italy. About 100% of these types of plants are produced in the nursery farms located in Emilia-Romagna region, near the Adriatic Sea, and in Veneto region, on well-drained and sandy soil. Also in Northern areas the use of “plug” plants is increasing.

Southern areas

Marsala area is the main Sicilian strawberry-cultivated area and the Italian earliest season area of about 200 ha, all with protected culture. Multiple tunnels are more and more adopted compared to traditional small structures with lateral openings (D’Anna et al., 2011; Palermo et al., 2012). The variety standard is dominated by the American variety ‘Florida Fortuna’, extra-early and very low chilling requirement variety. In this area, it is almost only aiming for the earliness of harvest, and therefore a larger and larger use of fresh “plug” plants is allowing extra-early productions. Particularly early plantings established with “plug” plants at the end of August permit productions starting from early November (about 60 days from planting). It has to be highlight the higher and higher diffusion of the second-year culture aiming to extra-early production; the plantation system is removed at the end of January.

In Calabria region, the strawberry industry is concentrated in **Lamezia Terme** flatland (Funaro et al., 2013). For a long period ‘Caramosa’ has been here the dominant variety, but an important renewal of the variety standard is now in progress. At the moment, the main grown varieties are ‘Nabila’ (25%), ‘Rania’ (21%), ‘Camarosa’ (20%), ‘Sabrina’ (14%) and ‘Kamila’ (10%). The bare-root plant is the most popular type of plant, to the detriment of “plug” plants which are not very much used at the moment. The culture is carried out in big tunnels ensuring an earlier ripening. The harvest goes from December to May. In this area, the open-field culture – once being the dominant one and aiming at spring productions adopting cold-stored plants - has almost disappeared. Recently, plantations of everbearing cultivars (‘Albion’, in particular) are popular in Sila mountain areas (1,000 m above sea level) aiming at summer productions. Cold-stored plants are planted in April for June-to-October productions.

In Campania region, the strawberry industry is mainly located in 2 areas: **Piana del Sele** and **Agro Aversano**. These two areas are quite similar for cultural technique, but different for types of farms: larger individual farms in Piana del Sele and smaller farms but associated in Growers’ Associations in Agro-Aversano area. Bare-root plants are used mostly, planted in mid-October in protected cultures with big multiple tunnels, but there are also cases of fresh “plug” plants plantations aiming at early productions or cases where cold-stored plants are used for autumn production, programmed to start the harvest of the first fruits 50 days after being planted. The variety ‘Sabrina’ - of Spanish origin - reached 58% in only 6 years from its commercial release (CSO-Ferrara data referred to a sample of 310 ha;

Fig. 2) and it represents the dominant variety because of its early ripening. This cultivar is followed by 'Amiga' (19%), 'Candonga' (9%), and 'Florida Fortuna' (6%).

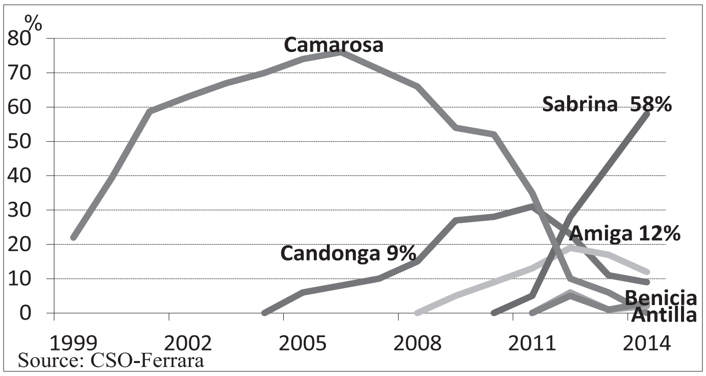


Figure 2. Campania Region variety importance from 1999 to 2014.

In Basilicata region, the strawberry industry is concentrated in **Metaponto** area. This area is characterized by the coldest weather conditions compared to the other Southern areas, and it is also the latest site to have adopted the fresh plant instead of the cold-stored one. This have allowed to have an early start of production, but on the other hand the damages caused by the drops in temperature particularly frequent in this area at the end of winter – early spring are higher. For this reason, in this area the use of double film covered tunnels is popular allowing a higher heat effect in winter months.

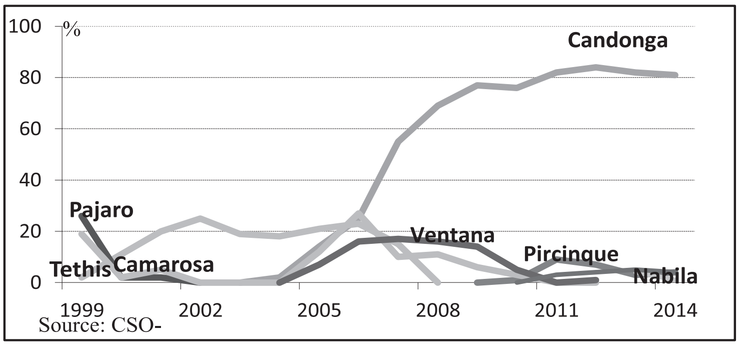


Figure 3. Basilicata Region variety importance from 1999 to 2014.

However, this solution reduces considerably the lightening, with possible negative consequences on fruit color, not always perfectly uniform. Since some years, the variety standard of this area has been dominated by the variety 'Candonga®Sabrosa' (Fig. 3), a variety that can express at the best its high fruit quality characteristics.

Central areas

Beyond many small areas where strawberries are cultivated to supply local markets, the area of **Terracina** - near Rome – has to be mentioned because here since more than 30 years, on a surface of about 100 ha, the old French cultivar ‘Favette’ – well-known for its peculiar fruit quality traits (flavor and sweetness) - has been grown (Maltoni et al., 2010). The main limit of this variety is the low flesh firmness and the low skin resistance reducing its *shelf-life*. However, this aspect is not so important for the “strawberry of Terracina” as the product is mainly commercialized on the near market of Rome. The traditional cultural technique includes the use of cold-stored plants grown in areas protected by medium-sized tunnels.

Northern areas

In the North, strawberry is cultivated both in the Po Valley (Cesena and Verona areas) and in the mountain areas of the Alps with two main areas of production located in Cuneo and Trentino-Alto Adige areas. The productions in these two sites cover different periods from April to November.

Cesena area represents about 80% of the whole Emilia-Romagna strawberry production. Here the most used cultural technique is still the open-field (72%), but the recent trend is to cover the strawberry fields with large tunnels aiming to avoid rain damage during the flowering-harvest time without affecting the ripening time of fruits. It has also to be remarked the importance of the traditional tunnel protected culture of Cesena area (almost 28% of the total) established at the end of January and aiming at an early fruit ripening by about 3 weeks compared to the open-field (Baruzzi and Faedi, 2010). In this area, the early-season variety ‘Alba’ established itself even if, in recent years, the interest for this variety has progressively decreased followed by ‘Roxana’, ‘Tecla’ and ‘Clery’ – the latter being very appreciated by the market for the good fruit taste (Fig. 4).

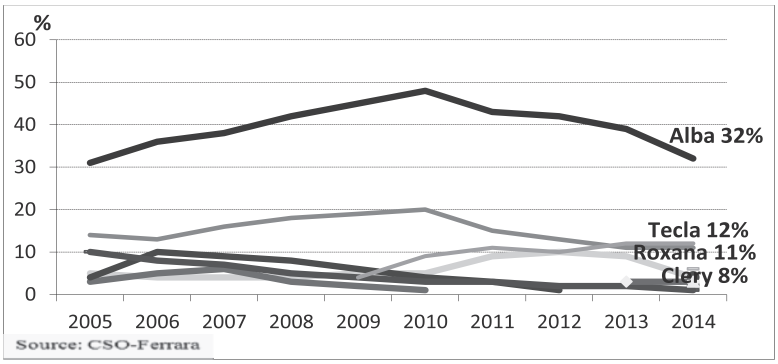


Figure 4. Emilia – Romagna Region variety importance from 1999 to 2014.

In Cesena area, also the role played by organic cultures (15% of the total) is interesting. Annually 40,000 - 50,000 “cold stored plants” per hectare are planted in summer (from the last week of July to the first of August) on a hill-row planting system. Fruit ripening starts in mid-April under tunnel culture, 3 weeks later in the open field, and it ends in early-June.

Verona area has been for a while the main site of production in the Northern areas. It is important to remark how Verona strawberry industry is the only one to maintained its own surfaces. The interest for strawberry culture in this area is due to the peculiar cultural technique known as “Verona fall culture” allowing a double harvest period from the same plants: for autumn production, A+ cold stored plants are planted in late-August. Density is usually between 60,000 and 70,000 plants/ha. Fruiting starts in early October and ends around mid-November. Fall yields fluctuate from 1 to 2 kg/m^2. The plants are overwintered to obtain a second crop in the following spring between mid-April and mid-May. Nearly 100% of the surface is protected in mid-September with a multiple tunnel. During winter tunnel are opened to chill the plants. Not all varieties adapt to this cultural technique and at present the cultivar ‘Eva’ dominates the variety standard (Fig. 5).

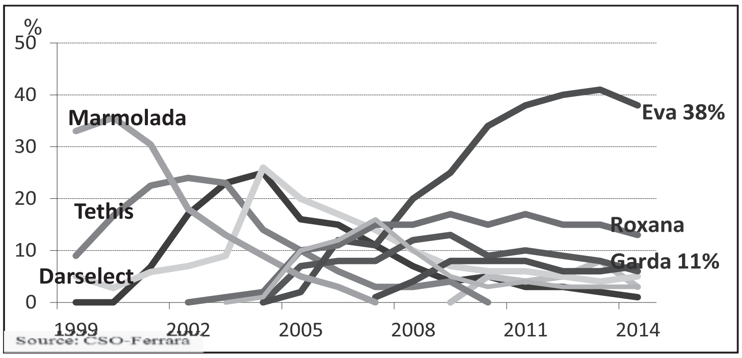


Figure 5. Veneto Region variety importance from 1999 to 2014.

‘Eva’ owes its success to its ability to have a second blooming after the main one, allowing a considerable extension of the production.

In **Trentino area**, the strawberry culture is aimed at producing strawberries (especially of the variety ‘Elsanta‘) in summer using mainly soilless protected “programmed cultures”. The cultural technique includes the use of “tray plants” grown in adequate plant trays from July to November and then cold-stored till the planting (10-12 plants/m^2) carried out from April to July depending on when the start of harvest is programmed (on the average, 45-50 days after planting). Basically, the plants having fructified once during the summer are maintained for a second year giving a concentrated flux production in the following spring (May-June depending on the altitude of the area). In Trentino cultivated areas, also some everbearing varieties as ‘Portola’, ‘Capri’ and ‘Murano’ are diffused allowing a prolonged and regular summer production planting one cold-stored plant (A) in April and solving in this way the problem of the very high cost of “tray plants” necessarily required instead by June-bearing cultivars.

In Alto Adige, the strawberry culture is mainly concentrated in **Val Martello** in altitudes from 1.200 to 1.700 m. The cultural technique adopted (unique case in Italy) includes the maintenance of strawberry cultivated field for 3 years. The plants are established in late spring, generally using “waiting bed” plants or “tray plants” (40.000 plants/m^2) giving a first production during the summer (programmed culture). The same planting system is maintained generally for the 2 following years giving concentrated productions in variable periods depending on the altitude (late June – mid-August). The strawberry culture in these environments – characterized by difficult weather conditions (winter with very cold temperatures, sometimes without snow covering and spring with frequent drops in temperature) – is dominated by ‘Elsanta’ and ‘Marmolada®Onebor’. However, at present a variety being able to adapt to these environments and fully satisfy the local growers does not seem to exist.

In Piedmont region, the strawberry culture is mostly concentrated in **Cuneo area** in altitudes going from 550 to 1,100 m aiming to later ripening seasons (for June-bearing cultivars from early June to mid-July) compared to those of the Po Valley. The protected culture with “light” tunnels is dominant; they aim at the protection from rain damage and not at an earlier fruit ripening. The “cold-stored plants” are planted at early or mid July depending on the altitude and the harvest occurs the following year (early June – mid-July). ‘Alba’, ‘Asia’ and ‘Roxana’ are the dominant varieties followed by ‘Clery’ and ‘Arosa’. Also the interest for Day-neutral everbearing varieties which are able to supply – with “cold-stored plants” planted in April – a production cycle from July to October. At the moment, the most diffused variety is ‘Portola’ of American origin.

Italian National Variety Network

In Italy, since 1993, the Ministry of Agriculture and several Regions founded a Project finalized to evaluate new strawberry varieties released from the main Breeding Programs - private and public – conducted in the world. In 2014, the Project activity gathered up the expertise of 12 Units working in 27 trial fields located in 11 regions. In the different trial fields the traditional cultural technique of the area of reference are adopted. Each year, a “List of positive varieties” is drawn up giving growers and Nursery Companies useful information on the variety tendencies. The Lists are annually published (Baruzzi et al., 2013; Baruzzi et al., 2014). From the start of the Project, more than 360 cultivars have been evaluated. Most part of the varieties (75%) were negatively evaluated since the first evaluation; another group of varieties (15%) was included in the “Positive Lists” of the previous years, but at the moment these varieties are no more considered as “Positive”. A group of varieties is currently considered as “Positive” for the single cultivated areas. In the South, the list includes 10 varieties with some differences among the different regions. Some new seemingly interesting varieties are under observation (‘Jonica’ and ‘Sahara’). In table 1, the List 2014 for Southern and Northern areas is also reported with 19 June-bearing and 7 everbearing varieties. The differences among the various areas are remarkable.

Table 1. List 2014 of the “positive” varieties for the main Southern and Northern strawberry cultivated areas

Campania	Basilicata	Calabria	Sicilia	Sardegna
Sabrina*	Nabila*	Nabila*	Florida Fortuna*	Nabila*
Pircinque*	Pircinque*	Sabrina*	Sabrina*	Pircinque*
Rania*	Sabrina*	Kamila*	Candonga*	Naiad
Camarosa*	Coral*	Rania*		
Candonga*	Candonga*			

Alto Adige	Trentino	Piemonte	Veneto	Emilia-Romagna
Elsanta	June bearing	June bearing	Alba-NF 311*	June bearing
Darselect*	Elsanta	Alba-NF 311*	Eva*	Alba-NF 311*
Marmolada	Darselect*	Clery*	Darselect*	Clery*
Arosa*	Everbearing	Sugar Lia-Lia*	Irma*	Queen Elisa*
Record*	Capri*	Joly*	Asia-NF 421*	Tecla*
	Portola*	Arosa*	Roxana-NF205*	Roxana-NF205*
	Ischia*	Argentera*		Argentera*
		Everbearing		Everbearing
		Evie2*		Monterey*
		Portola*		
		San Andreas*		

A brief profile of the varieties included in the List of positive varieties 2014 is following:

Varieties adapted to Southern areas:

Camarosa

Strong points: high productivity; excellent taste; high flesh firmness.

Weak points: irregular fruit shape; not-uniform dark color.

Candonga®Sabrosa

Strong points: plant hardiness; perfectly conical-elongated regular shape; long *shelf life*; high flesh firmness; excellent fruit taste.

Weak points: not always high productivity, especially with the late planting time of late-season fresh plants; quite late ripens.

Florida Fortuna

Strong points: high productivity also in the earliest ripening season, especially if grown with early planted "plug" plant (early September); big-sized and conical-elongated regular shaped fruit.

Weak points: susceptibility to soil-borne pathogens often causing death of plants or a stressful state with negative consequences on fruit quality, especially following increases in temperature in spring; it requires fertile and fumigated soils.

Kamila

Strong points: hardy plant; big-sized fruit (especially with "bare-root" fresh plants), regular-conical shape and deep bright red color of the fruit, firm flesh and good organoleptic qualities.

Weak point: low productivity.

Nabila

Strong points: hardy, vigorous and productive plant; very regular shaped fruit, with medium-high size, bright red color and good organoleptic qualities.

Weak points: low flesh firmness of fruits, especially with high temperatures in the harvest time.

Pircinque

Strong points: mid-early ripening, high productivity; excellent taste due to the high sweetness and flesh firmness.

Weak points: high plant vigour especially in very fertile or too fertilized soils; not completed color at the base in winter and it tends to become deep with the increase in temperatures; high rot susceptibility of fruits.

Rania

Strong points: highly vigorous, hardy and very productive plant; big-sized fruits.

Weak points: not always regular shape fruit, especially primary fruit; not always uniform color during the cycle of production, it tends to become very deep with increases in temperature.

Sabrina

Strong points: hardy and productive plant; very regular conical-elongated shape of the fruit thanks to the good pollen fertility; high flesh firmness and good organoleptic characteristics.

Weak points: susceptibility to powdery mildew.

Varieties in the List for the North:

Adria

Strong points: plant hardiness and adaptability also to non-fumigated and calcareous - clay soils; bright red-orange color and regular fruit shape.

Weak points: low skin resistance of fruit; susceptibility to Powdery Mildew and leaf-spot disease.

Alba

Strong points: earliness; high yield; easy to pick; very regular and elongated shape; very bright color.

Weak points: low flesh firmness and skin resistance especially with high temperatures; low organoleptic characteristics.

Antea

Strong points: regular conical-elongated fruit shape, high flesh firmness and good taste; second blooming in spring.

Weak points: susceptibility to soil borne pathogens; small fruit size during the second part of harvest.

Argentera

Strong points: very late season; plant hardiness; nice conical, regular, uniform fruit shape; red-orange color, very bright and stable also in the post-harvest.

Weak points: medium-small fruit size in the second part of the harvest; medium flesh firmness.

Arosa

Strong points: very regular conical-elongated fruit shape; high flesh firmness; good taste; very bright color.

Weak points: slight drop in fruit size during the harvest; high susceptibility to powdery mildew.

Asia

Strong points: high productivity; nice fruit conical-elongated shape; good taste.

Weak points: low flesh firmness and skin resistance; susceptibility to soil-borne pathogens.

Clery

Strong points: earliness; high plant hardiness; nice and very regular conical shape; excellent fruit taste.

Weak points: not always high productivity due to the drop in fruit size during the second part of harvest.

Cristina

Strong points: late-season; very hardy plant; good organoleptic quality, nice conical-elongated shape and bright red-orange color of the fruit.

Weak points: low flesh firmness and skin resistance.

Darselect

Strong points: excellent fruit taste.

Weak points: low productivity of plants; high susceptibility to powdery mildew and leaf-spot disease.

Elsanta

Strong points: excellent quality traits of the fruit; long shelf-life.

Weak points: high susceptibility to soil-borne pathogens and to powdery mildew.

Eva

Strong points: red-orange color, very bright and stable during storage; high flesh firmness; second blooming.

Weak points: irregular shape in primary fruit.

Joly

Strong points: hardiness and high productivity of the plant; excellent taste, high sweetness and aroma.

Weak points: fruit color tending to become too deep; low flesh firmness.

Marmolada®Onebor

Strong points: high plant productivity; resistance to winter cold (it is more preferred than Elsanta at the highest altitudes, from 1300-1700 m).

Weak points: susceptible to soil-borne pathogens; dark color and low fruit quality.

Queen Elisa

Strong points: earliness; good taste combined with high flesh firmness; very stable red-orange color.

Weak points: medium-small size in the second part of harvest.

Record

Strong points: very late season; high productivity and hardiness of plant; high plant resistance to winter cold; it is adapted till 1400 – 1600 m of altitude.

Weak points: low flesh firmness; low taste.

Romina

Strong points: earliness; hardy plant; the fruit has a nice conical-elongated shape; very bright color, good taste.

Weak points: low plant productivity; small fruit size in the second part of picking, dark red color.

Roxana

Strong points: high plant hardiness and productivity.

Weak points: low skin resistance and flesh firmness; low fruit taste.

Sugar Lia
Strong points: excellent fruit quality due to the high sweetness and aroma.
Weak points: low production; susceptibility to soil-borne pathogens.

Tecla
Strong points: high plant hardiness and productivity; very bright fruit color, stable during storage; good taste.
Strong points: too high plant vigour.

Unica
Strong points: high productivity and hardiness of the plant; big-sized fruits; nice regular conical shape.
Weak points: excessive plant vigor; very low organoleptic traits (sweetness, in particular).

Strong and weak points of the varieties included in the List of everbearing cultivars:

Capri
Strong points: everbearing variety with extended and regular blooming; conical shape, good organoleptic quality and bright red color of the fruit.
Weak points: not always regular shape of the fruit.

Evie 2
Strong points: high productivity in the early summer; nice regular conical fruit shape.
Weak points: low flesh firmness and fruit taste especially in peaks of production.

Irma
Strong points: high productivity and long harvest time thanks to the high reblooming ability; nice very regular conical-elongated shape of the fruit, deep bright red color.
Weak points: low flesh firmness and taste.

Ischia
Strong points: stable bright red color of the fruit, very attractive; good organoleptic quality.
Weak points: medium-low yield; medium-small fruit size.

Monterey
Strong points: excellent fruit taste, high sweetness also with summer high temperatures.
Weak points: dark fruit color and low skin resistance with summer high temperatures.

Portola
Strong points: high plant productivity; regular conical fruit shape; attractive bright red-orange color.
Weak points: low fruit organoleptic traits.

San Andreas
Strong points: high hardiness; excellent organoleptic traits of the fruit.
Weak points: not always high plant productivity; too dark fruit color.

New varieties in evaluation in 2014-‘15

The following is a brief description of the new varieties which are presently under evaluation. For these varieties a definite judgment has not been made, yet, as two years of evaluation are required. The descriptive notes of these varieties are those given by the breeder.

Varieties adapted to Southern areas (low winter chilling requirement)

Antilla (Fresas Nuevos Materiales - Spain): mid-late season June-bearing variety; nice fruit appearance and red-orange color.

Fontanilla (IFAPA - Spain): early June-bearing variety; high productivity in the early harvest; high flesh firmness.

Jonica (CRA-FRF e Piraccini Secondo srl. - Italy): June-bearing, mid-early ripening, characterized by plant hardiness, productivity and a uniform very bright fruit color, stable during conservation and good taste quality.

Niebla (Fresas Nuevos Materiales - Spain): June-bearing variety; early ripening; light red colored fruit.

Sahara (Planasa - Spain): very early June-bearing variety; hardy plant; nice fruit appearance, always regular conical-elongated shape; high flesh firmness.

Santaclara (IFAPA - Spain): early June-bearing; always regular elongated fruit shape; nice bright red color of the fruit and high flesh firmness.

Varieties adapted to Northern areas (medium-high winter chilling requirement)

New Italian varieties

Brilla (CRA-FRF and NewPlant- Italy): June-bearing variety; hardy and very productive plant; nice fruit appearance; very bright color, stable in the post-harvest; medium quality characteristics.

Garda (CRA-FRF, Aposcaligera-COZ, ISF - Provincia di Verona - Italy): Mid-early season June-bearing variety; nice fruit appearance; high flesh firmness; good taste.

Laetitia (CIV - Italy): late-season variety, very productive; high flesh firmness and aroma.

Linosa (CIV - Italy): everbearing variety; high productivity in early season followed by a second cycle of production; nice fruits; good quality traits.

Murano (CIV - Italy): everbearing variety; nice fruit appearance; high flesh firmness; bright red fruit color; long shelf-life.

Primy (CIV - Italy): early variety; excellent productivity.

Tily (CIV - Italy): early variety; high productivity.

Vivara (CIV - Italy): everbearing variety; red-orange fruit color, very stable during storage; good organoleptic quality.

New French varieties

Capriss (CIREF - France): June-bearing variety; hardy and productive plant; medium-small fruit size, but high quality standard.

New UK varieties

Buddy (HRI – UK): everbearing varieties, very hardy and productive plant; good quality traits and medium size of the fruit.

Cupid (HRI – UK): late-season June-bearing; vigorous, hardy plant, tolerant to the main soil-borne pathogens; bright red-orange fruit color; very regular conical shape.

Delia (HRI – UK): early-season June-bearing variety; medium vigorous plant; bright orange fruit color; conical shape; long shelf-life.

SallyBright (HRI – UK): early-season June-bearing variety; vigorous plant; very bright red color and conical shape of the fruit.

Sasha (HRI – UK): Mid-season June-bearing; medium vigorous plant; susceptible to verticillium wilt and powdery mildew; regular shape and red-orange color of the fruit.

Sweet Heart (HRI – UK): mid-season June-bearing variety; vigorous plant with compact growth habit; deep red color and conical shape of the fruit.

Vibrant (HRI – UK): early June-bearing variety; medium vigor; susceptibility to verticillium wilt; attractive fruit with very regular conical shape.

Conclusion

The search of varieties having high fruit quality parameters as sweetness, flesh firmness, attractive appearance and long shelf-life is of the utmost importance (Medina et al, 2014). The grower faces more and more economic difficulties and to get incomes he has to identify the varieties appreciated by the consumer, adapted to the local area, with high productivity and quality level (Della Casa and Baruzzi, 2013). Moreover, it is necessary that Italian strawberry companies, especially the ones of the North, extend the calendar of strawberry production to the “out of season” periods (Baruzzi and Faedi, 2010). The release of “new” everbearing varieties and the diversification of the different cultural techniques (Verona area autumn, Trento programmed and “plug” plants) allow this required considerable extension of the calendar promoting the development of more and more specialized farms being able to produce and profit for different months per year. These new systems of production would allow, on one hand, to supply the market in periods where strawberries are sought-after and well-remunerated and to avoid imports of product from abroad.

Strawberry has a high level of variety innovation. In the recent years, the public and private breeding has worked a lot to give to growers new varieties being able to satisfy the marked needs (Simpson, 2014). However, to make another further step, it is necessary to reduce the number of varieties now cultivated in Italy, making further choices. At present, in Italy, more than 30 varieties are cultivated (Baruzzi et al., 2014). This could happen if consumers will choose and buy strawberries with the best quality and not the ones with the cheapest price. Also the breeding world is adapting to these needs listening more carefully to the final user (Growers’ Organizations, Cooperatives, Private farms) in the development of varieties (Faedi et al., 2009). In this sense, many breeding actions now in progress among some Research Public Institutes, many Growers’ Associations and Commercial Companies seem to be of great interest.

References

Baruzzi, G., Faedi, W. 2010. Come uscire dalla crisi? Le risposte vengono dalla qualità e dall'aggregazione dell'offerta. Frutticoltura, 4, 4-6.

Baruzzi, G., Faedi, W. 2010 - Fragola in Emilia-Romagna. In: La Fragola (BayerCropScience/Script ART Edizioni), 108-113.

Baruzzi, G., Capriolo, G., Giongo, L., Mennone, C., Sbrighi, P., Faedi, W. 2013 - Si rinnova la Lista delle fragole: sette le nuove entrate L'Informatore Agrario, 29, 39-42.

Baruzzi, G., Lucchi, P., Sbrighi, P., Faedi, W., Capriolo, G., Capocasa, F., Giongo, L. 2014. Fragola: quattro nuove entrate nella Lista 2014. L'Informatore Agrario, 28, 37-40.

CSO – Ferrara. 2014. FRAGOLE ITALIA – superfici coltivate 2014. www.csoservizi.com

D'Anna, F., Caracciolo, G., Prinzivalli, C., Alessandro, R., Baruzzi, G. 2011. Miglioramento della produzione e della qualità: studi varietali e di propagazione in Sicilia Rivista di Frutticoltura e di Ortofloricoltura, 5, 8-15.

Della Casa, R., Baruzzi, G. 2013. Quale futuro per il mercato internazionale? Rivista di Frutticoltura e di Ortofloricoltura, 6, 4-7.

Faedi, W., Ballini, L., Baroni, G., Baruzzi, G., Baudino, M., Giordano, R., Lucchi, P., Maltoni, M.L., Migani, M., Placchi, L. 2009. Advances in strawberry breeding for North of Italy. Acta Horticulturae, 842, 545-548.

Funaro, M., Ambrosio, M., Grotteria, M., Longo, L., Matozzo, G., Spagnolo, G.F., Baruzzi, G., Lucchi, P., Magnani, S., Migani, M., Faedi, W. 2013. Primi risultati di un programma di breeding della fragola in Calabria Rivista di Frutticoltura e di Ortofloricoltura, 6, 24-29.

Lucchi, P. 2010. Tecniche vivaistiche. In: La Fragola (BayerCropScience/Script ART Edizioni), 152-163.

Maltoni, M.L., Baruzzi, G., Faedi, W. 2010. Indagine sullo stato nutrizionale dei fragoleti dell'Agro Pontino. Rivista di Frutticoltura e di Ortofloricoltura, 10, 64-68.

Palermo, M.L., Angileri, G., Signorino, G., Faedi, W., Baruzzi, G. 2012. Alternative alla fumigazione chimica nella fragolicoltura siciliana. Rivista di Frutticoltura e di Ortofloricoltura, 6, 44-48.

Simpson, D. W. 2012. Strawberry breeding and genetics research in North West Europe. Acta Horticulturae, 1049, 107-111.

Invited lecture

STRAWBERRY CULTURE IN THE UK – MANAGING WITHOUT SOIL ON A GRAND SCALE

Graham Moore

Fruit Advisory Services Team LLP (FAST) & Agronomist, Haygrove Ltd, UK
Email: graham.moore@fastllp.com

Abstract. Twenty years ago, production of English strawberries in soil-less substrates was the specialist occupation of a few growers using permanent tunnel structures and glasshouses. Coinciding with changes in berry marketing and retail systems a rapid expansion in the adoption of field scale poly-tunnels facilitated a 'boom' in strawberry production. For some years crops were mostly soil-grown, with poly-tunnels moved from field to field. Problems with soil-borne diseases such as *Verticillium* wilt and red core (*Phytophthora fragrariae*), constraints imposed by local government and a desire to reduce harvest costs have stimulated widespread adoption of soil-less growing systems so that perhaps more than 50% of English strawberries are now grown without soil. Having become used to producing strawberries in field-scale blocks, growers have continued to plant on a field scale instead of reverting to the smaller intensive units more typical of soil-less growing resulting in many structural and plant husbandry innovations. Yield targets are 45 – 60 T/ha and picking speeds at least 30% better than those of soil grown crops.

Key words: strawberries, Haygrove, polytunnels.

Introduction

Production of strawberries without soil is not new to growers in the UK, but the scale of production has changed dramatically over recent years. The essentials of the systems employed have changed little since 1997 when a popular trade journal published a booklet written by Dennis Wilson and entitled 'Strawberries under Protection".

The advantages of soil-less production according to Wilson (1997) are listed below:

1. Soil borne pests and diseases are virtually eliminated without the use of expensive and environmentally damaging soil sterilants and herbicides.

2. Crops can be raised off the floor to a convenient working height which allows for improved crop access, reduced harvesting costs and improved pest and disease control.

3. Control of over watering and plant nutrition is improved allowing greater manipulation of plant growth, fruit flavour and shelf life.

4. There is greater flexibility and a more rapid turn-around between crops. Plants can be removed quickly from the structure and a new crop installed within a very short time. This new crop may have been established in a nursery area prior to housing, giving the opportunity to harvest several crops in rapid succession.

Recommended support systems included 2nd use glasshouse heating pipe suspended from the structure of glasshouses, wire systems elevated on posts down and polythene covered straw bales.

However, in 1997, soil-less growing was limited to relatively small units, focussed on high value market opportunities. The establishment costs were a significant barrier to entry, involving a steep increase in the working capital required for a given land area' (Wilson, 1997) both for crop supporting structures and for the glass or strong poly-tunnels necessary to force and protect early crops.

In the late 1980s and early 1990s (NHF, 2011) British growers explored a variety of new production systems for soil-grown strawberries. Growing on polythene covered raised beds became widespread and new tunnel systems, based on structures imported from Spain, were tested. Haygrove Tunnels were part of this period of innovation, building and trialling modified structures in Herefordshire (Anderson, 1998). Tunnels that were much less prone to damage by strong winds were the result and a great many accessories and more efficient tunnel construction and management techniques were introduced.

A preference for home grown fresh produce and relatively high prices made UK supermarkets an ideal partner for expanding strawberry enterprises, now able to promise more consistent supplies to retailers for whom continuity of supply had become of critical importance.

The same consistency gave growers the confidence to risk more of their working capital on growing strawberries. Enterprises that once occupied a small niche within a larger orchard, vegetable growing or even an arable farming business were expanded to areas of 40 or more hectares.

By 2006 several factors coincided to bring about a rapid movement into soil-less growing systems, as follows:

1. Tightening labour supply
2. Rising labour costs (Figure 1)
3. Loss of methyl bromide as a soil sterilants (DEFRA, 2014)
4. Countryside planning restrictions
5. EU Producer Organisation funding

By contrast to the decisions facing growers in the 1997, the new breed of field-scale strawberry growers had already paid for a large part of the structural investment required: large areas of tunnels, established pack-houses, irrigation lakes and accommodation for workers. The move into field scale soil-less systems was a less expensive decision than before. Tunnels might need up-grading, but investments could be incremental.

Just as in the 1980s and 1990s the decision to purchase tunnels was driven by the positive outcome of simple short term pay-back calculations, by the same kind of mathematics it has been easy to justify additional investments in table top systems.

Figure 1. Trends in the value of strawberries (DEFRA, 2013) and labour costs (Anon, 2014). Real values extrapolated using web based price index calculator (Browning, 2014).

Systems employed

Table Top – Supporting Structures

At first, most attention was paid to the cost of materials so that growers used such items as creosote treated wooden orchard stakes. High tensile steel wire was preferred to glasshouse heating pipe for horizontal support. Strawberry ‘Grow Bags’ have been the dominant container for substrate, preferred to troughs, buckets and pots.

Agronomists tended to prefer rigid horizontal supports which promote uniformity of canopy height along the crop row and also of substrate moisture within individual bags. In the period 2006 – 2010 perhaps the most popular design was based on a combination of a single rigid pipe combined with two parallel HT wires to prevent sideways movement of the supported bags.

Instead of new galvanised steel, growers have tended to purchase old 60 mm hot water pipes retrieved from glasshouses during refurbishment (Figure 2). This pipe is used both for horizontal and vertical supports.

While growers were aware of the more sophisticated gutter-based systems used by glasshouse growers (tomato, pepper, strawberry, raspberry etc.) these were regarded as too expensive until Haygrove Tunnels developed a machine tool designed specifically for producing a standardised gutter. Without the complication of adjustments required to form gutters of another type and with the economy of scale provided by contracts to build field scale installations, Haygrove were able to provide a much improved growing system at a competitive price (Figure 3).

Figure 2. "Pre-used" glasshouse heating pipe installed as vertical supports for table top production

Growers had become increasingly concerned about the labour element of installing table top systems whereas gutter systems, especially when formed on-site, require significant less labour to assemble.

Figure 3. New gutter and steel system shortly after installation

Growing Media

Whereas peat was the standard medium even in 2006 – often from resources in the British Isles – campaigning pressure to conserve peat bog habitats lead to greater interest in coir (coco-peat). While it was standard practice to dispose of peat bags after 12 months, coir bags were often used for 1 or 2 additional cropping cycles off-setting the higher purchase cost.

Strawberry and raspberry growers still using peat as a component in substrates for fruiting crops – as distinct from propagation crops – are now very much in a minority.

Coir retains a more open structure into 2nd and 3rd use than peat, but it is still the case that some varieties perform less well in 2nd use bags than in new bags. The use of coarser grades, extra quantities of coir fibre and perlite are all used as a means to extend the useful life of bags.

Field scale strawberry production using bags certainly offers an incentive to suppliers to provide a competitive offer. A typical ‘field’ of bag grown strawberries requires a number of bags that, placed end on end, would extend for a distance of 15 – 20 kilometres.

Irrigation

Already essential for protected crops grown in the soil, irrigation has become an even more important function for bag-grown crops.

The majority of bags are irrigated via on-line dripper systems, with 3 – 6 emitters per 1 metre bag. Checking coir moisture content and maintaining drippers is a full time job at some farms. Irrigation system design plays a vital role in successful soil-less growing systems. Growing a crop without soil removes some major threats to production. There is the potential to harvest similar quantities from every square metre of land occupied by soil-less system. That potential cannot be realised if the irrigation system fails to deliver an equal amount of water and nutrients to every bag or plant grown on that land.

Table 1. Irrigation system and labour costs (Moore, 2014)

Per hectare cost *per annum*		
Fertiliser	£2,900	
Water	£3,500	Cost varies with source
Maintenance (materials)	£ 600	
Operation & checking (labour)	£2,000	
Removal and replacement of drippers between crops	£1,500	
System (depreciation)	£2,500	10 year period

Growers are eager to find ways to reduce the total cost of fertigation (irrigation + fertiliser) without reducing yield. Levy funded research into reducing water and fertiliser use and also into recycling is on-going. Larger farms have excavated substantial reservoirs to collect winter rain. Farms are also fixing metal gutters to their tunnels to collect roof water. The gutters are formed using similar machines to those used to form the crop gutters. These ‘leg row gutters’ also add strength to poly-tunnel structures.

Water use and the conductivity of the nutrient solution are monitored at ‘run off’ stations – usually at least one per irrigation block. A worker is assigned the task of checking this every day. Some of these tasks are automated using computer linked systems but most fields are still checked ‘by hand’ using a measuring jug and a combined ec/pH meter.

Variation between and within bags is checked using the popular Delta-T Devices WET probe system (De Nijs, 2014). There is considerable scope and need for automation of monitoring tasks to reduce the labour costs detailed in Table 1 and to improve the precision (timing, quantity).

Spraying

At the great majority of farms sprays are applied using tractor-trailed or tractor-mounted sprayers. Growers have no wish to move away from tractor based operations in the absence of more efficient alternatives. The ‘rental cost’ per square metre of land under field scale poly-tunnels is much less than that for glass so that the operational efficiencies provided by tractor use are reckoned to justify the space lost.

Narrow vineyard tractors (1 – 1.2 m) are commonly used. Whereas a tractor without a cab requires less space, many growers prefer to leave space for a tractor with a cab to facilitate safer operations and improve working conditions for the driver. New types of sprayer have been developed, notably by the engineering company N P Seymour Ltd (Seymour, 2014). Air assistance is preferred.

Plant material, yields and production cycles

In 1997 most soil-less strawberry blocks would have been focussed on production from short day varieties with the variety ‘Elsanta’ dominating. Today the situation is very different. Many of the largest soil-less blocks are now devoted to production from ‘everbearer’ varieties and even where short day varieties are still important, ‘Elsanta’ has often been replaced by ‘Sonata’ and a range of recent introductions.

Unfortunately ‘Elsanta’ is prone to yielding misshapen fruits which reduces class 1 yield and increases picking and post-harvest costs. ‘Elsanta’ grown on table top structures seems to be even more prone to this problem.

However a good ‘Elsanta’ crop still provides a benchmark against which to judge the performance of other varieties. Typical yields and crop timing for the south of England are shown in Table 2.

Table 2. Example of soil-less system yields for cv. 'Elsanta' established using tray plants (Carew, 2014)

		Bags on beds + Telescopic Tunnels	**Bags on table tops + Standard tunnels**
Autumn Crop	Planting date	5 July	4 July
	First pick	26 August	26 August
	Last pick	27 October	27 October
	Yield per hectare	23.5 Tonnes	25.2 Tonnes
Spring Crop	First pick	27 April	12 May
	Last pick	19 June	17 June
	Yield per hectare	25.2 Tonnes	29.2 Tonnes
Yield over 12 month cycle		48.7 Tonnes	54.9 Tonnes

Table 2 shows data from a good crop planted in July using cold-stored tray plants. After the final autumn pick any remaining fruits are removed, but the tunnels remain clad for at least two weeks in order to increase flower initiation. Even in the south of England it is important to avoid any delay to the date of planting. For standard types of field scale tunnels 5 – 7th July are considered to be the latest safe dates. Planting late delays the start of cropping which can push the peak harvest week into a higher price period but a lot of potential yield is lost when fruits fail to ripen as winter sets in. Worse still, such plants fail to initiate a good number of flowers for the spring crop.

With changing market conditions, autumn strawberry prices in the UK have been relatively low in recent years because of increased production from ‘everbearer’ varieties and primocane raspberries. Early spring prices are usually higher. It is therefore important to avoid any reduction in the number of spring flowers.

Table top growing systems are also, naturally, 8 – 10 days later than soil grown crops grown under the same tunnels, without heating. The difference between the two systems is illustrated by Table 3 and may amount to £0.40/kg at early sites. For late sites the difference shrinks to £0.11.

Picking costs are reputed to be at least 30% lower for table top grown crops. Typically this would amount to a saving of £0.15/kg.

Given that is important to finish the spring harvest in time to replant before 5th July a second crop may not be a viable option at many sites, especially after a late spring, such that only table tops housed in tunnels designed for exceptional earliness are viable unless the new plants are started at another site.

Table 3. Impact of earliness and system choice on income per kilo – Short day varieties (Moore, 2014)

			Difference[2] (Ground level – Table top)
Short day variety (eg. Elsanta)	Income[1] per kilo	Early site	+£0.39
		+ 1 week	+£0.29
		+ 2 weeks	+£0.14
	Relative picking costs		-£0.15

[1]Net of all post-harvest costs
[2]Figures are typical rather than actual values

Table 4. Impact of earliness on income per kilo - Everbearer varieties (Moore, 2014)

			Difference[2] (Relative to early site)
Everbearer variety example	Income[1] per kilo	Early site	£0.00
		+ 1 week	-£0.04
		+ 2 weeks	-£0.11

In the UK, ‘everbearer’ varieties (‘Driscoll Amesti’, ‘Sweet Eve’, ‘Eve’s Delight’, ‘Portola’, ‘Capri’, ‘Triumph’) can produce a similar and often greater yield over a 12 month period than short day varieties. While the ‘first flush’ of fruit given by ‘everbearer’ varieties is becoming more important, because the eating quality of some of the varieties grown is considered equal or even superior to short day varieties, the quantity of fruit produced in that first flush is lower. As a consequence the reward for early production is also lower. Most of the output from ‘everbearer’ varieties is harvested at a time when prices are relatively low, so that picking efficiency is a greater priority.

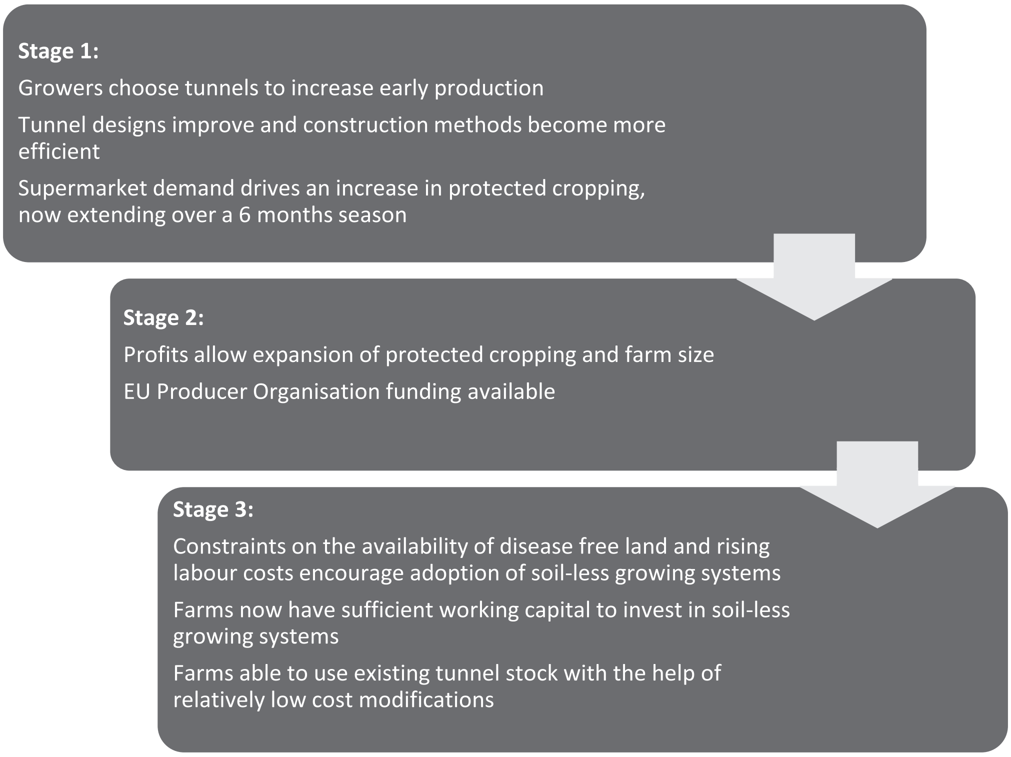
Getting the most out of soil-less growing systems (yield, quality, presentation of fruit for picking, spray coverage) requires additional husbandry work (leaf thinning, leaf and truss separation, irrigation management). Just as for picking, most of these tasks are cheaper to perform on table tops than they are for ground level crops. The difference can be > £0.20/kg.

These differences mean that, even at early farms, most fruit is harvested from table top systems and not from ground level systems.

Conclusion

Strawberry production in the UK has tended to expand most rapidly at farms with a background in field scale cropping – as distinct from intensive glasshouse production. The evolution of these farms into relatively intensive soil-less producers could be summarised by the chart in Table 5.

Table 5. Evolutionary process



Despite starting out by using growing systems that required relatively low levels of capital investment the success of field scale protected strawberry production generated sufficient profit for rapid business expansion and provided capital for the additional investments required for the move into soil-less production.

Field scale tunnel technology also changed to satisfy the need for more efficient and permanent structures but in such a way that growers are often able to modify existing structures instead of spending much larger sums of money on new structures.

References

Anderson, P. 1998. The Strawberry Handbook, pp. 37 – 42.

Anonymous. 2014. National minimum wage: historical rates. www.is4profit.com/business-advice/employment/national-minimum-wage-historical-rate

Browning, R. 2014. Historical inflation calculator: How the value of money has changed since 1990. www.thisismoney.co.uk

Carew, J. 2011. Physiology of the strawberry (presentation and course notes). FAST School of Fruit Growing.

DEFRA. 2013. Basic horticultural statistics hort-dataset. Department for the Environment & Rural Affairs.

DEFRA. 2004. New strawberry production system – growing without methyl bromide. Promotional document for Department for the Environment & Rural Affairs DEFRA HortLink project HL0 015/ HDC project SF 053.

De Nijs, B. 2014. News bulletin: http://www.freshplaza.com/article/131702/UK-WET-Sensor-saves-on-costs. Fresh Plaza.

Moore, G. 2014. Unpublished data collected from grower clients of FAST LLP.

NHF. 2011. National Horticultural Forum, pp. 3.

Seymour, N. 2014. Website: http://npseymour.co.uk/machinery/straddle-sprayer-for-table-top-strawberries/

Wilson, D. 1997. Grower Guide 6: Strawberries under protection. Grower Books. (ISBN 1 899372 11), pp. 5 – 6.

Invited lecture

ALTERNATIVE METHODS OF SOIL DISINFECTION IN STRAWBERRY PRODUCTION

Darinka Koron

Agricultural Institute of Slovenia, Ljubljana, Slovenia
E-mail: darinka.koron@kis.si

Abstract. Alternative methods of soil disinfection, biofumigation and solarisation, impact on strawberry (*Fragaria* x *ananassa* Duch.) growth, yield and arbuscular mycorrhiza in the field and pot experiment. Biofumigation was performed by adding the *Brassica juncea* (Bj), *Sinapis alba* (Sa) and *Eruca sativa* (Es) grind plants. Solarization was performed with black or transparent foil in the field experiment and by substrate heating (37 °C) in pot experiments. In comparison to dazomet (chemical disinfection), biofumigation and solarization in pot experiments had positive impact on growth and yield, but in comparison to the control, the growth and yield were better or the same. Biofumigation resulted in the increase of organic matter and nutrients in the soil and substrates. On average, the most effective biocidal plant was Sa, which also reduced the number of weeds, but not the same as chemical disinfection. Other treatments have been equalized with the control. The frequency of mycorrhiza, except in the dazomet treatment, was very high. In pot experiment dazomet prevents mycorrhizal colonization. Solarization had no impact on mycorrhizal colonization. In the field experiment, biofumigation and solarization had slight impact on growth, yield and mycorrhizal colonization. With molecular techniques PCR and TTGE in pot experiment we identified *Glomus* spp. and *Rhizoctonia* sp.

Key words: biofumigation, solarization, arbuscular mycorrhiza, growth, yield, weeds.

Introduction

Intensive strawberry production (*Fragaria* x *ananassa* Duch.) requires a change of soil cultivation and plant protection due to the concern for the environmental protection, care for human health and increasing transition of producers to organic production. The quantity and quality of strawberry yield are directly affected by physical, chemical and biological soil properties. In all cultivation technologies great emphasis has to be paid to the position of location of strawberry field, type of the soil and soil cultivation with respect to the multiannual crop rotation with suitable plants. This is to avoid a depletion of nutrients from soil and the most serious problem with soil pathogens which present one of the greatest issues in the strawberry production. In the very intensive strawberry technologies, crop rotation replaces chemical disinfection which is harmful and environmentally unfriendly. In sustainable agriculture, solarization and biofumigation are alternative methods of soil disinfection which can reduce the classical crop rotation from 3 or 5 to one to two years. For soil solarization, the soil is covered by a transparent plastic foil and so heated by the solar radiation to temperatures that are detrimental to soilborne pathogens (Pinkerton et al., 2002). For biofumigation, the biofumigant (biocidal) plants of the *Brassicaceae* family are characterised by high glucosinolates content which are released into the soil where they can influence microbial growth (Lazzeri and Manici, 2001; Seigies and Pritts, 2006). All disinfection methods affect the pathogen and beneficial microorganisms (MO), including the arbuscular mycorrhiza (AM) fungi. The effect on the beneficial MO and the indirect effect on yield depend on the type of disinfection, the growing and climatic conditions and the cultivated crops.

In the strawberry production, next to diseases, weeds are the biggest problem. Treatment with herbicides is difficult and expensive because it requires herbicides with selective activity. In the IP and EKO production the direct use of herbicides is not permitted. Planting on foil reduces the growth of weeds, but not those in the planting places where they still present a problem. The majority of soil disinfectants have herbicidal effect. Recent chemical disinfectants are more selective and less effective than methyl bromide which could be used in the past in several countries.

The main aim of this study was therefore to assess the effects of selected non-chemical soil fumigant treatments (biofumigation and solarization) on strawberry plant growth and fruit production and on AMF colonisation of strawberry plants, in comparison with untreated control and chemical fumigation.

Materials and methods

Field experiment was conducted on the experimental field of Agricultural Institute of Slovenia and pot experiments were carried out in greenhouse and laboratories. In the field experiment frigo plants of ‘Marmolada’ variety were planted and micropropagated plants were used in pot experiments. The effect of solarization and biofumigation on plant growth, fruit production and mycorrhiza was evaluated in pot experiments for three years and in a field experiment for one year. We compared the effect of alternative disinfection methods to that of chemical disinfection with dazomet (Basamid) and the control treatment. In the pot experiment, solarization was carried out by heating the soil to 37 °C while biofumigation was performed by adding the *Brassica juncea* (Bs), *Sinapis alba* (Sa) and *Eruca sativa* (Es) ground biocidal plants. We always added the same amount of biocidal organic mass (25 g of frozen and ground up plants were added to 250 g of soil from the experimental field). In the pot experiment half of the plants of each treatment were inoculated with natural mycorrhizal inoculum produced by growing the VA mycorrhiza on maize roots in the soil coming from an ecologic strawberry field. Each treatment of the pot experiment included 15 plants. In the field experiment the soil was solarized (covered) with black and transparent foil for 6 and 9 weeks. Biofumigation was carried out with green manure using the Bj, Sa and Es biocidal plants and compared with green manure using the *Vicia faba* (Vf) non-biocidal plant. In the field experiment we also compared the effect of alternative disinfection methods to dazomet and the control treatment. The field experiment was conducted in three blocks with 10 plants in each treatment.

Mycorrhizal, dark septate endophytes and pathogen fungi were evaluated by microscope (light microscope) of root samples. We identified the mycorrhiza and other fungi using PCR and TTGE methods.

STASTGRAPHICS Centurion XV.II programme (StatPoit, Inc., 2006) was used for analysis of variance (ANOVA). Significant differences were determined according to Duncan's Multiple Range Test ($P \leq 0.05$).

Results and discussion

Soil analyses

The conditions in the soil were essentially changed due to alternative disinfection methods, especially biofumigation (Table 1). On the basis of soil analyses made before and after the pot experiment (II), neutral or beneficial effect of green manure with biocidal plants and solarization on strawberry growth and development of beneficial AM fungi was proved.

Table 1. Chemical analysis of soil before and after the pot experiment

Treatment	pH	P_2O_5 (mg/100 g soil)	K_2O (mg/100 g soil)	Total nitrogen (%)	Organic matter (%)
Pre - treatment	6,0 ± 0,3	4,1 ± 0,1	25,9 ± 0,1	0,27 ± 0,01	3,4 ± 0,1
Post - treatment					
Bj	5,9 ± 0,1 b	7,9 ± 0.1 c	29,0 ± 0,3 a	0,28 ± 0,01ab	5,6 ± 0,1 b
Sa	6,2 ± 0,1 a	11,0 ± 0,1 a	25,0 ± 0,7 b	0,30 ± 0,00 a	6,3 ± 0,1 a
Es	5,8 ± 0,1 bc	11,0 ± 0,1 a	25,0 ± 0,3 b	0,27 ± 0,01 b	5,3 ± 0,1 c
SOL	5,2 ± 0,1 d	6,9 ± 0,3 d	10,0 ± 0,5 d	0,25 ± 0,00 b	4,1 ± 0,1 e
D	5,1 ± 0,0 d	5,8 ± 0,1 e	7,5 ± 0,1 e	0,25 ± 0,00 b	4,3 ± 0,1 e
K	5,5 ± 0,1 c	8,4 ± 0,1 b	13,0 ± 0,1 c	0,25 ± 0,01 b	4,8 ± 0,1 d

(Bj = *Brassica juncea*; Sa = *Sinapis alba*; Es = *Eruca sativa*; SOL = solarization; D = dazomet; K = control)

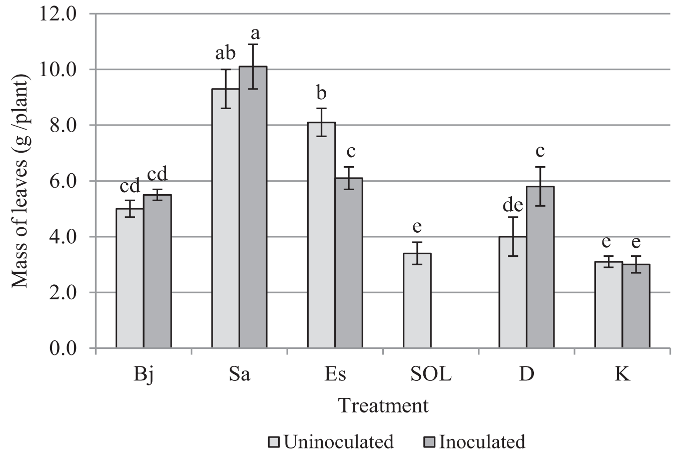
Solarization and biofumigation contributed to higher soil quality by raising the content of organic matter and nutrients in soil and the reestablishment of favourable ratio between beneficial and pathogenic MO. The *Brassicaceae* plants provide a significant effect on the N supply for the next culture (Smith et al., 2004; Marchetti et al., 2008). Even though in the field experiment with Sa the lowest quantity of organic mass was incorporated into the soil, the effect on the yield was very good. The effect of Sa was the most favourable in the pot experiments. In the field experiment, different amount of organic mass was incorporated with biocidal plants into the soil.

Plant growth and fruit production

Plant growth in pot and field experiment cannot be compared because of different plant material and different growing conditions. Differences between treatments in pot experiments were statistical significant (Figure 1). In all pot experiments Sa had a great impact on mass of leaves. In the field experiment on the plant growth chemical disinfection with dazomet, Es and Sa had the same effect.

Plant growth was statistically different from solarization treatments and the control. Plant growth of inoculated plants in pot experiments was higher in comparison to uninoculated plants but differences were not statistical significant.

a)



b)

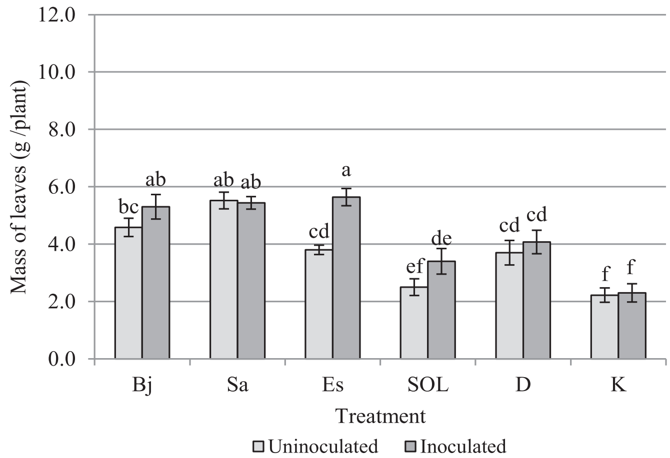


Figure 1. The mass of leaves per plant in the LP I (a) and LP II (b)
Column shows the mean ± SE. Values marked with different letters are statistically different at p <0.05 (ANOVA, Duncan's test) (Annex H nd I) (Bj = *Brassica juncea*; Sa = *Sinapis alba*; Es = *Eruca sativa*; SOL = solarization; D = dazomet; K = control)

Fruit production in pot experiment was evaluated with the number of fruit per plant and in the field experiment with the number and the mass of fruit per plant. In pot experiments the highest average yield was at Sa treatments and the lowest at chemical disinfection. In most of the treatments, except at Bj and Es the yield was higher in treatments with inoculation (Figure 2). In the field experiment the greatest yield was at Sa treatment and at chemical disinfection with dazomet. Growth conditions in the field were different and the duration of chemical disinfection was shorter than in the greenhouse because of external factors. In comparison to the control and solarization (or heating in pot experiments) biofumigation with various biocidal plants had a major impact in strawberry yield.

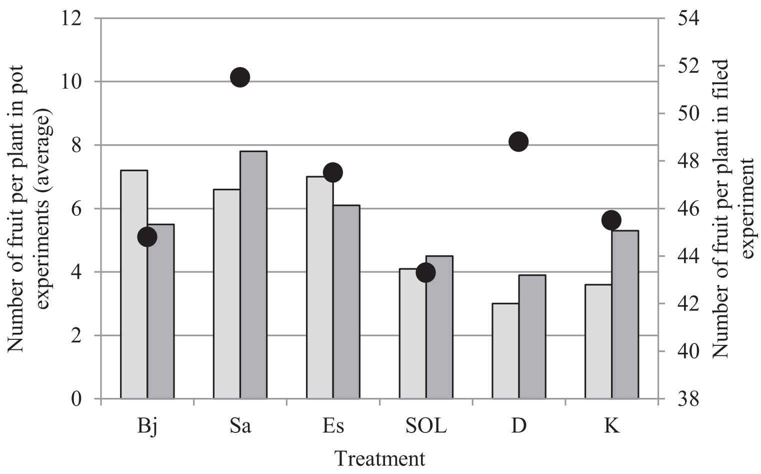


Figure 2. The number of fruits per plant in pot experiments compared with similar treatments in the field experiment
(Bj = *Brassica juncea*; Sa = *Sinapis alba*; Es = *Eruca sativa*; SOL = solarization; D = dazomet; K = control; Pot experiment – Uninoculated; Pot experiment - Inoculated; Field experiment)

Weeds

In our field and pot experiments, dazomet was successful against weeds if compared with alternative methods. In the field experiment, treatments with biocidal plants had more weeds.

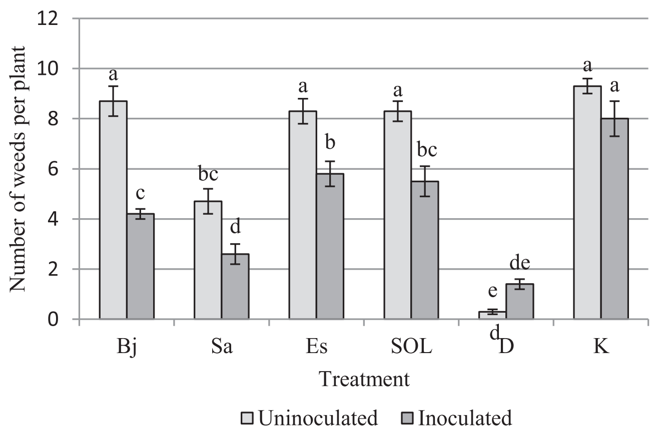


Figure 3. The number of weeds in the planting site in LP I and LP II
Values marked with different letters are statistically different at $p < 0.05$ (ANOVA, Duncan's test) (Annex J) (Bj = *Brassica juncea*; Sa = *Sinapis alba*; Es = *Eruca sativa*; SOL = solarization; D = dazomet; K = control)

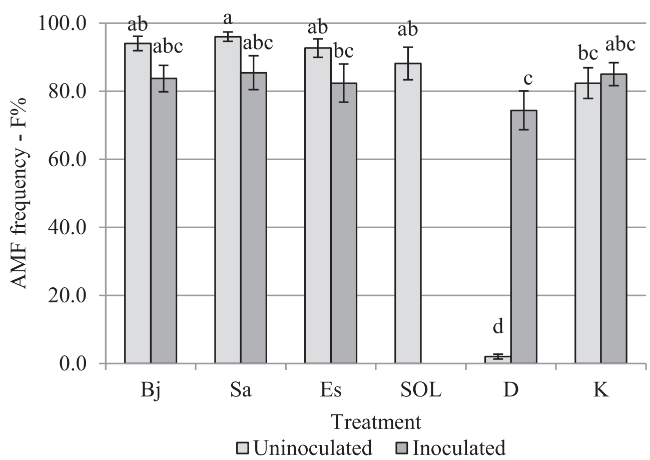
The number of weeds in all treatments with green manure, including biocidal plants, was higher, probably due to the increased organic matter in soil. The maximum weediness was observed in the Bj treatment and the minimum one in the Sa treatment.

We cannot confirm the hypothesis that biofumigation reduces the weeds, because in all experiments only the Sa treatment reduced the weed growing. Solarization with the transparent foil in the field experiment has the greatest influence on weeds among alternative methods. There was no statistical difference between solarization treatment and dazomet treatment. In pot experiments, Sa treatment had the greatest influence on weeds and it was not statistically different from dazomet treatment (Figure 3).

Mycorrhizal colonization

The strawberry mycorrhizal colonization is influenced by external, genetic and technological factors (Branzanti et al., 2002; Vestberg et al., 2002). The incorporation of large amount of organic mass increases the amount of nutrients and MO in the soil. The average mycorrhizal colonization in the field experiment was lower in comparison with that in the pot experiments. The main reason for that was the difference between the natural environment and the isolated conditions in the greenhouse. The frequency of strawberry mycorrhiza was very high in our experiments, with the exception of dazomet treatments. In the field experiment it ranged from 37% to 55.5% and in the LP I and LP II without MI it ranged from 47.3% to 96%. The frequency of mycorrhiza was higher in the inoculated treatments. The responses of strawberries in different treatments to AM inoculation were varied. With the biofumigation, some of the beneficial MO gained or incurred a loss (Scott and Kundsen, 1999; Mattner et al., 2008). The biocidal plant toxicity is avoided by sowing or planting the succeeding crop a few weeks after the incorporation of biocidal plants (Scott and Kundsen, 1999). From the data of the impact of biocidal plants on mycorrhizal colonization and control treatment (without MI) a very small negative effect of biocidal plants on mycorrhizal colonization (field experiment, LP II) or even their beneficial effect (LP I and LP III) was observed (Figure 4).

a)



b)

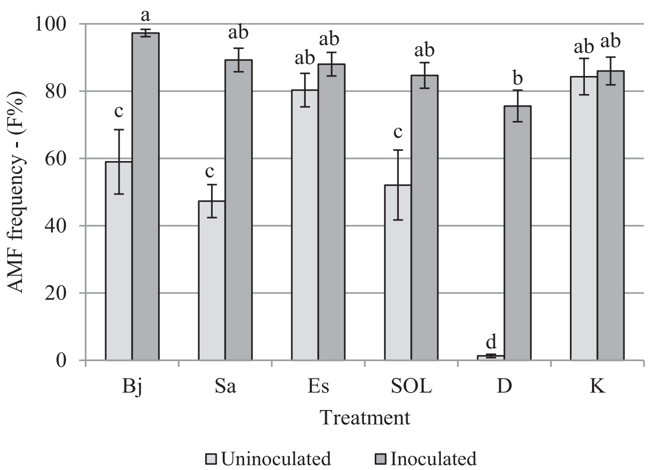


Figure 4. Frequency of mycorrhiza (F%) in the LP I (a) and LP II (b)
Column shows the mean ± SE. Values marked with different letters are statistically different at $p < 0.05$ (ANOVA, Duncan's test) (Annex O and P) (Bj = *Brassica juncea*; Sa = *Sinapis alba*; Es = *Eruca sativa*; SOL = solarization; D = dazomet; K = control)

In the Slovenian climatic conditions the combination of solarization and biofumigation is a perspective technological step because with solarization it is difficult to achieve the required amount of high temperatures. In the field experiment we proved a beneficial or neutral effect of solarization on the beneficial soil MO. We achieved higher soil temperature under transparent foil than under the black one. The differences decreased with the depth. Under transparent foil in the field experiment the critical temperature of 37 °C at the depth of 10 cm was exceeded in 6 days. The duration of high soil temperatures in all types of covering was too short. Transparent foil in the field experiment undoubtedly reduced weeds in comparison with other alternative methods and the control treatment but did not have any influence on the mycorrhizal colonization and yield. In comparison with other treatments, mycorrhiza was the most developed under black foil. The duration of solarization had an effect on mycorrhiza. In the treatment which was three weeks longer covered with transparent foil, F was by 5.4% lower and under black foil it was lower by 2.9%.

Chemical disinfection of soil destroys the mycorrhiza or inhibits its development (Branzanti et al., 2002). The presence of individual MO species in soil is highly influenced by seasons. Chemical disinfection has a diversified effect on the AM fungi. In the field experiment the effect of dazomet was minimal. The frequency of strawberry mycorrhiza in the dazomet treatment was only by 1% lower in comparison with the control treatment. The reason for the poor effect of dazomet on the mycorrhiza fungi in the field experiment may have been the external factors and the high soil re-mycorrhization (Niemi and Vestberg, 1992). In the pot experiments dazomet almost completely destroyed the mycorrhizal fungi.

On the basis of molecular determination we confirm the presence of the genus *Glomus* sp. and the species *Glomus intraradices* and also the presence of the pathogenic fungi *Rhizoctonia* sp. Biocidal plants had a greater influence on the diversity of mycorrhizal fungi than on the frequency of mycorrhizal colonization.

Conclusion

With alternative disinfection methods we made favourable plant growing conditions, and at the same time conditions for symbiosis between plants and soil microorganisms. In our experiments we find out that biofumigation and solarization had neutral or positive impact on growth parameters, yield and plant health. With biocidal plants, organic matter was incorporated with nutrients into the soil therefore higher P in the soil had negative impact on mycorrhiza (in one experiment). Against weeds, in the field experiment solarization has been only successful and Sa in the pot experiments. On the basis of experiments we can say that for alternative soil disinfection with biofumigation in regular field production we have to increase the amount of incorporated mass of biocidal plants and prolong the duration of covering with transparent foil (solarization).

References

Branzanti, M.B., Gentili, M., Perini, R., Neri, D., Cozzolino, E. 2002. The mycorrhizal status of strawberry plants under different pre planting and cultivation techniques in the field. Acta Horticulturae, 567, 495-489.

Lazzeri, L., Manici, L.M. 2001. Allelopathic effect of glucosinolate-containing plant green manure on *Pythium* sp. and total fungal population in soil. HortScience, 36, 7, 1283-1289.

Marchetti, R., Lazzeri, L., Malaguti, L., Orsi, A., Ponzoni, G. 2008. Potentially mineralizable nitrogen is soil green manured with biocidal crops. 16th IFOAM organic World Congress, Modena, Italy, June 16-20. http://orgprints.org/11969 (17. dec. 2011)

Mattner, S.W., Porter, I.J., Gounder, R.K., Shanks, A.L., Wren, D.J. Allen, D. 2008. Factors that impact on the ability of biofumigants to suppress fungal pathogens and weeds of strawberry. Crop Protection, 27, 1165-1173.

Niemi, M., Vestberg, M. 1992. Inoculation of commercially grown strawberry with VA mycorrhizal fungi. Plant and Soil, 144, 133-142.

Pinkerton, J.N., Ivors, K.L., Reeser, P.W., Bristow, P.R., Window, G.E. 2002. The use of soil solarization for the management of soilborne plant pathogens in strawberry and red raspberry production. Plant Disease, 6, 645-651.

Scott, J.S., Knudsen, G.R. 1999. Soil amendment effects of rape (*Brassica napus*) residues on pea rhizosphere bacteria. Soil Biology and Biochemistry, 31, 1435-1441.

Seigies, A.T., Pritts, M. 2006. Cover crop rotations alter soil microbiology and reduce replant disorders in strawberry. HortScience, 41, 5, 1303-1308.

Smith, R., Subbarao, K., Koike, S., Fennimore, S., Barber, A. 2004. Mustard cover crops for control soilborne disease and weeds, and nitrogen cycling in cool season vegetable production in the salinas valley. HortScience, 39, 4, 832.

Vestberg, M., Kukkonen, S., Uosukainen, M. 2002. Occurrence and effectiveness of indigenous mycorrhiza of some strawberry fields in Finland. Acta Horticulturae, 567, 499-502.