Eesti Maaülikool
Estonian University of Life Sciences

EFFECT OF ORGANIC MANAGEMENT METHODS ON YIELD AND QUALITY OF CARROT AND ON WEEDS

MAHEVILJELUSE MEETODITE MÕJU PORGANDI SAAGILE JA KVALITEEDILE NING UMBROHTUDELE

INGRID BENDER

A Thesis
for applying for the degree of Doctor of Philosophy
in Agriculture

Väitekiri
filosoofiadoktori kraadi taotlemiseks
põllumajanduse erialal

Tartu 2021

Eesti Maaülikooli doktoritööd

Doctoral Theses of the Estonian University of Life Sciences

Eesti Maaülikool
Estonian University of Life Sciences

EFFECT OF ORGANIC MANAGEMENT METHODS ON YIELD AND QUALITY OF CARROT AND ON WEEDS

MAHEVILJELUSE MEETODITE MÕJU PORGANDI SAAGILE JA KVALITEEDILE NING UMBROHTUDELE

INGRID BENDER

A Thesis
for applying for the degree of Doctor of Philosophy
in Agriculture

Väitekiri
filosoofiadoktori kraadi taotlemiseks
põllumajanduse erialal

Tartu 2021

Institute of Agricultural and Environmental Sciences
Estonian University of Life Sciences

According to verdict No 6-14/18-1, of November 15th 2021, the Doctoral Committee of the Agricultural Sciences of the Estonian University of Life Sciences has accepted the thesis for the defence for the degree of doctor of Philosophy in Agriculture.

Opponent: **Terhi Suojala-Ahlfors**, PhD, Senior Scientist
Natural Resources Institute Finland (Luke)

Supervisors: **Anne Luik**, PhD, Professor Emeritus
Estonian University of Life Sciences

Evelin Loit, PhD, Associate Professor
Estonian University of Life Sciences

Ilmar Tamm, PhD, Senior Researcher
Estonian Crop Research Institute

Defence of the thesis:
Estonian University of Life Sciences, Fr. R. Kreutzwaldi 5, Tartu on December 17th 2021 at 10.15

The English language was edited by Piret Rääbus, University of Tartu

The Estonian language was edited by Ülle Tamm, Estonian Crop Research Institute and Reet Bender, University of Tartu

ISSN 2382-7076
ISBN 978-9916-669-15-0
ISBN 978-9916-669-16-7 (pdf)

CONTENTS

LIST OF ORIGINAL PUBLICATIONS

This thesis is based on the following research papers, which are referred to by their Roman numerals:

I **Bender, I.**, Edesi, L., Hiiesalu, I., Ingver, A., Kaart, T., Kaldmäe, H., Talve, T., Tamm, I., Luik, A. 2020. Organic carrot (*Daucus carota* L.) production has an advantage over conventional in quantity as well as in quality. *Agronomy*, 10, 1420.

II **Bender, I.**, Ess, M., Matt, D., Moor, U., Tõnutare, T., Luik, A. 2009. Quality of organic and conventional carrots. *Agronomy Research*, 7, 572−577.

III **Bender, I.**, Moor, U., Luik, A. 2015. The effect of growing systems on quality of carrots. *Research for Rural Development* 2015, 1, 118−123.

IV Navarro-Miró, D., Blanco-Moreno, J.M., Ciaccia, C., Chamorro, L., Testani, E., Kristensen, H.L., Hefner, M., Tamm, K., **Bender, I.**, Jakop, M., Bavec, M., Védie, H., Lepse, L., Canali, S., Sans, F.X. 2019. Agroecological service crops managed with roller crimper reduce weed density and weed species richness in organic vegetable systems across Europe. *Agronomy for Sustainable Development*, 39, 55.

Papers are reproduced by kind permission of the journals concerned.

The contribution of Ingrid Bender to the papers was the following:

Paper	Idea and study design	Data collection	Data analyses	Manuscript preparation
I	*	*	*	*
II		*	*	*
III	*	*	*	*
IV	*	*		*

LIST OF ABBREVATIONS

ADI	acceptable daily intake
ASC	agroecological service crops
C	conventional treatment
C : N	carbon nitrogen ratio
CON1	conventional treatment, sprayed one time
CON3	conventional treatment, sprayed three times
CON5	conventional treatment, sprayed five times
CON-AV	average of three conventional production treatments
DM	dry matter
EC	European Commission
ECRI	Estonian Crop Research Institute
EFSA	European Food Safety Authority
EPPO	European and Mediterranean Plant Protection Organization
EPRS	European Parliamentary Research Service
EU	European Union
FAO	Food and Agriculture Organization of United Nations
FiBL	Research Institute of Organic Agriculture
FW	fresh weight
GM	green manure
IFOAM	International Federation of Organic Agriculture Movements
ILRC	in-line tillage/roller crimper
JaccD	Jaccard distance
LTA	long-term monthly average
MRL	maximum residue level
N	nitrogen
NO_3	nitrate
NWPC	non-woven polypropylene cover
NPK	nitrogen, phosphorus, potassium
O	organic treatment (TP2)
ORG	organic treatment (TP1)
RC	roller crimper
SCF	The European Commission's Scientific Committee on Food
TP1	trial period one (carrot), years from 2008 to 2009
TP2	trial period two (carrot), years from 2011 to 2014
TS	total sugars
Y1	trial period one (no-till), 2015/2016
Y2	trial period two (no-till), 2016/2017

1. INTRODUCTION

The European Green Deal aims to expand the use of sustainable practices, including organic farming (European Commission, 2021). Organic production has been one of the fastest growing food sectors globally, as there is increasing demand for organic food products, including vegetables, throughout the world (Smith *et al.*, 2009; Niggli, 2015; IFOAM, 2018; Rahman *et al.,* 2021). Organic food produced without the use of conventional pesticides and synthetic fertilizers is attractive for consumers, as it is perceived to be healthier than food produced by conventional agriculture and more sustainable for the environment (Tuomisto *et al.*, 2012; Orsini *et al.*, 2016; Bosona & Gebresenbet, 2018; Gomiero, 2018; Massey *et al.*, 2018; Ditlevsen *et al.*, 2019). Organic production is regulated by and supported according to EU standards, products are controlled, certified and labelled (Reeve *et al.*, 2016; Kirdar, 2018), thereby an organic label helps consumer to make more trustworthy choices (El-Hage Scialabba, 2007).

Organic systems yield less food all over the world but at the same time contain significantly less to no synthetic pesticide residues compared with conventionally produced foods (Baker *et al.*, 2002; Bourn & Prescott, 2002; Winter & Davis, 2006; Zicari *et al.*, 2011). The adoption of organic agriculture under agroecological conditions where it performs best may close the yield gap between organic and conventional systems (Badgley *et al.*, 2007; de Ponti *et al.*, 2012; Seufert *et al.*, 2012; Ponisio *et al.*, 2015; Reganold & Wachter, 2016). Organic farming has positive effect on the important agronomical components of soil, these soils have a higher content of organic matter (Bulluck, *et al.* 2002; Mäder *et al.*, 2002; Mondelaers *et al.*, 2009; Reeve *et al.*, 2016; Bai *et al.*, 2018; FiBL, 2018; Vaitkevičiene *et al.*, 2020) and therefore, yields may increase.

Several earlier comparisons have led to a conclusion that significant differences in the nutrient and contaminant content between organic and conventional vegetables have not been confirmed (Dangour *et al.*, 2009; Hoefkens *et al.*, 2009; Smith-Spangler *et al.* 2012). Nevertheless, at the same time Giuseppina *et al.* (2011) have pointed out that even if organic products have not yet been proven to have a higher nutrient content, it should certainly have the lowest content of pesticides and substances harmful to health, such as a high content of nitrates. Hurtado-Barroso *et* *al.* (2019) refer to the advantage of organic food as it has a higher content of bioactive compounds (e.g., polyphenols, vitamin C and carotenoids).

The composition of a vegetable is known to depend on a wide range of genetic and environmental factors, many of which, such as climate, air pollution and maturity at harvest, are independent of the production system (Gobbo-Neto & Lopes, 2007). Only factors that differ systematically between organic and conventional farming have a potential to cause a systematic difference in product composition (Brandt *et al.*, 2011). It has been pointed out that studies comparing the yield and quality of organic *vs.* conventional vegetables have often provided inconsistent results due to methodological problems in their experimental design (Fjelkner-Modig *et al.*, 2000; Dangour *et al.*, 2009; Seljåsen *et al.*, 2013; Bernacchia *et al.*, 2016; EPRS, 2016; Reeve *et al.*, 2016). A typical concern has been the fact that fertilization rates of the main plant nutrients have been higher in conventional than organic crop production (EPRS, 2016). This problem can be reduced by adding more organic matter in the organic system, thereby improving soil health and reaching the same levels of nutrients as in the conventional system (Reeve *et al.*, 2016; Tejada *et al.*, 2008; Diacono & Montemurro, 2010; Bai *et al.*, 2018). Kirchmann *et al.* (2016) have stressed that at least three criteria should be followed to ensure correct interpretation of comparative studies of organic *vs.* conventional production: i) the initial soil fertility must be similar between plots; ii) only the same type of crop production is compared; iii) the rates of nutrient input to each system must be quantified. Taking into account the above-mentioned criteria, we compared the yield and quality indicators of carrots produced in an organic and in a conventional system, with the same initial soil fertility. Fertilization rates in organic treatment in the four-year experiment were within the optimal range of 80–180 N kg ha^{-1} as recommended by Kaack *et al.* (2001) and Seljåsen *et al.* (2012) and in the two-year experiment lower than optimum. Fertilization rates in conventional treatments were different but in the range of optimal rates.

Weed control is a problem in organic production. In organic systems agroecological service crops (ASC), also known as cover crops, green manures or catch crops, are considered a key strategy for managing weeds. They suppress weeds and improve at the same time soil quality (Gallandt, 2014). ASCs improve the whole agroecosystem not primarily in terms of higher yield, but in terms of enhanced ecosystem services

(Canali *et al.*, 2015), such as improved physical, chemical and biological properties of soil, weed suppression (Blanco-Canqui *et al.,* 2015) and reduction of nitrogen (N) leaching (Tonitto *et al.*, 2006). ASC will be terminated before the subsequent cash crop to avoid competition and reduce weed emergence. The most widespread management technique is their incorporation into the soil by noninversion tillage (sometimes ploughing) as green manure (GM), while no-till methods are hardly used (Peigné *et al.*, 2016). However, in recent years, the no-till roller crimper (RC) for ASC management has attracted the interest of organic farmers and researchers across Europe (Casagrande *et al.*, 2016; Vincent-Caboud *et al.*, 2019). The RC allows flattening of the ASC by creating a dense layer of plant residues (i.e., mulch) connected to the soil by the roots. The presence of mulch has physical and chemical effects, which can limit weed germination and seedling emergence (Ciaccia *et al.,* 2015). To the flattened surface it is possible to plant or sow a cash crop. This method is still poorly investigated and not well implemented in vegetable production. For the first time in Estonia, we studied the treatment of ASC (rye and triticale) with RC for weed control purposes. This study is needed for the further development of the no-tilling system in organic vegetable production. Investigation was carried out under the SoilVeg (ERA-Net CORE-Organic Plus) project.

2. REVIEW OF LITERATURE

2.1. Comparison of the effect of organic and conventional production system on yield and quality of carrot

2.1.1. Yield

Usual practice has been that crop (including vegetables) yields are lower in the organic system than in the conventional system (Fjelkner-Modig *et al.*, 2000; Rembiałkowska, 2000; De Ponti *et al.,* 2012; Seufert *et al.,* 2012; Lee *et al.,* 2015; Ponisio *et al.,* 2015; Wierzbowska *et al.,* 2017). Dresbøll *et al.* (2008) and Orsini *et al.* (2016) have suggested that the lower yield under organic farming is possibly caused by genetic determinants of specific varieties used in the system and/or an exposure to biotic and abiotic stresses that may affect organic crops. According to the EPRS (European Parliamentary Research Service) study (2016), a typical problem is that fertilization rates of the main plant nutrients are higher in conventional than organic crop production. The problem can be overcome by reaching the same levels of nutrients as in the conventional system (Tejada *et al.*, 2008; Diacono & Montemurro, 2010; Reeve *et al.,* 2016; Bai *et al.,* 2018). The closure of the yield gap between organic and conventional farming can be a matter of time and organic farming may result in greater spatial stability of the biotic and abiotic properties of soil and soil processes (Schrama *et al.*, 2018; Seufert 2019).

However, several studies also reveal data on more or less equal carrot or other vegetable yields in both organic and conventional production (Dresbøll *et al.*, 2008; Thorup-Kristensen *et al.*, 2012; Kniss *et al.*, 2016). According to Sink *et al.* (2017), one of the three carrot varieties produced the same yield in both, organic and conventional production, and two varieties had higher yields in organic production.

Physiological disorders of carrots depend on the soil type, soil moisture, N availability and plant variety (Gutezeit, 2001; Hartz *et al.*, 2005; Paoletti *et al.*, 2012). The share of discarded yield in the total in comparison of conventional and organic carrot yield has generally been little reported in research. Only Dresbøll *et al.* (2008) have observed no differences in the carrot discard rate between the two systems. In addition to the previous, Brainard and Noyes (2012) have mentioned that in one of the two experimental years, the application of compost decreased the percentage of forked and small carrots in total yield.

2.1.2. Nutritional quality

Total sugars (TS). Carrot among other vegetables, such as beets, onions, peas, and tomatoes, is the one having a high content of TS (100 g FW contains 4.7 g TS) (U.S. Department of Agriculture, 2020). The content of sugars in vegetables is an important sensory component and varies in carrots depending on plant nutrition, variety, weather conditions, location and soil (Baardseth *et al.*, 1996; Nookaraju *et al.*, 2010; Seljåsen *et al.*, 2013). A higher temperature sum during the growing period in Denmark experiments resulted in a higher TS content in carrots (Bach *et al.*, 2015). At the beginning of the carrot harvest period, the TS content was higher in a colder year than in warmer years (Suojala, 2000).

According to several studies, organic vegetables and other plant food contain more TS than their conventional counterparts (Rembiałkowska, 2003; Rembiałkowska, 2007; Rembiałkowska & Średnicka, 2009; Hallmann, 2012). The reason for the differences in the content of TS might be the fact that the analyzed vegetables were grown in different locations and under different nutrition. In addition, we have no information about the varieties. However, other studies have shown no differences in the content of TS of conventionally and organically produced carrots (Btandt & Mølgaard, 2001; Bach *et al.*, 2015; Sink *et al.*, 2017; Hlisnikovský *et al.*, 2021). Rosenfeld *et al.* (1998) have also come to a conclusion that sugar content in carrots seems to be affected more by climate-related factors (temperature, precipitation, light intensity, etc.) than by the production method.

Vitamin C is the most important vitamin in vegetables, one of the basic nutritional quality factors in many horticultural crops, and has numerous biological activities in the human body (Lee & Kader, 2000). Furthermore, vitamin C plays important roles in regulating almost all physiological processes during plant growth and development, including seed dormancy, seed germination, and fruit maturity (Dong *et al.*, 2015).

The content of vitamin C in vegetables depends on several factors, such as the genotype, maturity at harvest, fertilizer type, pre-harvest weather conditions, and soil type (Lee & Kader, 2000; Mozafar, 2018). The effect of fertilization on plant composition shows that the increasing presence of plant available nitrogen reduces the accumulation of defence related to vitamin C (Mozafar, 1993; Lee & Kader, 2000; Brandt & Mølgaard, 2001; Worthington, 2001; Brandt *et al.*, 2011). The differences here may be due to the rapid or slow release of N from synthetic or organic fertilizers, respectively, resulting in less N available to plants in organic production.

The vitamin C content was 6% higher in organic plants than in the corresponding conventional samples (Brandt *et al.*, 2011). Several research publications also state that vitamin C of organic production exceed that of the plants grown conventionally (Leclerc *et al.,* 1991; Rembiałkowska, 2003; Rembiałkowska, 2007; Benbrook *et al.,* 2008; Szafirowska & Elkner, 2008; Rembiałkowska & Średnicka, 2009; Hunter *et al.*, 2011; Jensen *et al.*, 2013; Kapusta-Duch & Leszczyńska, 2013; Sink *et al.*, 2017). Contradictory results have been reported from other studies, i.e., for carrots, significantly higher concentrations of vitamin C were registered in the plant food from conventional farming (Hoefkens *et al.,* 2009; Zakir *et al.,* 2012). However, many studies of vegetables and other crops could not verify significant differences due to the growing system (Warman & Havard, 1996; Warman & Havard, 1997; Fjelkner-Modig *et al.,* 2000; Brandt & Mølgaard, 2001; Masamba & Nguyen, 2008; Lairon, 2009; Bender & Ingver, 2012; Smith-Spangler *et al.,* 2012; Barański *et al.,* 2014; Pereira *et al.*, 2016).

Dry matter (DM) content in vegetables depends on the year, location, subspecies, variety and soil conditions (Seljåsen *et al.*, 2013; Putra & Yuliando, 2015; Shabetya *et al.*, 2020). A higher temperature sum resulted in a higher content of DM in carrots (Bach *et al.*, 2015). Increasing the amount of nitrogen applied decreased the DM content linearly (Kaak *et al.*, 2001).

According to earlier studies, organically grown vegetables had a higher DM content compared with conventional ones (Leszczynska, 1996; Woëse *et al.*, 1997; Fjelkner-Modig *et al.*, 2000; Bourn & Prescott, 2002; Rembiałkowska, 2007; Sikora *et al.*, 2009; Bender & Ingver, 2012). On the other hand, the results of other researchers have confirmed that the DM content of the product grown in organic systems did not differ significantly from that produced in the conventional system (Brandt *et al.*, 2011; Thorup-Kristensen *et al.,* 2012; Bach *et al.*, 2015).

Nitrogen and nitrates. Nitrogen (N) is an essential macronutrient that affects plant growth and development. It can often be the most limiting element for plant growth in agro-ecosystems (Liebman & Davis, 2000). N is an important component of chlorophyll, amino acids, nucleic acids, and secondary metabolites. Nitrate N is one of the most abundant N sources in the soil (O'Brien *et al.*, 2016).

Inorganic nitrate (NO_3) is a naturally occurring compound in foods, especially plant foods and vegetables, and the largest amount of dietary NO_3 is derived from vegetables, especially green leafy vegetables (Bahadoran *et al.,* 2016; Colla *et al.*, 2018).

NO_3 accumulation in vegetables depends on the amount and kind of nutrients present in the soil and is closely related to the time of application, the amount and composition of the fertilizers applied (Zhou *et al.*, 2000; Gajewski *et al.*, 2009). NO_3 concentration depends on growth and weather conditions, the season, temperature, light intensity, harvesting time, moisture stress, plant species, plant age and soil pH (Salehzadeh *et al.*, 2020). Under the conditions of low light intensity, an increase in temperature enhances NO_3 accumulation (Santamaria *et al.*, 2001). Caused by unequal N fertilization levels in conventional and organic production, the roots of carrot from conventional production contained more N and NO_3 compared to organic production (Wierzbowska *et al.,* 2017). The soil type is one of the factors influencing the content of NO_3 in carrot roots. Seljåsen *et al.* (2013) argue that the content of NO_3 was lowest in carrot grown on sandy soil.

The NO_3 content of various parts of a plant differs and the vegetable organs can be listed by their decreasing NO_3 content as follows: petiole, leaf, stem, root, inflorescence, tuber, bulb, fruit, seed (Santamaria *et al.*, 1999). Nitrate levels are generally low in carrots (200–500 mg NO_3 kg^{-1} FW) (Santamaria, 2006) as carrots require low fertilization during their growing period (Seljåsen *et al.,* 2016). Gutezeit (1999) has proposed a soil mineral N target value of 75 kg ha^{-1} for carrots for the processing industry. The European Commission's Scientific Committee on Food (SCF) has set an acceptable daily intake (ADI) of NO_3 of 0–3.7 mg kg^{-1} bodyweight or 222 mg for a 60-kg person (Santamaria, 2006). Undesirable accumulation of nitrate in carrots seems to occur in rare cases when high amounts of nitrogen fertilizer are applied shortly before harvest (Smolen & Sady, 2009).

2.1.3. Content of pesticide residues

Synthetic pesticides are not found in nature, but are necessary to increase yield through protection against unwanted organisms. Residues of these substances accumulate in plants and move along the food chain, disturbing the balance of natural environment and damaging animal and human organisms (Rembiałkowska, 2016). Accumulated pesticide residues in food products have been associated with a broad variety of human health hazards, ranging from short-term impact to long-term toxic effects (Grewal *et al.*, 2017). The presence of pesticide residues is a major bottleneck in the international trade of food commodities (Bajwa & Sandhu, 2014).

Pesticide residues have been found in various vegetables. Organic food is reported to contain much lower amounts of residues than conventional food (Woëse *et al.*, 1997; Baker *et al.*, 2002; Winter & Davis, 2006; Rembiałkowska, 2007; Tasiopoulou *et al.*, 2007; Hoefkens *et al.*, 2009; Smith-Spangler *et al.*, 2012; Jensen *et al.*, 2013; Barański *et al.,* 2014; EFSA, 2020). In 2016 (EFSA, 2018), one or more quantifiable residues were detected in 44% of conventionally produced food samples and in 7% of organically produced samples. Lairon (2009) argues in his review article that 94–100% of organic food does not contain any pesticide residues. Results from the monitoring of pesticide residues in fruits and vegetables on the Danish market show that only 2.8% of organic samples were contaminated (Poulsen & Andersen, 2003) and all values were below the maximum residue level (MRL), the highest level of a pesticide residue that is legally tolerated (Regulation (EC) No 396/2005). In addition to above, there are some studies that have not found any pesticide residues in organic vegetables (Bourn & Prescott, 2002; Rembiałkowska & Hallmann, 2007).

There is a good perspective that hazardous pesticides will diminish in the nearest future. According to the European Green Deal goals, the use of chemical pesticides and their potential risks must be significantly reduced. The European Commission aims to boost innovation for the development of safe and sustainable chemicals, and increase protection of human health and the environment against hazardous chemicals (European Commission, 2020).

2.2. The effect of agroecological service crops (ASC) in no-till roller crimper (RC) management on weeds in organic vegetable production

Weeds are one of the key issues in organic production. Reduced tillage can benefit soil fertility and climate change mitigation (Armengot *et al.,* 2016; Iocola *et al.,* 2017; Kleijn *et al.,* 2019). However, reducing soil tillage can influence weed communities (Armengot *et al.,* 2016). Several authors have pointed out that weed control effectiveness can be improved by combining reduced or no tillage with ASC (Canali *et al.,* 2013; Wayman *et al.*, 2015; Ciaccia *et al.,* 2016). Therefore, the term Agroecological Service Crops has been introduced to overcome the lack of a comprehensive and all-embracing term which would include all crops used in agro-ecosystems to provide or enhance its environmental functions (Canali *et al.*, 2015). ASCs can be cultivated as i) buffer zones used in the parts or portions of a farm/field that are generally not intended for growing cash crops (Marshall & Moonen, 2002; Tilman *et al.*, 2002); ii) living mulches, where ASC is intercropped with a cash crop and maintained as a living ground cover throughout the growth cycle; iii) break crops, which are cultivated as a sole crop in the rotation, between two consecutive cash crops (Canali *et al.*, 2015). In sustainable/organic farming systems, ASCs represent a powerful tool for farmers to positively influence the agro-ecosystem by promoting the whole soil-plant system equilibrium in space and time (Kremen & Miles, 2012; Canali, 2013; Wezel *et al.*, 2014). ASCs may have impact on soil fertility (Thorup-Kristensen *et al.*, 2012; Montemurro *et al.*, 2013) or the occurrence of weeds (Hayden *et al.*, 2012), diseases and pests (Patkowska & Konopiński, 2013).

ASCs can be managed as GM or by using RC technology (Canali *et al.*, 2015). More widespread RC models are comprised of a steel cylinder (about 41–51 cm diameter) with steel dull blades welded perpendicular to the cylinder in a chevron pattern (Canali *et al.*, 2015). Prior to ASC termination the cylinder is filled with water to provide an additional weight to aid in mechanical termination. The RC is designed to crush or crimp ASC stems, rather than cut or chop them (Ashford & Reeves, 2003). Crimping the ASC tissue causes plant injury and accelerates its termination or senescence (Kornecki *et al.*, 2012).

The use of RC technology was started by Brazilian family farmers as an alternative to expensive herbicides (Petersen *et al.*, 1999). Retained on the soil surface, the residues of non-cash crop species suppress weeds, leading to reduced weed density (Sarrantonio & Gallandt, 2003). Plant residues that shade the soil surface filter light and reduce the ratio of red spectrum, which can inhibit the germination of weed species that need full sunlight to germinate (Altieri *et al.*, 2011). A plant residue covering also affects soil temperature, diminishing the thermal amplitude of the upper soil layers during the day. It would affect weed seeds that are sensitive to temperature alternation for germination (Altieri *et al.*, 2011). Several researchers (Teasdale & Mohler, 2000; Canali *et al.*, 2013; Wayman *et al.*, 2015; MacLaren *et al.*, 2019) claim that the quantity of residue is more important than its type and weed suppression is less affected by allelopathic than by physical properties of mulches. Additionally, Liebman & Davis (2000) have found that the effect of ASC residues on weed control is species-specific and is the result of i) a sufficient quantity of ASC biomass; ii) the energy reserves of a given weed species (i.e., large seed *vs.* small seeded; perennial *vs.* annual). Other scientists also reveal that successful weed control by mulches is highly dependent on substantial biomass (Teasdale & Mohler, 2000; Reberg-Horton *et al.*, 2012). In general, ASC mulches are better at suppressing small-seeded summer annuals and are largely ineffective in suppressing large seeded species (Teasdale & Mohler, 2000; Leavitt *et al.*, 2011; Mirsky *et al.*, 2013).

Poacea species introduced as ASC are considered particularly suitable for weed suppression with in-line tillage/roller crimper (ILRC) termination due to the high amount of biomass produced and to the slow decay of their residues as a result of high C : N ratio (Radicetti *et al.*, 2013; Halde & Entz, 2016). Rye generally attains greater dry matter and produces better weed suppressive mulch than legume ASC (Mirsky *et al.*, 2013). The physical influence of rye is possibly the primary mechanism suppressing weeds (Mirsky *et al.*, 2011). According to a later study, rye remains the best candidate for a successful organic ASC-based RC technology (Wayman et al., 2015; Vincent-Caboud et al., 2019). The allelopathic effect of rye apparently suppresses weed seed germination to a greater degree than that achieved by other cereal grain species. In addition, rye is more winter hardy and reaches anthesis earlier than triticale.

Although RC technology has several benefits, there are some drawbacks as well. The RC technology does not control emerged weed seedlings and successful weed management is dependent upon the prevention of weed seedling emergence through the production of ASC biomass (Mirsky et al., 2013). Moreover, the ASC must be at a growth stage where it is susceptible to mechanical control, which can delay cash crop planting and reduce its yield (Nord et al., 2012; Eslami & Davis, 2018).

3. HYPOTHESES AND AIMS OF THE STUDY

This thesis concludes the main results obtained about organic and conventional carrot cultivation depending on the fertilization level. In conventional treatments, nitrogen fertilization rates within the recommended optimal range were used. Nitrogen rates within and below the optimal rates were used in organic treatments. The other aspect that has been little studied in the world is the share of discarded yield in the total yield of carrot. Safe and nutritious food is a choice of consumers and this research provides some answers on this topic. In the light of innovative proposals in Europe (Green Deal, Farm to Fork strategy) to expand the use of sustainable practices, weed control is part of the current study on an important topic in organic vegetable cultivation. For the first time in Estonia, no-till roller-crimper technology was used.

Hypotheses:

1. The marketable yield and discarded yield of carrot are similar in organic and conventional carrot production under optimal levels of used N fertilization and remain lower in organic management in the case of below optimal N fertilization (**I, II, III**).

2. Organically produced carrots have a higher content of total sugars, vitamin C and dry matter compared to conventional systems (**I, II, III**).

3. Conventionally produced carrots have a higher content of nitrogen and nitrates than organic carrots and they contain pesticide residues (**I, II, III**).

4. Rolling and crimping of agroecological service crops (cover crops) reduces weed density and species richness and changes weed composition in comparison to the green manure method in organic vegetable production (**IV**).

The main objectives:

1. To estimate carrot yield and the share of discarded yield in both organic and conventional production under the optimal level of N fertilization and below optimal N fertilization only in organic production.

2. To determine the content of total sugars, vitamin C and dry matter in conventional and organic cropping systems.

3. To investigate the content of nitrogen and nitrates in organic and conventional production and pesticide residues in conventional carrots.

4. To study the effect of rolling-crimping technology on weed density, species richness and weed community in Estonian conditions.

4. MATERIALS AND METHODS

4.1. Experimental site and soil

The field experiments were carried out at the Estonian Crop Research Institute (ECRI) at 58°76'N, 26°40'E. The soil type on the plots was clay loam classified as Endogleyc Luvisol (FAO, 2014). The whole experimental area (0.15 ha) had been out of intensive use for at least 30 years, and for the last four years it had been managed uniformly in accordance with organic farming practice (no use of synthetic fertilizers and pesticides). A pooled topsoil sample was analyzed before the establishment of the experiments (2008) using the following methods: pH – ISO 10390; P, K, Ca, Mg, Cu, Mn – Mehlich III; B – by Berger and Truogi; C_{org} – by NIRS. The following results were obtained: pH 6.4, P 356 mg kg^{-1}, K 220 mg kg^{-1}, Ca 2067 mg kg^{-1}, Mg 210 mg kg^{-1}, Cu 4.0 mg kg^{-1}, Mn 117 mg kg^{-1}, B 0.08 mg kg^{-1}, and C_{org} 2.0%. No pesticide residues were present in the soil. Soil samples were analyzed in the Laboratory of Agrochemistry at the Agricultural Research Centre.

4.2. The effect of production system on yield and quality of carrot

4.2.1. Experimental design

Two field experiments were carried out, one from 2011 to 2014 (**I**) and the other in 2008 (**II**) and in 2009 (**III**) in the same area.

The randomized complete block design with four experimental plots (5.0 m x 2.0 m each) per block in three replications was used from 2011 to 2014. In each block, three plots had conventional production treatment (CON5, CON3 and CON1) and one organic treatment (ORG) (**I**). The area of the plots of conventional (C) and organic (O) treatment was 100 m^2 altogether, with four replications per treatment used in 2008 and in 2009 (**II, III**).

4.2.2. Treatments

Conventional treatments differed in the types of pesticides and number of sprayings during the growing period (Table 1). Synthetic pesticides were applied according to the recommended mean doses to control weeds, insects and diseases (**I, II, III**).

In the trial period from 2011 to 2014 (TP1), CON5 was sprayed five times, the plots receiving two herbicides, the same insecticide twice, and one fungicide; CON3 was sprayed three times, the plots receiving one of each pesticide; and CON1 was sprayed once, the plots receiving one herbicide (**I**).

In the trial period from 2008 to 2009 (TP2) O plots were covered after sowing for two months with a non-woven polypropylene cover (NWPC) (17 g m^{-2}) to control insects. C treatment plots received two herbicides, the same insecticide twice, and one fungicide (**I, II**).

Table 1. Synthetic pesticides used in conventional (CON5, CON3, CON1, C) and organic (ORG, O) treatments, classification by category (h – herbicide, i – insecticide, f – fungicide), trade names and applied rates in the conventional cultivation over the study period 2008–2014.

Used pesticides a.s.* and category	Trade name	Treatment	Application rate, publication No
Aclonifen (h)	Fenix	CON5, CON3,	
		CON1	2.0 l ha^{-1}, **I**
		C	2.5 l ha^{-1}, **II, III**
Propaquisafop (h)	Agil 100 EC	CON5, C	1 l ha^{-1}, **I, II, III**
Cypermethrin (i)	Fastac 50	CON5, CON3	0.15 l ha^{-1}, **I**
		C	0.3 l ha^{-1}, **III**
Thiamethoxam (i)	Actara 25 WG	C	120 g ha^{-1}, **II**
Boscalid +			
pyraclostrobin (f)	Signum	C	0.75 kg ha^{-1}, **II, III**
Chlorothalonil (f)	Bravo 50SC	CON5, CON3	3.0 l ha^{-1}, **I**

*a.s. – active substance

4.2.3. Fertilization

For basic fertilization in conventional treatment, 1 t ha^{-1} of Cropcare 8-12-23 (N 80 kg ha^{-1}, P 50 kg ha^{-1}, K 190 kg ha^{-1} plus micronutrients) from 2011 to 2014 (**I**) and 0.8 t ha^{-1} (N 65 kg ha^{-1}, P 40 kg ha^{-1}, K 152 kg

ha^{-1} plus micronutrients) was applied to the plots in 2008 (**II)** and 2009 (**III**).

Organic plots (TP1) were fertilized with horse manure compost (Matogard Ltd) containing 1–2% total N, 0.1–0.3% P and 0.6–0.9% K (by the product label). To ensure the minimum level of optimal nitrogen fertilization (N 80 kg ha^{-1}) used in conventional treatment, 8 t ha^{-1} of compost was added (**I**). In TP2, plant residue composts, 2 t ha^{-1} (N 24 kg ha^{-1}, P 40 kg ha^{-1}, K 75 kg ha^{-1}), were applied in 2008 (**II**) and (N 20 kg ha^{-1}, P 40 kg ha^{-1}, K 33 kg ha^{-1}) (**III**) in 2009.

Conventional plots were fertilized during TP2 with ammonium nitrate (N 50 kg ha^{-1}) and sprayed with foliar fertilizer Folicare 18-18-18 (N 4 kg ha^{-1}). Organic carrot plants were fertigated at a rate of 1 litre per meter of a row with a solution of humic substances (Humistar, diluted by 1:20) (**II, III**).

4.2.4. Sowing, maintenance and harvesting

Orange-coloured old (from 1952) Estonian carrot variety (*Daucus carota* L.) 'Jõgeva Nantes' was used in experiments (**I, II, III**). Carrot seeds were sown at the end of May at the seeding density of 100 seeds m^{-1}. The seeds were sown in a pair of rows, 20 cm between the rows and 50 cm between each pair of rows. After the sowing, organic plots were protected with NWPC against insects such as carrot psyllid (*Trioza viridula* Zetterstedt) and carrot fly (*Psila rosae* Fabricius) (**II, III**).

To control weeds, all experimental plots, including the conventional treatment plots, were weeded twice by hand and hoeing. Carrots were harvested manually at the beginning of October in 2008, 2009, 2011 and 2012 and in the middle of September in 2013 and 2014.

4.2.5. Measurements and analyses

Two yield fractions, marketable and discarded yield, were quantified in both, conventional and organic production systems. Discarded yield consisted mainly of cracked, but also of forked and small roots (diameter < 2 cm). A randomly selected sample of marketable yield of 8 kg was taken from each plot. From this, a random 600 g sample was taken for laboratory analyses the following days after harvest.

Total sugar content was determined following the modified Bertrand method, as described by Turbas and Oll (1969). Vitamin C content was specified according to ISO 6557/2:1984. Dry matter (DM) content was measured according to EVS-EN 12-145:2000. All mentioned determinations were performed in the Laboratory of Agrochemistry at the Agricultural Research Centre (**II, III**) and in the Plant Biochemistry Laboratory at the Estonian Crop Research Institute (**I**). Total N content was determined by the copper catalyst Kjeldahl method, and nitrate (NO_3) content by flow injection analysis, using Fiastar 5000 (ISO 13395) in the Plant Biochemistry Laboratory at the Estonian University of Life Sciences (**I, II, III**).

Residues of the applied pesticides were tested using the multi-residue QuEChERS method combining gas and liquid chromatography following the acetonitrile extraction of the sample and clean-up by dispersive solid phase extraction, as described in the European Standard EVS-EN 15662:2008, and validated according to the requirements of SANCO/10684/2009. One sample of pesticide residues per conventional treatment was analyzed each year in the Laboratory of Agrochemistry at the Agricultural Research Centre (**I, II, III**).

4.3. The effect of agroecological service crops (ASC) managed with roller crimper in organic systems

4.3.1. Experimental design and management

In the studies, fourteen original datasets from five European countries (Denmark, Estonia, Italy, Slovenia and Spain) were involved in the SoilVeg project (**IV**). Two datasets came from Estonia, from the most northern country in the above-mentioned project. In each country and trial, different environmental conditions, experimental designs, and cash crops were established. The organic vegetable field experiments were conducted at the organic research field during two cropping cycles: 2015/2016 (Y1) and 2016/2017 (Y2). In the Estonian trials, the plots were established to an adjacent area of the same experimental field. ASC was sown on August 25, 2015 and on September 8, 2016. The previous crop was red clover in both years.

The experimental design was a strip-plot design with ASC strips and ASC management crossed with the fertilizing factor (i.e., manure *vs.*

without manure), with three replicates per treatment. The plot size was 6 m × 4 m. Two organic management systems were used: i) ASC was flattened by RC and narrow transplanting furrows were created by an added in-line tiller (hereafter ILRC), and ii) ASC was incorporated as green manure (GM). ASC was rolled by RC as follows: i) rye (*Secale cereale* L.) and Italian ryegrass (*Lolium multiflorum* Lam.) on June 6 and 9, 2016; ii) rye and triticale (x *Triticosecale blaringhemii* A. Camus) on June 19, 2017. The phenological stage of ASC at termination was as follows: full flowering for rye, first flowering for Italian ryegrass and for triticale. GM was moved/chopped and incorporated into the soil on June 9, 2016 and June 19, 2017. White cabbage was transplanted in Y1 from June 13 to 16, 2016 and in the Y2 on June 19, 2017. The harvest was carried out on October 7, 2016, and from October 4 to 6, 2017. The timescale diagram below gives a clear idea of the works carried out (Fig. 1). Plots belonging to the fertilization treatment were fertilized before the ASC seed sowing with the application of 30 t ha^{-1} solid cattle manure (N 153 kg ha^{-1}, P 57 kg ha^{-1} and K 81 kg ha^{-1}). In Y2, all plots were fertilized with 12 t ha^{-1} of horse manure compost (12 kg ha^{-1} N, 1.2 kg ha^{-1} P, and 4.8 kg ha^{-1} K).

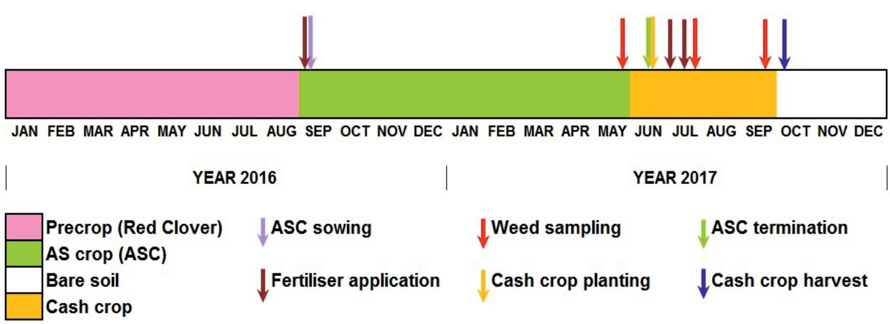

Figure 1. Timescale diagram of second trial period (Y2). ASC: agroecological service crops.

4.3.2. Sampling methods

Weeds and ASC species abundance was assessed before ASC termination on June 1 and 2, 2016 and 2017 (Table 2). Four weed and ASC biomass samples per plot were taken with the frame of 1 x 1 m. The second sampling of weeds was carried out at an early stage of the cash crop (cabbage). Four weed density samples per plot were taken with the frame of 0.5 x 0.5 m. Both germinated and resprouting individuals were counted and identified at the species level prior to weeding operations.

Table 2. Data of agroecological service crops (ASC) and weeds proportion of the total dry biomass (±SE) before ASC termination. Different letters indicate statistically significant differences (p<0.05).

		2016		2017	
ASC species	ASC proportion, %	ASC dry biomass, t ha^{-1}	Weed proportion of the total biomass, %	ASC dry biomass, t ha^{-1}	Weed proportion of the total biomass, %
Rye	100	9.78 a	0.7±0.2	7.10 a	2.5±0.7
Italian ryegrass	100	4.99 b	3.4±0.9		
Triticale	100			4.60 b	1.4±0.2

These data provided information on weed density and weed species richness. Weed density (individual m^{-2}) comprised the total number of germinated and resprouting individuals, including weed and ASC species, to account for the entire potential competition towards cash crops. On the other hand, weed species richness (number of species per sample) and community composition referred exclusively to weeds germinated at the beginning of the cash crop. In these cases, we analyzed exclusively germinated weeds to isolate the response of weed communities to different ASC management methods. Weed species abundances were averaged for each plot in all trials. On Estonian trials weeds four samples were evaluated in each plot. In the first year, weeds were sampled 69 days after transplanting, while in the second year, the sampling was carried out 37 days after transplanting (**IV**).

4.4. Weather conditions

Temperature and precipitation were recorded at the meteorological station at the ECRI approximately 500 m from the experimental fields.

4.4.1. Trial periods TP1 (2011–2014) and TP2 (2008–2009) of carrot

In summary, monthly average air temperature was higher and the amount of precipitation was lower than the long-term monthly averages (LTA) during the growing seasons of 2011 and 2013 (Table 3), whereas the

Table 3. Average air temperature and sum of precipitation of the long-term monthly average (LTA, 1991–2020) and deviations from the average during the study period.

	Temperature (°C)					Precipitation (mm)				
	Deviation									
	May	**June**	**July**	**Aug.**	**Sept.**	**May**	**June**	**July**	**Aug.**	**Sept.**
LTA	**11.0**	**14.7**	**17.2**	**15.6**	**10.6**	**49**	**79**	**76**	**93**	**60**
2008	0.0	-0.3	-1.2	-0.1	-1.0	-27	38	-22	106	-21
2009	0.8	-0.9	-0.2	-0.4	2.0	-23	28	6	21	-10
2011	0.7	2.9	3.8	0.9	2.0	-13	-31	-45	-14	-12
2012	1.1	-1.0	1.2	-0.7	1.5	14	41	7	41	-6
2013	4.0	3.2	0.8	1.2	0.3	35	-32	-42	-19	-33
2014	1.3	-1.4	2.5	1.1	0.9	16	88	-30	34	-38

summer of 2011 was extremely dry (**I**). The vegetation period of 2012 was characterized by higher than the LTA precipitation and close to the average temperature. Rain was frequent in June on twenty-two days out of thirty. The distribution of precipitation in 2014 was irregular: June and August were wetter, whereas July and September were drier than the LTA. Therefore, the temperature from May to the end of August was more or less close to the LTA.

The whole growing season of 2008 was a little cooler than the LTA and the first part of the vegetation period was unusually dry, but August was extremely rainy. The first part of the vegetation period of 2009 was similar to 2008. Therefore, the second part of the vegetation period was drier than in 2008.

4.4.2. Year one (Y1) and two (Y2) of no-till management trial

The autumn and winter of Y1 were warmer than the LTA (Fig. 2). The vegetation period started on April 5, being 17 days earlier than usually. May, warmer and dryer than the LTA, caused a shortage of moisture in the soil. August was rainy, but September was dry (IV).

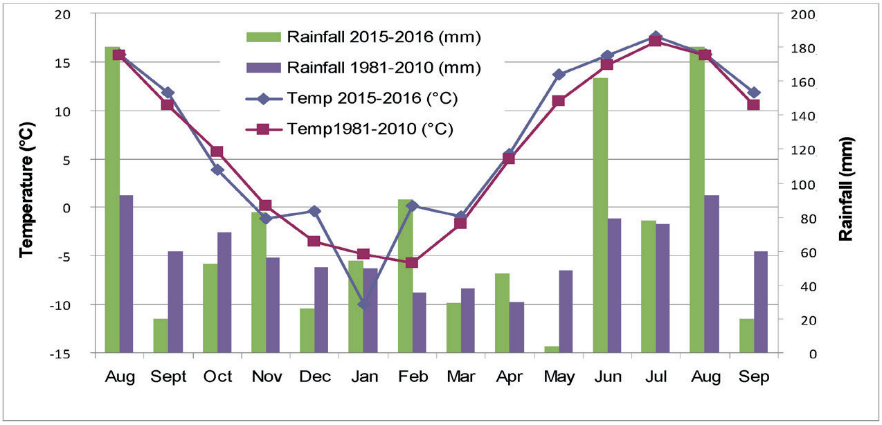

Figure 2. Monthly average temperature and sum of precipitation from sowing of agroecological service crops (ASC) in 2015 until cabbage harvest compared to long-term monthly average (LTA).

October and November of Y2 were cooler and the following winter was warmer than the LTA (Fig. 3). From April to the beginning of August, it was cooler and dryer than the LTA, but it rained unevenly in large quantities (IV).

4.5. Statistical analyses

Two-way analysis of variance (ANOVA) was used to determine the effects of treatment and year, also their interactions, on carrot yield and quality parameters in TP1. Two different analyses were performed: at first all four treatments (CON5, CON3, CON1, ORG) were compared, and secondly, an average of the three conventional production treatments (CON-AV) was calculated and only two treatment groups (CON-AV and ORG) were compared. The pairwise differences (CON-AV and ORG) were compared. The pairwise differences between treatments within years and overall as well as between years within treatments were tested with the Tukey-Kramer (HSD) test. These statistical analyses were performed using JMP 5.0.1.2 software SAS, 2002 (SAS Institute, Inc., Cary, NC, USA) (**I**).

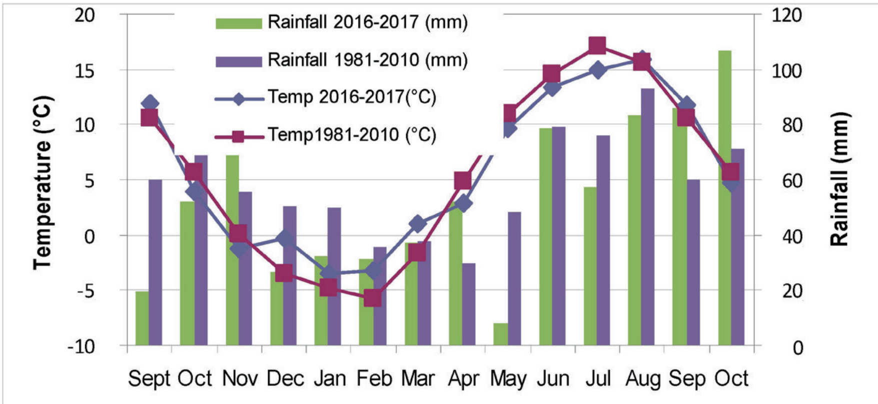

Figure 3. Monthly average temperature and sum of precipitation from sowing of agroecological service crops (ASC) in 2016 until cabbage harvest compared to long-term monthly average (LTA).

Differences of data between cultivation techniques were tested by one-way analysis of variance at the significance level of $P \leq 0.05$ within trial years and two-way analyses for average results over years. The pairwise differences between treatments within years and between TP2 average results were tested with the Tukey-Kramer (HSD) test. These statistical analyses were performed using JMP 5.0.1.2 software SAS, 2002 (SAS Institute, Inc., Cary, NC, USA) (**II, III**).

Statistics included termination (GM and ILRC) and year (Y1 and Y2) as explanatory variables. The weighted Z test was used for a meta-analytic approach to analyze the effect of the ASC management on weed density and weed species richness across all trials. All statistical analyses were performed with R software (R Core Team, 2017). The weed abundance measurements were transformed into presence/absence data and the Jaccard distance (JaccD) was used to compute the distances between two sets in weed community composition (**IV**). JaccD is a measure to show how dissimilar two sets are (Vorontsov *et al.,* 2013).

5. RESULTS

5.1. The effect of production system on yield and quality of carrot (I, II, III)

5.1.1. Marketable and discarded yield

Marketable yield was significantly (p=0.012) affected by the production system of TP1 (CON-AV *vs.* ORG). Across TP1, the average marketable yield of ORG production was 14.5% higher than that of CON-AV (Fig. 4). The average marketable yield of carrots ranged from 6.2 in 2011 to 29.2 t ha^{-1} in 2012. Differently, the average marketable yield of TP2 was not affected by the cropping system (C *vs.* O), where NWPC and humic substances product Humistar were used (Fig. 4). Nevertheless, the year influenced significantly the marketable yield of both trials (TP1 and TP2).

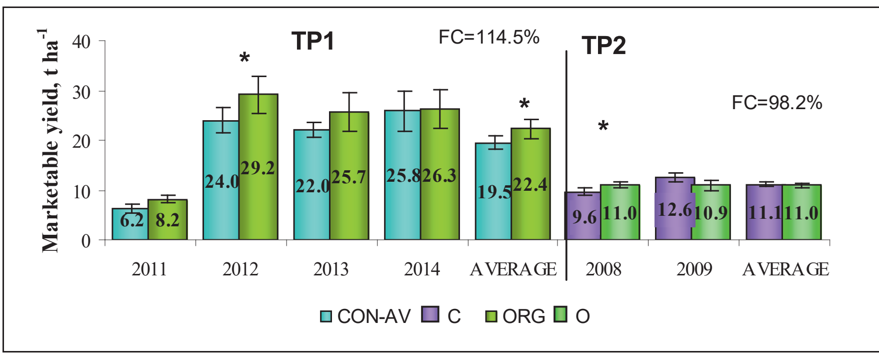

Figure 4. Comparison of marketable yield in conventional and organic (CON-AV and ORG in TP1: trial period one; C and O in TP2: trial period two) carrots (± STDEV). FC: fold change (*100%), indicates change of ORG with respect to CON-AV as four-year average and change of O with respect to C as two-year average. Significance code: * $p \leq 0.05$.

The share of **discarded yield** was significantly higher in the conventional production system in TP1 (p=0.023) and in TP2 (p=0.005) (Fig. 5), exceeding organic discarded yield by 10.0% (TP1) and 12.9% (TP2). Moreover, the share of discarded yield was also significantly affected by year in TP1. The share of conventional discarded yield ranged from 18.1% to 68.0% depending on year.

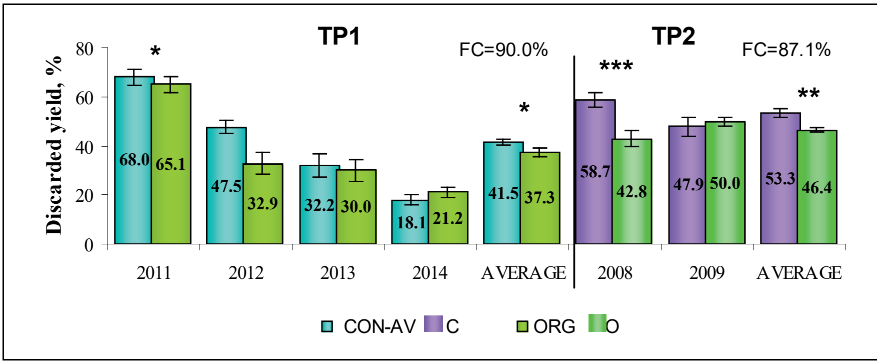

Figure 5. Comparison of the share of discarded yield in conventional and organic (CON-AV and ORG in TP1: trial period one; C and O in TP2: trial period two) carrots (± STDEV). FC: fold change (*100%), indicates change of ORG with respect to CON-AV as four-year average and change of O with respect to C as two-year average. Significance codes: *** $p \leq 0.001$; ** $p \leq 0.01$; * $p \leq 0.05$.

5.1.2. Nutritional quality

The content of **TS** in the carrots was affected by year in TP1 (p=0.001) (Fig. 6). Carrots grown in ORG only in 2013 contained significantly more TS (22.3%) than in CON-AV. The share of TS in carrots fluctuated between 6.0% and 8.5% during both trial periods.

Vitamin C content in carrots was significantly affected by the production method as the average of TP1 (p=0.026) (Fig. 6). The average vitamin C content of ORG carrots of four-year trials exceeded CON-AV by 10.0%. The most exceeded the content of vitamin C in ORG carrots CON-AV in 2011 (p=0.046). Moreover, vitamin C content in TP1 was significantly affected by year (p<0.001). The average vitamin C content ranged from 1.5 mg 100^{-1} to 6.2 mg 100^{-1} in both trial periods.

Only in 2009 (TP2) (p=0.02) **DM** content was significantly influenced by the production method, being higher in O (10.6%) than in C (10.1%) (Fig. 7). In TP1, DM content ranged from 9.9% to 13.0%.

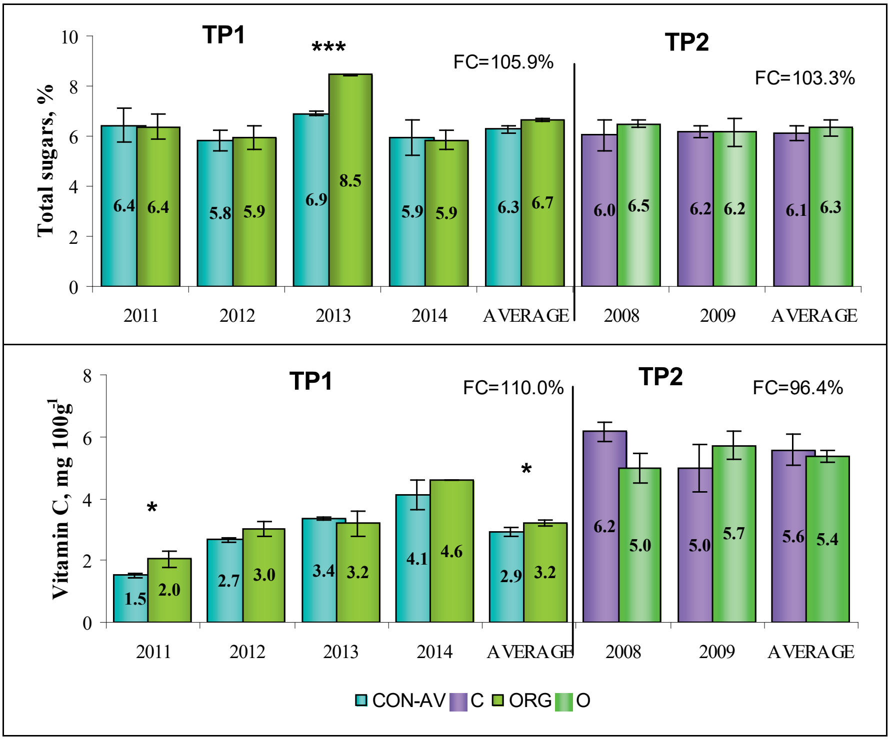

Figure 6. Comparison of content of total sugars and vitamin C in conventional and organic (CON-AV and ORG in TP1: trial period one; C and O in TP2: trial period two) carrots (± STDEV). FC: fold change (*100%), indicates change of ORG with respect to CON-AV as four-year average and change of O with respect to C as two-year average. Significance codes: *** $p \leq 0.001$; * $p \leq 0.05$.

The average content of **N** was significantly affected by the production system only in TP2 ($p<0.001$) (Fig. 7), where the N content in carrots of C exceeded the O variant by 33.3%. In TP1, the content of N was influenced by year ($p=0.001$). The average N content over the trial periods ranged from 0.9% to 2.5%.

The average **NO_3** content depended significantly on the production system in both, TP1 ($p=0.017$) and TP2 ($p<0.001$) (Fig. 7), the carrots containing 13.1% more NO_3 in conventional production in TP1 and even 89.5% more in conventional production in TP2. In addition, NO_3 content was affected by year in both, in TP1 and in TP2. NO_3 was absent in 2008 (in O) and for both trial periods, the content of nitrates was highest in 2011 (292 mg kg^{-1}) (in ORG).

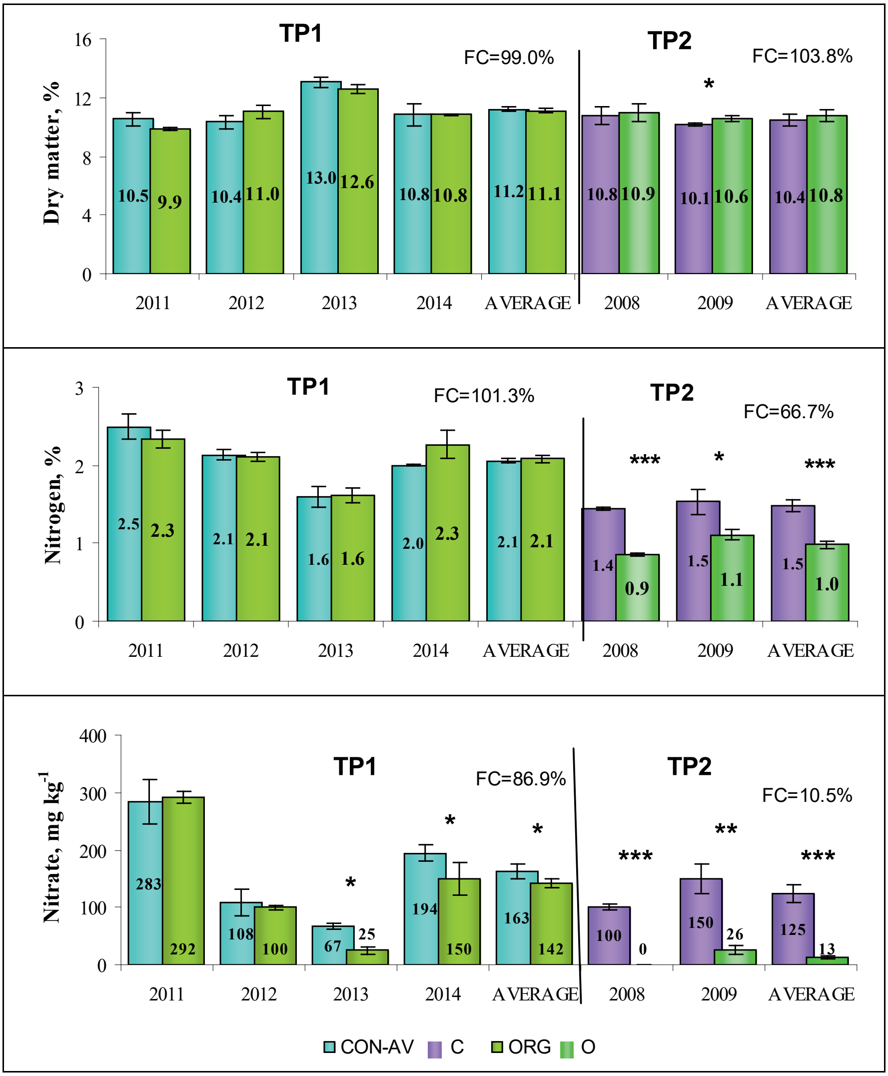

Figure 7. Comparison of content of dry matter, nitrogen and nitrates in conventional and organic (CON-AV and ORG in TP1: trial period one; C and O in TP2: trial period two) carrots (± STDEV). FC: fold change (*100%), indicates change of ORG with respect to CON-AV as four-year average and change of O with respect to C as two-year average. Significance codes: *** $p \leq 0.001$; ** $p \leq 0.01$; * $p \leq 0.05$.

5.1.3. Content of pesticide residues

Out of the seven analyzed pesticides, residues of five (aclonifen, boscalid, chlorothalonil, cypermethrin and pyraclostrobin) were detected in five out of six trial years in conventional production (Table 4). Residues of the herbicide aclonifen and fungicide chlorothalonil were identified in the conventionally grown carrots in four years. Residues of the herbicide propaquizafop and residues of the insecticide thiamethoxam were not detected in any of the trial years.

Table 4. Pesticides active substances, found in conventionally (C, CON5, CON3 and CON1) produced carrots.

Trial year, used pesticides a.s.*	Content of determined pesticide residue in conventional treatments, mg kg^{-1}			
	C	CON5	CON3	CON1
2008				
aclonifen	-	-	-	-
propaquizafop	-	-	-	-
thiamethoxam	-	-	-	-
boscalid	0.320	-	-	-
pyraclostrobin	0.090	-	-	-
2009				
aclonifen	-	-	-	-
propaquizafop	-	-	-	-
cypermethrin	<0.01	-	-	-
boscalid	-	-	-	-
pyraclostrobin	-	-	-	-
2011				
aclonifen	-	bdl.	-	bdl.
propaquizafop	-	-	-	-
cypermethrin	-	-	-	-
chlorothalonil	-	0.013	-	-
2013				
aclonifen	-	-	-	nd.
propaquizafop	-	-	-	nd.
cypermethrin	-	-		nd.
chlorothalonil	-	0.223	0.080	nd.
2014				
aclonifen	-	0.008	bdl.	nd.
propaquizafop	-	-	-	nd.
cypermethrin	-	0.028	-	nd.
chlorothalonil	-	0.007	-	nd.

*a.s. = active substances; - = pesticide residues not found; bdl. = below detection limit; nd. = the content of residues was not determined.

The content of all detected residues was below the respective MRL, which were as follows: aclonifen 0.08, boscalid 2.0, chlorothalonil 0.3, cypermethrin 0.05 and pyraclostrobin 0.5 mg kg^{-1} (Maximum Residue Levels, 2021).

5.2. The effect of agroecological service crops (ASC) in no-till roller crimper management on weeds (IV)

In Y1, 45 and in Y2, 43 weed species pooled in GM and ILRC were identified. ASC management had clear effect on weed density, species richness, and community composition at an early stage of the cash crop. ILRC management dramatically reduced weed density and weed species richness. Analyzing our results for both years pooled, ILRC management significantly ($p \leq 0.01$) reduced weed density (69.9 %) (Fig. 8). Weed species richness also had a consistent response to ILRC management in Estonian trials and this trend was significant in both years of experimentation (Fig. 8).

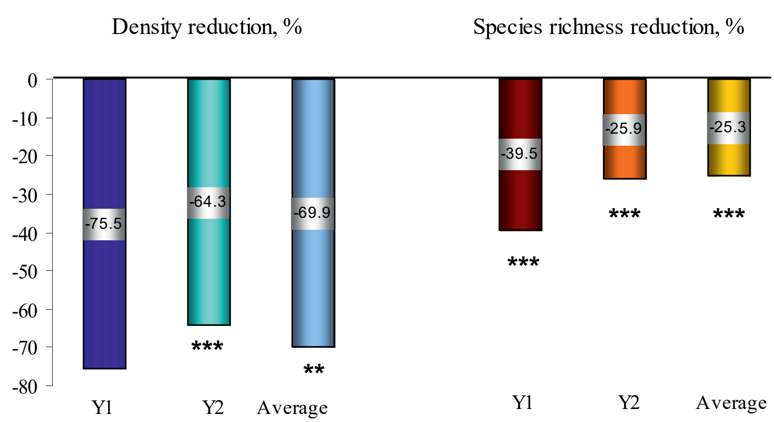

Figure 8. Percentage of weed density reduction and species richness reduction in ILRC: in-line tillage/roller crimper in comparison with GM: green manure at early stages of the cash crop. Y1: trial period one, Y2: trial period two. Significance codes: *** $p \leq 0.001$; ** $p \leq 0.01$.

The effect of ILRC to weed community composition was studied for the five most abundant weeds (Table 5). Weed community composition was affected by ASC management in both years. JaccD between GM (Y1+Y2) and ILRC (Y1+Y2) was 0.52 for five most abundant weeds. This means that the number of weed species in GM differed on a large scale (52%) from the ILRC number of weed species in weed community composition. JaccD between two years in ILRC plots was 0.50, differing more than between two years in GM plots, for which JaccD was 0.40. The share of perennial weeds in the pooled years showed that the proportion of perennial weeds in the ILRC variant was 3 times higher than in GM. In ILRC management, the most abundant perennials were *Sonchus arvensis, Poa trivialis* and *Elymus repens* and in GM management *Artemisia vulgaris.*

Table 5. Weed community composition (EPPO codes of weeds*) at an early stage of the cash crop, average Jaccard distance between termination per year, trial and agroecological service crops (ASC) management. Share of perennial weeds in pooled years.

Community composition	Green manure (GM)		In-line tillage/roller crimper (ILRC)	
	Year 1	Year 2	Year 1	Year 2
First more abundant	ARTVU	CHEAL	MATIN	STEME
Second more abundant	ERYCH	STEME	LAMPU	VIOAR
Third more abundant	CAPBP	LAMPU	SONAR	POATR
Fourth more abundant	LAMPU	VIOAR	MYOAR	MYOAR
Fifth more abundant	CHEAL	ERYCH	AGRRE	LAMPU
Jaccard distance (JaccD)				
GM		0.40		
ILRC		0.52		0.50
Share of perennial weeds, %		10		30

*AGRRE, *Elymus repens* (L.) Gould; ARTVU, *Artemisia vulgaris* L.; CAPBP, *Capsella bursa-pastoris* (L.) Medik.; CHEAL, *Chenopodium album* L.; ERYCH, *Erysimum cheiranthoides* L.; LAMPU, *Lamium purpureum* L.; MATIN, *Matricaria perforata* Mérat; MYOAR, *Myosotis arvensis* (L.) Hill; POATR, *Poa trivialis* L.; SONAR, *Sonchus arvensis* L.; STEME, *Stellaria media* (L.) Vill.; VIOAR, *Viola arvensis* Murray.

Weeds classification: annual, winter annual, perennial

6. DISCUSSION

6.1. The effect of production system on yield of carrot

The results of our TP1 study showed that organic management can have an advantage in both, yield and quality of carrots at least at the same level of N fertilization as in the conventional (**I**). The results of the TP2 study showed that organic management can have a similar yield and better quality even at unequal N fertilization levels (**II, III**). We dedected a lower discarded yield and lower NO_3 content at both N fertilization levels (TP1 and TP2) in organic conditions. In addition, organic production resulted in a higher marketable yield and vitamin C content in TP1.

Compared to conventionally produced carrots, the yield of organically produced carrots was on average 14.5% higher in TP1 and at the similar level in TP2. Opposite to our results, the research comparing organic and conventional carrot cropping systems has found 34% lower yields in organic production (Boone et al., 2019). In the previous research of De Ponti et al. (2012) on organic carrot, yields ranged from 75% to 106% compared to conventional production. One of the main factors limiting organic yield has been lower nutrient availability, while fertilization rates were higher in conventional systems (Knapp & Heijden, 2018). Applied nitrogen in organic conditions may vary depending on compost nutrient composition, therefore, the fertilization level (N 80 kg ha^{-1}) used in our conventional trial could have been exceeded. Furthermore, the availability of N in compost varies and by the results of Amlinger et al. (2003) may remain even below 15%. Consequently, it is important to emphasize here that in our TP1 we added compost to organic carrots ensuring at least a minimum level of the optimal range recommended by Seljåsen *et al.* (2013) (N 80–180 kg ha^{-1}). Since there is limited information available about horse manure compost as nutrient source, future studies should more carefully investigate the N content, N availability and other effects (i.e., microorganisms, etc.). Composts also have a number of indirect positive effects on plant growth and development. It is known from previous studies that organic fertilizers have advantages over mineral fertilizers since they increase the total organic carbon content and soil organic matter, stimulate the activity of microorganisms and increase enzymatic activity in soil, and thus increase the availability of nutrients for the plants (Henneron et al., 2015; Lesur-Dumoulin et al., 2017; Tian et al., 2017; Bai et al., 2018; Schrama et al., 2018; Eremeev et al., 2019; Vaitkevičiene et al., 2020). However, Ponisio et al. (2015) found a yield gap of 9%, being lower in organic compared to conventional treatment when N inputs were similar, and a gap of 30% when N inputs were higher in conventional systems. The results of our carrot experiments do not support either statement. Compared to the average of the trial years, the fertilization scheme used in our TP1 resulted in higher and in TP2 similar organic yields.

Contrary to expectations, the marketable yield was same and discarded yield lower in organic production than in conventional carrots in TP2 despite the fact that the organic carrots were fertilized with a smaller amount of N. NWPC was used to protect organic carrots from pests in TP2 and it could improve the thermal regime and maintain humidity. A protecting cover may create a favorable growth environment and raise the organic marketable yield of carrots. Our assumption is supported by previous studies on carrot (Gimenez et al., 2002), zucchini (Kołota & Adamczewska-Sowińska, 2011) and field-grown capsicum (Goldwater et al., 2018) which demonstrate the same effects of NWPC. Furthermore, experiments with crisphead lettuce yielded as much as 73% heavier plants under the NWPC (Rekika et al., 2009). Chinese cabbage under the NWPC gave 47% higher yield compared to open field plants (Kalisz et al., 2014). Another contributor to the yield increase of organic carrots in TP2 might be the applied humic substances product Humistar, which has been proposed as an agronomic tool to counteract abiotic stresses (Bulgari et al., 2019). It is well known from previous studies that humic acids improve the chemical and physical quality of soil and, in general, enhance root growth and development (Canellas et al., 2002; Trevisan et al., 2010; Rouphael & Colla, 2018; Drobek et al., 2019). This is reflected in a better uptake of nutrients and water, and enhanced tolerance to environmental stresses (Canellas et al., 2015; Nardi et al., 2016).

In addition, the prevailing weather during the growing period was another important factor influencing crop yield. The increased content of organic matter in the soil makes the organic farming system less susceptible to extreme drought events and provides an opportunity to obtain higher yields (Lotter et al., 2003; Schrama et al., 2018). In our experiments, there was a shortage of precipitation in TP1 in two trial years out of four, and the results followed the above-mentioned tendency.

Dry seed sowing and the germination period was the cause of uneven establishment of carrot plants and low carrot yields in TP2. The lowest yield of two trial periods in 2011 was accompanied by significantly lower discarded yield in organic production. This is consistent with Gutezeit (1999) and Thorup-Kristensen et al. (2012), who found that the highest share of discarded yield in both organic and conventional production systems was produced by water stress in the year with the lowest amount of precipitation.

According to our results, the proportion of discarded yield in conventional production was significantly higher in both trial periods, in TP1 and TP2. Discarded yield in all treatments was caused mostly by physiological disorders of carrots. The higher share of discarded yield in conventional treatments was probably caused by periodical increased availability of N and more intensive uptake by plants. There may also have been some advantage in using the old variety 'Jõgeva Nantes' in our experiments. Several researchers claim that old varieties can be genetically heterogeneous and might have specific adaptation traits relevant for organic conditions (Finckh, 2008; Dawson *et al.,* 2011; Cortés-Olmos *et al*., 2014). This could also explain why the application of pesticides in conventional production did not result in lower discarded yield than in organic production.

6.2. The effect of production system on quality of carrot

An earlier study has concluded that TS content in carrots seems to be affected more by climate-related factors than by the production method (Rosenfeld *et al.* 1998). Moreover, Hlisnikovský et al. (2021) have reported that the content of TS was not affected by different fertilization rate and type. Our results are also consistent with the previous findings as the production system did not influence the TS content in carrots in our study, except in one out of six trial years. The rate of fertilization in TP2 had also no effect on TS content.

In our experiments, the vitamin C content in organic carrots as an average of TP1 was significantly higher compared to conventional carrots. This is in line with some previous studies reporting a higher vitamin C content in organically grown vegetables (Fjelkner-Modig *et al*., 2000: Brandt *et al*., 2011; Hallmann, 2012; Kapusta-Duch & Leszczyńska, 2013; Oliveira *et al*., 2013; Vinha *et al*., 2014). However, there were no differences of vitamin C content in our TP2 carrots. This result is in line with several previous studies (Warman & Havard, 1997; Wunderlich *et al.*, 2008; Bender & Ingver, 2012). We know from previous research that the content of vitamin C in vegetables depends on many factors – mainly the genotype, variety, maturity, climatic conditions, agronomic factors, soil type and harvest time (Lee & Kader, 2000; Mozafar, 2018). All these factors, except the fertilizer type, were the same in our TP1 carrots. We suppose that the differences in the content of vitamin C could have been due to a different fertilizer type: compost *vs.* mineral fertilizer. However, nutrients release slowly from compost (Sanchez & Richard, 2009) and therefore, nitrogen was more easily available to plants in conventional production. However, it is known that the increasing presence of plant available N reduces the accumulation of defence related vitamin C (Mozafar, 1993).

Based on our DM content results there were no significant differences between organic and conventional carrots in five years out of six. DM content was higher ($p \leq 0.05$) in organic carrots in 2009. Our result is consistent with several earlier studies (Brandt *et al.*, 2011; Gąstoł *et al.*, 2011; Bach *et al.*, 2015). DM in our experiments was influenced by the weather conditions of the trial years, being higher in both production systems in the warmer than the LTA year of 2013 compared to the other trial years. Nevertheless, Bach et al. (2015) claim that the different temperature sums in their three-year experiment in Denmark had no effect on the DM content. Still, in extreme weather conditions, the results may have been affected by the different type of soil in Danish and Estonian trials (sandy loam *vs.* sandy clay loam).

The differences in N content in our carrots did not differ between production systems in TP1, where the applied N levels were optimal in both cropping systems. In compliance with higher fertilization in TP2 conventional production, N content was higher in conventional carrots. However, there was a significant year effect on the N content of carrots, which was lower in 2013 than in other trial years, probably due to a shortage of precipitation from June to the harvest in the middle of September. NO_3 content, on the other hand, was significantly influenced by both, the cropping system and year in TP1, being lower in the organic than in the conventional production and highly variable across all trial years. NO_3 content of the carrots was highest in the extremely dry 2011 but still remained low (200 – 500 mg kg^{-1} FW) according to Santamaria

(2006). Grzebelus and Barański (2001) have reported that NO_3 content in garden beet was lower in the year that had a high amount of precipitation. Some earlier studies have also shown that organic carrots contain less NO_3 than conventional ones (Lairon, 2009; Seljåsen *et al.*, 2013; Barański *et al.*, 2014; Wierzbowska, *et al.*, 2017) and that the year can have a significant effect on this characteristic (Ilić & Šunić, 2015). Gennaro and Quaglia (2003) concluded in their review that lower NO_3 levels in organic vegetables seemed to be due to differences in the N fertilization level. However, we found a lower NO_3 content in organic production in TP1 at the N fertilization levels which were at least comparable in both systems. The mineral fertilizer used in conventional production directly provides NO_3, while compost is slowly decomposable and N releases gradually (Matallana González *et al.,* 2010). In general, the content of NO_3 in our experiments was low, except in 2011. In addition, Custic *et al.* (2003) argued that plant NO_3 levels were more influenced by weather conditions than the form and application rates of fertilizers. Smolen and Sady (2009) revealed that plant N nutrition is more influenced of soil organic matter mineralization than by N fertilization.

No pesticide residues were found in our organic carrots, whereas residues of five out of the seven used pesticides were detected in the conventional carrots. We know from previous research that organic food is reported to contain fewer or no residues (Hoogenboom *et al.*, 2008; Lima & Vivanello, 2011; Barański *et al.*, 2014; Gomiero, 2018; EFSA, 2020). In the summer of 2012, the amount of precipitation during the main spraying period was high, and therefore, the chemical control measures were not successful, which resulted in a single year of absence of pesticide residues in conventional carrot samples. Chlorothalonil and aclonifen were the most frequently detected pesticide residues in our conventional carrots. The common occurrence is explained by the fact that chlorothalonil is a broad-spectrum fungicide with low aqueous solubility and has often been found in conventionally produced vegetables (Yuan *et al.,* 2014; Ahoudi *et al.,* 2018; Divakara & Sharma, 2019; Office of Environmental ..., 2019; U.S. Food ..., 2019). Aclonifen, a systemic and selective herbicide, has been characterized as not highly soluble in water, but has been found in many organic solvents and is moderately persistent in soil (Onder Erguven *et al.,* 2016). The insecticide cypermethrin, which contained in our conventional carrots of two trial years, persists in the environment from 14.6 to 76.2 days (half-life), depending on the physicochemical properties of the soil (Chen *et al.,* 2012). Nevertheless, pesticide residues detected in our conventional carrots can pose a threat to the environment and consumers. Even legislatively determined "safe" levels of residues (below the MRL), in the case of simultaneous exposure of multiple chemical substances, may have synergistic effects and cause unknown adverse health problems (Nicolopoulou-Stamati *et al.,* 2016).

6.3. The effect of agroecological service crops (ASC) in no-till roller crimper (RC) management on weeds

In organic farming, it is necessary to consider alternatives to reduce weeds, and one of them is RC technology. According to our results, RC technology had clear effect on weed density at an early stage of the catch crop in both trial years (**IV**). This effect was significant only in Y2 because of the incompatibility of Italian ryegrass with RC technology in Y1. Italian ryegrass developed a strong regrowth after the RC termination. Therefore, it was possible to collect weed data only from rye ILRC management in Y1. In Y2, triticale as the second ASC was used after rye. The mean weed density reduction across seven project experiments in ILRC management was 35.1% and, in our trials, even 69.9% compared to GM. Previous experiments carried out in Italy by Canali et al. (2013) and Ciaccia et al. (2016) have also shown a dramatic reduction of weed density (86% and 84%, respectively) in ILRC plots in comparison with GM. Weber et al. (2017) from Germany have reported a weed density reduction of 61% in no-till with RC management compared to control treatment, which was without weed control. Campanelli et al. (2019) have also claimed that all five ASCs in no-till RC technology reduced significantly weed density compared to control, tilled and without ASC. The reason for such a good result in Estonian trials may have been a sufficiently high amount of biomass, especially that of rye. The other cause might be a precisely timed RC technology application, which resulted in a thick mulch layer without regrowth of ASCs. Some researchers have also stressed that to suppress weeds throughout the entire cash crop season, rapid cover crop establishment and high biomass are required (Reberg-Horton et al., 2012; Mirsky et al., 2013). Cover crop management, including species selection, seeding date and rate, termination date, equipment and fertilization, are critical for producing adequate biomass and achieve effective termination. Optimization of these factors can efficiently improve weed suppression (Mirsky et al., 2012; Schmidt et al., 2019). Our results have also been confirmed by the results of previous studies which state that cover crop sowing and timing of termination have often been observed to play a key role in ASC biomass production (Mischler et al., 2010; Mirsky et al., 2011).

Weed species richness in our experiments also had a consistent response to ILRC management in both years. The reduction of species richness was 23.8% across seven trials. The result of Estonian trial was close to the average (25.3%) and significant in both years. Similar reduction has been obtained by Halde et al. (2015). In both years of the experiments of the Italian partner of the SoilVeg project, weed density and species richness did not decrease (IV). This atypical case of weed density could be related to the ASC and weed resprouting, while the absence of effect on weed species richness might be a consequence of the low level of weed density in the experimental field. On the contrary, in our experimental fields the density of weeds and weed species diversity was naturally high, due to which the effect of ILRC management on the abundance of weeds and weed species was obvious.

The high diversity of weed species allowed us to obtain more drastic results on the change in weed community composition due to the ILRC management compared to GM and in comparison to the results of our partners. Analyzing and comparing five most abundant species in ILRC and GM management gave us a clear understanding of the changes in the weed community of our trials. Weed community composition generally had a significant but low response to ILRC vs. GM management in Estonian trials (IV). If we compare five most abundant weed species of our result of two years pooled, JaccD is 0.52. The share of perennial weeds in ILRC was 3 times higher than in GM. An analogous result has been obtained in many previous studies (Peigne et al., 2007; Armengot et al., 2015; Nichols et al., 2015; Armengot et al., 2016; Ciaccia et al., 2020). Several researchers reveal in their studies that the mulch-based no-till practice shows a strong selective pressure on weeds in the short term, shifting the community towards a suite of traits able to survive the flattening, which overcome the mulch barrier (Jokela & Nair, 2016; Testani et al., 2019).

7. CONCLUSIONS

The hypothesis that organic and conventional marketable yield of carrot is similar under the optimal levels of used N fertilization and remains lower in organic management in the case of below optimal N fertilization was not confirmed. On the contrary, higher carrot yield was produced in organic treatment in TP1 in the conditions were at least the same level of N fertilizer was applied in organic compared to conventional treatment. In our two-year comparison trial (TP2), despite a lower N fertilization level, the marketable yield in organic production was similar to that achieved with conventional treatment.

We found a significantly higher marketable yield (14.5%) and lower discarded yield (10.0%) in organic compared to conventional production (TP1). Discarded yield was also lower (12.9%) in organic production in TP2. These advantages of organic production over conventional can be explained by the influence of organic compost on the properties and functioning of the soil compared to the synthetic fertilizer.

The hypothesis that organically produced carrots have a higher content of TS, vitamin C and DM compared to the conventional system was partly correct. Our results showed that only the content of vitamin C was higher in organically produced carrots (10.0%) if N fertilization levels in both production systems were comparable (TP1). Despite lower N application levels in organic production, the content of TS, vitamin C and DM was the same in both management systems (TP2).

Conventionally produced carrots had a higher N content only in TP2, which partly confirms the hypotheses. As was hypothesized, conventionally produced carrots had a higher content of NO_3 than organic carrots and contained pesticide residues in both trials. In TP1, conventional carrots contained 13.1% and in TP2, 89.5% more NO_3 than organic carrots. The residues of three fungicides (boscalid, chlorothalonil and pyraclostrobin), one herbicide (aclonifen) and one insecticide (cypermethrin) were identified in conventional carrots. The content of all detected residues was below the MRL. Nevertheless, pesticide residues detected in conventional carrots can pose a threat to the environment and, in the case of simultaneous exposure of multiple chemical substances, may have synergistic effects and cause unknown adverse health problems. Therefore, in general, we can argue that one of the superior advantages of organically produced carrots is the fact that they contain fewer nitrates and in particular, are free of pesticide residues.

In addition to management effects, these variables were also influenced by the weather conditions of trial years.

Our study of comparison of the conventional and organic production provides considerable evidence about the advantages of organic production over the conventional one in terms of carrot yield and quality if N fertilization in organic production is at least at the same level as in conventional production. There are few previous experiments carried out under the same soil and microclimate conditions and at least the same N fertilization levels. Our results provide a successful example that can contribute to the understanding that organic products are of good quality and free from pesticide residues. Furthermore, organic production is environmentally friendly and our study will help to achieve the goals of the European Green Deal.

The hypothesis that rolling and crimping of agroecological service crops (cover crops) reduces weed density and species richness and changes weed composition in comparison to the green manure method in organic vegetable production was fully supported. ILRC management reduced weed density (69.9%) and weed species richness (25.3%) in comparison with GM. The number of weed species in weed community composition in GM differed from the ILRC number of weed species in weed community composition on a large scale (52%). Estonian results of the two-year study along with the outcome of the other four countries in the SoilVeg project provided, for the first time, solid evidence of the effectiveness of ILRC management for weed control at early stages of crop growth in different vegetable systems, soils and climate conditions across Europe. Our results show that with weed management in organic vegetable systems it is possible to reduce the dependence on tillage.

ILRC management of ASCs has proved to be an effective strategy for controlling weeds in an early stage of cash crop and is worth to be introduced in organic vegetable production. Further research is required to identify the influence of mulch in ILRC management on the environmental conditions of the soil surface and to find out how it affects the emergence of weeds along the cash crop cycle.

REFERENCES

Ahoudi, H., Gnandi, K., Tanouayi, G., Ouro-Sama, K., Yorke, J., Creppy, E., Moesch, C. 2018. Assessment of pesticides residues contents in the vegetables cultivated in urban area of Lome (southern Togo) and their risks on public health and the environment Togo. *Int. J. Biol. Chem. Sci.*, 12, 2172–2185.

Altieri, M.A., Lana, M.A., Bittencourt, H.V., Kieling, A.S., Comin, J.J., Lovato, P.E. 2011. Enhancing crop productivity via weed suppression in organic no-till cropping systems in Santa Catarina, *Brazil. J. Sustain. Agric.*, 35, 855–869.

Amlinger, F., Götz, B., Dreher, P., Geszti, J. 2003. Nitrogen in biowaste and yard waste compost: dynamics of mobilisation and availability – a review. *Eur. J. Soil Biol.,* 39, 107–116.

Armengot L., Berner A., Blanco-Moreno J.M., Mäder, P., Sans, X.S. 2015. Long-term feasibility of reduced tillage in organic farming. *Agron. Sustain. Dev.*, 35, 339–346.

Armengot, L., Blanco-Moreno, J.M., Bàrberi, P., Bocci, G., Carlesi, S. Aendekerk, R., Berner, A., Celette, F., Grosse, M., Huiting, H., Kranzler, A., Luik, A., Mäder, P., Peigné, J., Stoll, E., Delfosse, P., Sukkel, W., Surböck, A., Westaway, S., Sans, F.X. 2016. Tillage as a driver of change in weed communities: a functional perspective. Agric. Ecosyst. Environ. 222, 276–285.

Ashford, D.L. & Reeves, D.W. 2003. Use of a mechanical roller-crimper as an alternative kill method for cover crops. *Am. J. Altern. Agric.*, 18, 37–45.

Baardseth, P., Rosenfeld, H.J., Sundt, T.W., Skrede, G., Lea, P., Slinde, E. 1996. Evaluation of carrot varieties for production of deep fried carrotchips – II. Sensory aspects. *Food Res. Int.*, 28, 513–519.

Bach, V., Kidmose, U., Kristensen, H.L., Edelenbos, M. 2015. Eating quality of carrots (*Daucus carota* L.) growing in one conventional and three organic cropping systems over three years. *J. Agric. Food Chem.*, 63, 9803–9811.

Badgley, C., Moghtader, J., Quintero, E., Zakem, E., Chappell, M.J., Avilés-Vázquez2, K., Samulon, A. Perfecto, I. 2007. Organic agriculture and the global food supply. *Renew. Agric. Food Syst.*, 22, 86–108.

Bahadoran, Z., Mirmiran, P., Jeddi, S., Azizi, F., Ghasemi, A., Hadaegh, F. 2016. Nitrate and nitrite content of vegetables, fruits, grains, legumes, dairy products, meats, and processed meats. *J. Food Compos. Anal.*, 51, 93–105.

Bai, Z., Caspari, T., Gonzalez, M.R., Batjes, N.H., Mäder, P., Bünemann, E.K., de Goede, R., Brussard, L., Minggang, X., Ferreira, C.S.S. *et al.* 2018. Effects of agricultural management practices on soil quality: a review of long-term experiments for Europe and China. *Agric. Ecosyst. Environ.*, 265, 1–7.

Bajwa, U. & Sandhu, K.S. 2014. Effect of handling and processing on pesticide residues in food — a review. *J. Food Sci. Techn.*, 52, 201–220.

Baker, B.P., Benbrook, C.M., Groth, E., Benbrook, L. 2002. Pesticide residues in conventional, integrated pest management (IPM) – growth and organic foods: insights from three US data sets. *Food Addit. Contam.,* 19, 427–446.

Barański, M., Średnicka-Tober, D., Volakakis, N., Seal, C., Sanderson, R., Srewart, G.B., Benbrook, C., Biavati, B., Markellou, E., Giotis C. *et al.* 2014. Higher antioxidant and lower cadmium concentration and lower incidence of pesticide residues in organically grown crops: a systematic literature review and meta-analyses. *Br J Nutr.*, 5, 794–811.

Benbrook, C., Zhao, X., Yáñez, J., Davies, N., Andrews, P. 2008. New evidence confirms the nutritional superiority of plant-based organic foods. *The Organic Center Critical Issue Report,* Organic Center, Washington, DC.

Bender, I. & Ingver, A. 2012. The influence of production methods on yield and quality of carrots and swedes. *Acta Hortic.*, 960, 293–298.

Bernacchia, R., Preti, R., Vinci, G. 2016. Organic and conventional foods: Differences in nutrients. Review. *Ital. J. Food Sci.*, 28, 565–578.

Blanco-Canqui, H., Shaver, T.M., Lindquist, J.L., Shapiro, C.A. Elmore, R.W., Francis, C.A., Hergert, G.W. 2015. Cover crops and ecosystem services: insight from studies in temperate soils. *Agron. J.*, 107, 2449–2474.

Boone, L., Roldán-Ruiz, I., van Linden, V., Muylle, H., Dewulf, J. 2019. Environmental sustainability of conventional and organic farming: accounting for ecosystem service in life cycle assessment. 2019. *Sci. Total Environ.*, 695, 133841.

Bosona, T. & Gebresenbet, G. 2018. Swedish consumers' perception of food quality and sustainability in relation to organic food production. *Foods*, 7.

Bourn, D. & Prescott, J. 2002. A comparision of nutritional value, sensory qualitites and food safety of organically and conventionally produced foods. *Crit. Rev. Food Sci. Nutr.,* 42, 1–34.

Brainard, D.C. & Noyes, D.C. 2012. Strip tillage and compost influence carrot quality, yield, and net returns. *HortSci.*, 47, 1073–1079.

Brandt, K. & Mølgaard, J.P. 2001. Organic agriculture: does it enhance or reduce the nutritional value of plant foods? *J. Sci. Food. Agric.*, 81, 924–931.

Brandt, K., Leifert, C., Sanderson, R., Seal, J.C. 2011. Agroecosystem management and nutritional quality of plant foods: the case of organic fruits and vegetables. *Crit. Rev. Plant Sci.*, 30, 177–197.

Bulgari, R., Franzoni, G., Ferrante, A. 2019. Biostimulants application in horticultural crops under abiotic stress conditions. *Agronomy,* 9, 306.

Bulluck, L.R. & Ristaino, J.B. 2002. Effect of synthetic and organic soil fertility amendments on southern blight, soil microbial communities, and yield of processing tomatoes. *Phytopathology*, 92, 181–189.

Campanelli, G., Testani, E., Canali, S., Ciaccia, C., Leteo, F., Trinchera, A. 2019. Effects of cereals as agro-ecological service crops and no-till on organic melon, weeds and N dynamics. *Biol. Agric Hortic.*, 35, 275–287.

Canali, S. 2013. Ecological Services providing crops (ESCs) in organic vegetable production systems. Available online: https://orgprints.org/22570/ (accessed on 25 Jan 2021).

Canali, S., Campanelli, G., Ciaccia, C., Leteo, F., Testani, E., Montemurro, F. 2013. Conservation tillage strategy based on the roller crimper technology for weed control in Mediterranean vegetable organic cropping systems. *Eur. J. Agron.,* 50, 11–18.

Canali, S., Diacono, M., Campanelli, G., Montemurro, F. 2015. Organic no-till with roller crimpers: agro-ecosystem services and applications in organic mediterranean vegetable productions. *Sustain. Agric. Res.,* 4, 70–79.

Canellas, L.P., Olivares, F.L., Aguiar, N.O., Jones, D.L., Nebbioso, A., Mazzei, P., Piccolo, A. 2015. Humic and fulvicacids as biostimulants in horticulture. *Sci. Hortic.*, 196, 15–27.

Canellas, L.P., Olivares, F.L., Okorokova-Facanha, A.L., Facanha, A.R. 2002. Humic acids isolated from earthworm compost enhance root elongation, lateral root emergence and plasma membrane H+-ATPase activity in maize roots. *Plant Physiol.*, 130, 1951–1957.

Casagrande, M., Peigné, J., Payet, V., Mäder, P., Sans, F.H., Blanco-Moreno, J.M., Antichi, D., Bàrberi, P., Beeckman, A., Bigongiali, F., Cooper, J., Dierauer, H., Gascoyne, K., Grosse, M., Heß, J., Kranzler, A., Luik, A., Peetsmann, E., Surböck, A., Willekens, K., David, C. 2016. Organic farmers' motivations and challenges for adopting conservation agriculture in Europe. *Org. Agr.*, 6, 281–295.

Chen, S.; Geng, P.; Xiao, Y.; Hu, M. 2012. Bioremediation of β-cypermethrin and 3-phenoxybenzaldehyde contaminated soils using *Streptomyces aureus* HP-S-01. *Appl. Microbiol. Biotechnol.*, 94, 505–515.

Ciaccia, C., Testani, E., Campanelli, G. Sestili, S., Leteo, F., Tittarelli, F., Riva, F., Canali, S., Trinchera, A. (2015) Ecological service providing crops effect on melon-weed competition and allelopathic interactions. *Org Agric.,* 5, 199–207.

Ciaccia, C., Canali, S., Campanelli, G., Testani, E., Montemurro, F., Leteo, F., Delate, K. 2016. Effect of roller-crimper technology on weed management in organic zucchini production in a Mediterranean climate zone. *Renew. Agric. Food Syst.*, 31, 111–121.

Ciaccia, C., Martinez, L.A., Testani, E., Leteo, F., Campanelli, G., Trinchera, A. 2020. Weed functional diversity as affected by agroecological service crops and no-till in a mediterranean organic vegetable system. *Plants*, 9, 689.

Colla, G., Kim, H., Kyriacou, M.C., Rouphael, Y. 2018. Nitrate in fruits and vegetables. *Sci. Hortic.*, 237, 221–238.

Cortés-Olmos, C., Leiva-Brondo, M., Roselló, J., Raigón, D.M., Cebolla-Cornejo, J. 2014. The role of traditional varieties of tomato as sources of functional compounds. *J. Sci. Food Agric.*, 94, 2888–2904.

Custic, M., Poljak, M., Coga, L., Cosic, T., Noth, N., Pecina, M. 2003. The influence of organic and mineral fertilization on nutrient status, nitrate accumulation, and yield of head chicory. *Plant Soil Environ.*, 49, 218–222.

Dangour, A.D., Dodhia, S.K., Hayter, A., Allen, E., Lock, K., Uauy, R. 2009. Nutritional quality of organic foods: a systematic review. *Am. J. Clin. Nutr.*, 90, 680–685.

Dawson, J.C., Murphy, K.M., Huggins, D.R., Jones, S.S. 2011. Evaluation of winter wheat breeding lines for traits related to nitrogen use under organic management. *Org. Agr.*, 1, 65–80.

De Ponti, T., Rijk, B., van Ittersum, M.K. 2012. The crop yield gap between organic and conventional agriculture. *Agric. Syst.*, 108, 1–9.

Diacono, M. & Montemurro, F. 2010 Long-term effects of organic amendments on soil fertility. A review. *Agron. Sustain. Dev.*, 30, 401–422.

Divakara, J. & Sharma, D. 2019. Dissipation of chlorothalonil in leafy vegetables accelerated by use of biofertilizer. *Pest Manag. Hortic. Ecosyst.*, 25, 109–115.

Ditlevsen, K., Sandøe, P., Lassen, J. 2019. Healthy food is nutritious, but organic food is healthy because it is pure: the negotiation of healthy food choices by Danish consumers of organic food. *Food Qual. Prefer.*, 71, 46–53.

Dong, T., Park, Y., Hwang, I. 2015. Ascorbic acid: biosynthesis, inactivation, homoeostasis and signalling. *Essays Biochem.*, 58, 29–48.

Dresbøll, D.B., Bjørn, G.K., Thorup-Kristensen, K. 2008. Yields and the extent and causes of damage in cauliflower, bulb onion and carrot grown under organic or conventional regimes. *J. Hortic. Sci. Biotehnol.* 83, 770–776.

Drobek, M., Frac, M., Cybulska, J. 2019. Plant biostimulants : importance of quality and yield of horticultural crops and the improvement of plant tolerance to abiotic stress – a review. *Agronomy,* 9, 335.

EFSA (European Food Safety Authority), Medina-Pastor P and Triacchini G, 2020. The 2018 European Union report on pesticide residues in food. *EFSA J.,* 18, 6057. https://doi.org/10.2903/j.efsa.2020.6057.

EFSA (European Food Safety Authority). 2018. The 2016 European Union report on pesticide residues in food. Scientific research. European Food Safety Authority, Parma, Italy.

El-Hage Scialabba, N. 2007. Organic agriculture and food security. In: *Report of the International Conference on Organic Agriculture and Food Security*, May 3-5, Rome, Italy, 22 p.

EPPO. 2021. EPPO Global Database. Available online: https://gd.eppo.int

EPRS (European Parliamentary Research Service). Human Health Implications of Organic Food and Organic Agriculture. 2016. Available online: https://www.europarl.europa.eu/RegData/etudes/STUD/2016/581922/EPRS_STU(2016)581922_EN.pdf (accessed on 29 March 2021).

Eremeev, V., Talgre, L., Kuht, J., Mäeorg, E., Esmaeilzadeh-Salestani, K., Alaru, M., Loit, E., Runno-Paurson, E., Luik, A. 2019. The soil microbial hydrolytic activity, content of nitrogen and organic carbon were enhanced by organic farming management using cover crops and composts in potato cultivation. *Acta Agric. Scand. B Soil Plant Sci.*, 70, 87–94.

Eslami, S.V. & Davis, A.S. 2018. Weed interference with no-till soyabeans influenced by fine-scale covariation between soil properties and cover crop performance. *Weed Res.*, 58, 463–474.

European Commission. EU Green Deal. Actions being taken by the EU. Available online: https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/actions-being-taken-eu_en (accessed on 5 Nov 2020).

European Commission. EU Green Deal. Organic action plan. https://ec.europa.eu/info/food-farming-fisheries/farming/organic-farming/organic-action-plan_en (accessed on 7 Nov 2021).

FAO. World Reference Base for Soil Resources 2014. International Soil Classification System for Naming Soils and Creating Legends for Soil Maps World Soil Resources, Report 106. FAO, Rome, Italy, 2015. Available online: http://www.fao.org/3/a-i3794en.pdf (accessed on 28 May 2021).

FiBL. Research and development in and for the field. Activity report 2018.

Finckh M.R. 2008. Integration of breeding and technology into diversification strategies for disease control in modern agriculture. In: *Sustainable disease management in a European context*. Collinge D.B., Munk L., Cooke B.M. Eds., Springer, Dordrecht, pp. 399–409.

Fjelkner-Modig, S., Bengtsson, H., Stegmark, R., Nystrom, S. 2000. The influence of organic and integrated production on nutritional, sensory and agricultural aspects of vegetable raw materials for food production. *Acta Agric. Scand., B, Soil Plant Sci.*, 50, 102–113.

Gajewski, M., Weglarz, Z., Sereda, A., Bajer, M., Kuczkowska, A., Majewski, M. 2009. Quality of carrots grown for processing as affected by nitrogen fertilization and harvest term. *Veg. Crops Res. Bull.*, 70, 135–144.

Gallandt, E. 2014. Weed management in organic farming. In: *Recent advances in weed management*. Chauhan, B.S., Mahajan, G. Eds. Springer New York, NY, USA, pp. 63–85.

Gąstoł, M., Domagała-Świątkiewicz, I., Krośniak, M. 2011. Organic versus conventional — a comparative study on quality and nutritional value of fruit and vegetable juices. *Biol. Agric. Hortic.*, 27, 310–319.

Gennaro, L. & Quaglia, G.B. 2003. Food safety and nutritional quality of organic vegetables. *Acta Hortic.*, 614, 675–680.

Gimenez, C., Otto, R.F., Castilla, N. 2002. Productivity of leaf and root vegetable crops under direct cover. *Sci. Hort.* 94, 1–11.

Giuseppina, P., Lima, P., Vivanello, F. 2011. Review on the main differences between organic and conventional plant-based foods. *Food Sci. Technol.*, 46, 1–13.

Gobbo-Neto, L. & Lopes, N.P. 2007. Medicinal plants: factors of influence on the content of secondary metabolites. *Quimica Nova*, 30, 374–381.

Goldwater, A.D., Ekman, J.H., Rogers, G.S. 2018. The effects of floating row covers on yield and quality of field-grown capsicum (*Capsicum annuum* L.). *Acta Hortic.*, 1205, 891–896.

Gomiero, T. 2018. Food quality assessment in organic vs. conventional agricultural produce: finding and issues. *Appl. Soil Ecol.*, 123, 714–728.

Grewal, A.S., Singla, A., Kamboj, P., Dua, J.S. 2017. Pesticide residues in food grains, vegetables and fruits: a hazard to human health. *J.Med. Chem. Toxicol.*, 2, 1–7.

Grzebelus, D. & Baranski, R. 2001. Identification of accessions showing low nitrate accumulation in a germplasm collection of garden beet. *Acta Hortic.*, 563, 253–255.

Gutezeit, B.B. 1999. Yield and nitrate content of carrots (*Daucus carota* L.) as affected by nitrogen supply. *Acta Hortic.*, 506, 87–91.

Gutezeit, B.B. 2001. Yield and quality of carrots as affected by soil moisture and N-fertilization. *J. Hortic. Sci. Biotechnol.*, 76, 732–738.

Halde, C., Bamford, K.C., Entz, M.H. 2015. Crop agronomic performance under a six-year continuous organic no-till system and other tilled and conventionally-managed systems in the northern Great Plains of Canada. *Agric. Ecosyst. Environ.*, 213, 121–130.

Halde, C. & Entz, M.H. 2016. Plant species and mulch application rate affected decomposition of cover crop mulches used in organic rotational no-till systems. *Can. J. Plant Sci.,* 96, 59–71.

Hallmann, E. 2012. The influence of organic and conventional cultivation systems on the nutritional value and content of bioactive compounds in selected tomato types. *J. Sci. Food Agric.*, 92, 2840–2848.

Hartz, T.K., Johnstone, P.R., Nunez, J.J. 2005. Production environment and nitrogen fertility affect carrot cracking. *HortSci.*, 40, 611–615.

Hayden, Z. D., Brainard, D. C., Henshaw, B., Ngouajio, M. 2012. Winter annual weed suppression in rye-vetch cover crop mixtures. *Weed Technol.*, 26, 818–825.

Henneron, L., Bernard, L., Hedde, M., Pelosi, C., Villenave, C., Bertrand, M., Girardin, C., Blanchart, E. 2015. Fourteen years of evidence for positive effects of conservation agriculture and organic farming on soil life. *Agron. Sustain. Dev.*, 35, 169–181.

Hlisnikovský, L., Mešnik, L., Krížová, K., Kunzová, E. 2021. The effect of farmyard manure and mineral fertilizers on sugar beet beetroot and top yield and soil chemical parameters. *Agronomy*, 11, 133.

Hoefkens, C., van Dekinderen, I., de Meulenaer, B., Devlieghere, F., Baert, K., Sioen, I., de Henauw, S., Verbeke, W., van Camp, J. 2009. A literature-based comparison of nutrient and contaminant contents between organic and conventional vegetables and potatoes. *Br. Food J.*, 111, 1078–1097.

Hoogenboom, L.A.P., Bokhorst, J.G., Northolt, D.M., van de Vijver, L.P.L., Broex, N.J.G., Mevius, D.J., Meijs, J.A.C., van der Roest, J. 2008. Contaminants and microorganisms in Dutch organic food products: a comparison with conventional products. *Food Addit. Contam.* Part A, 25, 1195–1207.

Hunter, D., Foster, M., McArthur, J., Ojha, R., Petocz, P., Samman, S. 2011. Evaluation of the micronutrient composition of plant foods produced by organic and conventional agricultural methods. *Crit. Rev. Food Sci. Nutr.,* 51, 571–582.

Hurtado-Barroso, S., Tresserra-Rimbau, A., Vallverdú-Queralt, A., Lamuela-Raventós, R.M. 2019. Organic food and the impact on human health. *Crit. Rev. Food Sci. Nutr.*, 59, 4, 704–714.

IFOAM. 2018. Consolidated Annual Report of IFOAM-Organics International. IFOAM, Bonn, Germany.

Ilić, Z.S. & Šunić, L. 2015. Nitrate content of root vegetables during different storage conditions. *Acta Hortic.*, 1079, 659–665.

Iocola, I., Bassu, S., Farina, R., Antichi, D., Basso, B., Bindi, M., Marta, A.D., Danuso, F., Doro, L., Ferrise, R., Giglio, L., Fabrizio Ginaldi, F., Mazzoncini, M., Mula, L., Orsini, R., Corti, G., Pasqui, M., Seddaiu, G., Tomozeiu, R., Ventrella, D., Villani, G., Roggero, P.P. 2017. Can conservation tillage mitigate climate change impacts in Mediterranean cereal systems? A soil organic carbon assessment using long term experiments. *Eur. J. Agron.*, 90, 96–107.

Jensen, M.M., Jørgensen, H., Lauridsen, C. 2013. Comparison between conventional and organic agriculture in terms of nutritional quality of food – a critical review. *CAB Reviews*, 8, 1–13.

Jokela, D. & Nair, A. 2016. Effects of reduced tillage and fertilizer application method on plant growth, yield, and soil health in organic bell pepper production. *Soil Tillage Res.*, 163, 243–254.

Kaack, K., Nielsen, M., Christensen, L.P., Thorup-Kristensen, K. 2001. Nutritionally important chemical constituents and yield of carrot (*Daucus carota* L.) roots grown organically using ten levels of green manure. *Acta Agric. Scand. B Soil Plant Sci.*, 51, 125–136.

Kalisz, A., Cebula, S., Siwek, P., Sekara, A., Grabovska, A., Gil, J. 2014. Effects of row covers using non-woven fleece on the yields, rate of bolting, and quality of heading Chinese cabbage in early spring cultivation. *J. Japan. Soc. Hort. Sci.*, 83, 133–141.

Kapusta-Duch, J. & Leszczyńska, T. 2013. Comparison of vitamin C and ß-carotene in cruciferous vegetables grown in diversified ecological conditions. *Pol. I. Environ. Stud.*, 22, 167–173.

Kirchmann, H., Kätterer, T., Bergström, L., Börjesson, G., Bolinder, M.A. 2016. Flaws and criteria for design and evaluation of comparative organic and conventional cropping systems. *Field Crop Res.*, 186, 99–106.

Kirdar, S.S. 2018. Comprehensive review of organic foods throughout the world. *Int. J. Agric. Environ. Res.,* 1, 220–230.

Kleijn, D., Bommarco, R., Fijen, T.P.M., Garibaldi, L.A., Potts, S.G., van der Putten, W.H. 2019. Ecological intensification: bridging the gap between science and practice. *Trends Ecol. Evol.*, 34, 154–166.

Knapp, S. & van der Heijden, M.G.A. 2018. A global meta-analysis of yield stability in organic and conservation agriculture. *Nat Commun.*, 9, 3632.

Kniss, A.R., Savage, S.D., Jabbour, R. 2016. Commercial crop yields reveal strengths and weakness for organic agriculture in the United States. *PLoS ONE*, 11, e0161673.

Kołota, E. & Adamczewska-Sowińska, K. 2011. Application of synthetic mulches and flat covers with perforated foil and agrotextile in zucchini. *Acta Sci. Pol. Hortorum Cultus,* 10, 179–189.

Kornecki, T.S., Arriaga, F.J., Price, A.J. 2012. Roller type and operating speed effects on rye termination rates, soil moisture, and yield of sweet corn in a no-till system. *HortScience*, 47, 217–223.

Kremen, C. & Miles, A. 2012. Ecosystem services in biologically diversified versus conventional farming systems: benefits, externalities, and trade-offs. *Ecol. Soc.*, 17, 40.

Lairon, D. 2009. Nutritional quality and safety of organic food. A review. *Agron Sustain Dev.*, 30, 33–41.

Leavitt, M.J., Sheaffer, C.C., Wyse, D.L., Allan, D.L. 2011. Rolled winter rye and hairy vetch cover crops lower weed density but reduce vegetable yields in no-tillage organic production. *HortScience*, 46, 387–395.

Leclerc, C., Miller, M., Joliet, E., Roquelin, G. 1991. Vitamin and mineral contents of carrot and celery grown under mineral or organic fertilization. *Biol. Agr. Hort.*, 7, 339–348.

Lee, J., Hwang, S., Ha, I., Min, B., Hwang, H., Lee, S. 2015. Comparison of bulb and leaf quality and antioxidant compounds of intermediateday onion from organic and conventional systems. *Hortic. Environ. Biotechnol.*, 56, 427–436.

Lee, S.K. & Kader, A.A. 2000. Preharvest and postharvest factors influencing vitamin C content of horticultural crops. *Postharvest Biol. Technol.*, 20, 207–220.

Leszczyńska, T. 1996. Nitrates and nitrites in vegetables from conventional and ecological cultures. *Bromatologia I Chemia Toksykologiczna,* 29, 289–293.

Lesur-Dumoulin, C., Malézieux, E., Ben-Ari, T., Langlais, C., Makowski, D. 2017. Lower average yields but similar yield variability in organic versus conventional horticulture. A meta-analysis. *Agron. Sustain. Dev.*, 37, 45.

Liebman, M. & Davis, A.S. 2000. Integration of soil, crop and weed management in low-external-input farming systems. *Weed Res.,* 40, 27–47.

Lima, G.P.P. & Vianello, F. 2011. Review on the main differences between organic and conventional plant-based foods. *Int. J. Food Sci. Technol.*, 46, 1–13.

Lotter, D.W., Seidel, R., Liebhardt, W. 2003. The performance of organic and conventional cropping systems in an extreme climate year. *Am. J. Altern. Agric.*, 18, 146–154.

MacLaren, C., Swanepoel, P., Bennett, J.W., Dehnen-Schmutz, K. 2019. Cover crop biomass production is more important than diversity for weed suppression. *Crop Sci.*, 59, 733–748.

Marshall, E.J.P. & Moonen, A.C. 2002. Field margins in northern Europe: their functions and interactions with agriculture. *Agric. Ecosyst. Environ.*, 89, 5–21.

Masamba, K.G. & Nguyen, M. 2008. Determination and comparison of vitamin C, calcium and potassium in four selected conventionally and organically grown fruits and vegetables. *Afr. J. Biotechnol.*, 7, 2915–2919.

Massey, M., O'Cass, A., Otahal, P. 2018. A meta-analytic study of the factors driving the purchase of organic food. *Appetite,* 125, 418–427.

Matallana González, M.C., Martínez-Tome, M.J., Torija Isasa, M.E. 2010. Nitrate and nitrite content in organically cultivated vegetables. *Food Addit. Contam. B*, 3, 19–29.

Maximum Residue Levels. 2021. https://ec.europa.eu/food/plants/pesticides/maximum-residue-levels_en (accessed on 30 August 2021).

Mirsky, S.B., Curran, W.S., Mortensen, D.M., Ryan, M.R., Shumway, D.L. 2011. Timing of cover-crop management effects on weed suppression in no-till planted soybean using a roller-crimper. *Weed Sci.,* 59, 380–389.

Mirsky, S.B., Ryan, M.R., Curran, W.S., Teasdale, J.R., Maul, J., Spargo, J.T., Moyer, J., Grantham, A.M., Weber, D., Way, T.R. Camargo, G.G. 2012. Conservation tillage issues: cover crop-based organic rotational no-till grain production in the mid-Atlantic region, USA. Renew. Agric. Food Syst., 27, 31–40.

Mirsky, S.B., Ryan, M.R., Teasdale, J.R., Curran, W.S., Reberg-Horton, C.S., Spargo, J.T., Wells, M.S., Keene, C.L., Moyer, J.W. 2013. Overcoming weed management challenges in cover crop–based organic rotational no-till soybean production in the eastern united states. *Weed Technol.*, 27, 193–203.

Mischler, R., Duiker, S.W., Curran, W.S., Wilson, D. 2010. Hairy vetch management for no-till organic corn production. *Agron. J.*, 102, 355–362.

Mondelaers, K., Verbeke, W., Van Huylenbroeck, G. 2009. Importance of health and environment as quality traits in the buying decision of organic products. Br. Food J., 111, 1120–1139.

Montemurro, F., Fiore, A., Campanelli, G., Tittarelli, F., Ledda, L., Canali, S. 2013. Organic fertilization, green manure, and vetch mulch to improve organic zucchini yield and quality. *HortSci.*, 48, 1027–1033.

Mozafar, A. 1993. Nitrogen fertilizers and the amount of vitamins in plants. A review. *J. Plant Nutr.*, 16, 2479–2506.

Mozafar, A. 2018. Plant vitamins: agronomic, physiological and nutritional aspects. Boca Raton, CRC Press, FL, Taylor & Francis Group.

Mäder, P., Fliessbach, A., Dubois, D., Gunst, L., Fried, P., Niggli, U. 2002. Soil fertility and biodiversity in organic farming. *Sci.* 296, 1694–1697.

Nardi, S., Pizzeghello, D., Schiavon, M., Ertani, A. 2016. Plant biostimulants: physiological responses induced by protein hydrolyzed-based products and humic substances in plant metabolism. *Sci. Agric.*, 73, 18–23.

Nichols, V., Verhulst, N., Cox, R., Govaerts, B. 2015. Weed dynamics and conservation agriculture principles. A review. *Field. Crop Res.*, 183, 56–68.

Nicolopoulou-Stamati, P., Maipas, S., Kotampasi, C., Stamatis, P., Hens, L. 2016. Chemical pesticides and human health: the urgent need for a new concept in agriculture. *Front. Public Health*, 4.

Niggli, U. 2015. Sustainability of organic food production: challenges and innovations. *Proc. Nutr. Soc.*, 74, 83–88.

Nookaraju, A., Upadhyaya, C.P., Pandey, S.K., Young, K.E., Hong, S.J., Park, S.K., Park, S.W. 2010. Molecular approaches for enhancing sweetness in fruits and vegetables. *Sci. Hortic.*, 127, 1–15.

Nord, E.A., Ryan, M.R., Curran, W.S., Mortensen, D.A., Mirsky, S.B. 2012. Effects of management type and timing on weed suppression in soybean no-till into rolled-crimped cereal rye. *Weed Sci.,* 60, 624–633.

O'Brien, J.A., Vega, A., Bouguyon, E., Krouk, G., Gojon, A., Coruzzi, G., Gutiérrez, R.A. 2016. Nitrate transport, sensing, and responses in plants. *Mol. Plant*, 9, 837–856.

Office of Environmental Health Hazard Assessment. Proposition 65. Interpretive Consumption of Chlorothalonil Residues in Certain Foods. 2019. Interpretive Guidelines No. 2019-01—2019-09. Available online: Oehha.ca.gov/media/downloads/crnr/chlorothalonilig111519.pdf (accessed on 29 May 2021).

Oliveira, A.B., Moura, C.F.H., Gomes-Filho, E., Marco, C.A., Urban, L., Miranda, M.R.A. 2013. The impact of organic farming on quality of tomatoes is associated to increased oxidative stress during fruit development. *PLoS ONE*, 8, e56354.

Onder Erguven, G., Byhan, H., Demir, G., Ikizoglu, B., Kanat, G. 2016. Monitoring aclonifen remediation in soil with a laboratory-scale research. *J. Chem.*, article ID 5059049.

Orsini, F., Maggio, A., Rouphael, Y., de Pascale, S. 2016. "Physiological quality" of organically grown vegetables. *Sci. Hortic.*, 208, 131–139.

Paoletti, F., Raffo, A., Kristensen, H.L., Thorup-Kristensen, K., Seljåsen, R., Torp, T., Busscher, N., Ploeger, A., Kahl, J. 2012. Multi-method comparison of carrot quality from a conventional and three organic cropping systems with increasing levels of nutrient recycling. J Sci Food Agric., 92, 2855–2869.

Patkowska, E. & Konopiński, M. 2013. Harmfulness of soil-borne fungi towards root chicory (Cichorium intybus L. var. sativum Bisch.) cultivated with the use of cover crops. Acta Sci. Pol.- Hortoru,12, 3–18.

Peigné, J., Ball, B.C., Roger-Estrade, J., David, C. 2007. Is conservation tillage suitable for organic farming? A review. *Soil Use* Manag., 23, 129–144.

Peigné, J., Casagrande, M., Payet, V., David, C., Sans, F.X., Blanco-Moreno, J.M., Cooper, J., Gascoyne, K., Antichi, D. Bàrberi P. *et al.* 2016. How organic farmers practice conservation agriculture in Europe. *Renew. Agric. Food Syst.*, 31, 72–85.

Pereira, F.O., Pereira, R.S., Rosa, L.S., Teodoro, A.J. 2016. Organic and conventional vegetables: Comparison of the physical and chemical characteristics and antioxidant activity. *Afr. J. Biotechnol.*, 15, 1746–1755.

Petersen, P., Tardin, J.M., Marochi, F. 1999. Participatory development of no-tillage systems without herbicides for family farming: the experience of the center-south region of Paraná. *Environ. Dev. Sustain.*, 1, 235–252.

Ponisio, L.C., M'Gonigle, L.K., Mace, K.C., Palomino, J., de Valpine, P., Kremen, C. 2015. Diversification practices reduce organic to conventional yield gap. *Proc. R. Soc. B*, 282, 20141396.

Poulsen, M.E. & Andersen J.H. 2003. Results from the monitoring of pesticide residues in fruit and vegetables on the Danish market, 2000-01. *Food Addit. Contam.,* 20, 742–757.

Putra, A. & Yuliando, H. 2015. Soilless culture system to support water use efficiency and product quality: a review. Agric. Agric. Sci. *Procedia, 3, 283–288.*

Radicetti, E., Roberto, M., Campiglia, E. 2013. Influence of winter cover crop residue management on weeds and yield in pepper (*Capsicum annuum* L.) in a Mediterranean environment. *Crop Prot.,* 52, 64–71.

Rahman, S.M.E., Mele, M.A., Lee, Y., Islam, M.Z. 2021. Consumer preference, quality, and safety of organic and conventional fresh fruits, vegetables, and cereals. 2021. *Foods*, 10, 105.

R Core Team (2017) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna https://www.R-project.org/.

Reberg-Horton, S.C., Grossman, J.M., Kornecki, T.S., Meijer, A.D., Price, A.J., Place, G.T., Webster, T.M. 2012. Utilizing cover crop mulches to reduce tillage in organic systems in the southeastern USA. *Renew. Agric. Food Syst.*, 27, 41–48.

Reeve, J.R., Hoagland, L.A., Villalba, J.J., Carr, P.M., Atucha, A., Cambardella, C., Davis, D.R., Delate, K. 2016. Organic farming, soil health, and food quality: considering possible links. In: *Advances in Agronomy*, 137, Sparks, D.L., Ed., Academic Press, Chennai, India, pp. 319–368.

Reganold, J.P. & Wachter, J.M. 2016. Organic agriculture in the twenty-first century. *Nat. Plants*, 2, 15221.

Regulation (EC) No 396/2005. Available online: https://ec.europa.eu/food/plant/pesticides/eu-esticides-db_en (accessed on 15 February 2021).

Rekika, D., Stewart, K.A., Boivin, G., Jenni, S. 2009. Row covers reduce insect populations and damage and improve early season crisphead lettuce production. *Int. J. Veg. Sci.*, 15, 71–82.

Rembiałkowska, E. 2007. Quality of plant products from organic agriculture. Review. *J. Sci. Food Agric.*, 87, 2757–2762.

Rembiałkowska, E. & Hallmann, E. 2007. Influence of cultivation method (organic vs. conventional) on selected quality attributes of carrots (*Daucus carota*). *Zywienie Czovieka I Metabolizm*, 34, 550–556.

Rembiałkowska, E. & Średnicka, D. 2009. Organic food quality and impact on human health. *Agron. Res.*, 7, 181–186.

Rembiałkowska, E. 2000. The nutritive and sensory quality of carrots and cabbage from organic and conventional farms. In IFOAM 2000: The world grows organic. Proceedings. 13th International IFOAM Scientific Conference. Zurich, 297.

Rembiałkowska, E. 2003. Organic farming as a system to provide better vegetable quality. *Acta Hortic.*, 604, 473–479.

Rembiałkowska, E. 2007. Quality of plant products from organic agriculture. A review. *J. Sci. Food Agric.*, 87, 2757–2762.

Rembiałkowska, E. 2016. Organic food: effect on nutrient composition. In: *The Encyclopedia of Food and Health*. Caballero, B., Finglas, P.M., Toldrá, F., Eds. Vol. 4, Academic Press, Oxford, pp. 171–177.

Rosenfeld, H.J., Samuelsen, R.T., Lea, P. 1998. Relationship between physical and chemical characteristics of carrots grown at northern latitudes. *J. Hortic. Sci. Biotechnol.*, 73, 65–73.

Rouphael, Y. & Colla, G. 2018. Synergistic biostimulatory action: designing the next generation of plant biostimulants for sustainable agriculture. *Front. Plant Sci.,* 9, 1–24.

Salehzadeh, H., Maleki, A., Rezaee, R., Shahmoradi, B., Ponnet, K. 2020. The nitrate content of fresh and cooked vegetables and their health-related risks. *PLoS ONE,* 15, e0227551.

Sanchez, E.S. & Richard, T.L. 2009. Using organic nutrient sources. *Penn State Agricultural Research and Cooperative Extension Publication*, 20 Feb.

Santamaria, P. 2006. Nitrate in vegetables: toxicity, content, intake and EC Regulation. *J. Sci. Food Agr.*, 86, 10–17.

Santamaria, P., Elia, A., Gonnella, M., Parente, A., Serio, F. 2001. Ways of reducing rocket salad nitrate content. *Acta Hortic.*, 548, 529–537.

Santamaria, P., Elia, A., Serio, F., Todaro, E. 1999. A survey of nitrate and oxalate content in fresh vegetables. *J. Sci. Food Agric.*, 79, 1882–1888.

Sarrantonio, M. & Gallandt, E. 2003. The role of cover crops in North American cropping systems. *J. Crop Prod.*, 8, 53–74.

SAS Institute, 2010. SAS user's guide: Statistics. The SAS Institute Inc. Cary, NC.

Schmidt, J.H., Jungr, S., Finkh, M.R. 2019. Cover crops and compost prevent weed seed bank buildup in hebicide-free wheat-potato rotations under conservation tillage. *Ecol. Evol.*, 9, 1–10.

Schrama, M., de Haan, J.J., Kroonen, M., Verstegen, H., van der Putten, W.H. 2018. Crop yield cap and stability in organic and conventional farming system. *Agric. Ecosyst. Environ.*, 256, 123–130.

Seljåsen, R., Kristensen, H.L., Kretzschmar, U., Birlouez-Aragon, I., Paoletti, F., Lauridsen, C., Wyss, G.S., Busscher, N., Mengheri, E., Sinesio, F., Zanoli, R., Vairo, D., Beck, A., Kahl, J. 2016. How to understand the complexity of product quality and the challenges in differentiating between organically and conventionally grown products – Exemplified by fresh and heat-processed carrots (*Daucus carota* L.). *Org. Agric.*, 6, 31–47.

Seljåsen, R., Kristensen, H.L., Lauridsen, C., Wyss, G.S., Kretzschmar, U., Birlouez-Aragone, I., Kahl, J. 2013. Quality of carrots as affected by pre- and postharvest factors and processing. *J. Sci. Food Agr.,* 93, 2611–2626.

Seljåsen, R., Lea, P., Torp, T., Riley, H., Berentsen, E., Thomsen, M., Bengtsson, G.B. 2012. Effects of genotype, soil type, year and fertilisation on sensory and morphological attributes of carrots (*Daucus carota* L.). *J. Sci. Food Agr.,* 92, 1786–1799.

Seufert, V., Ramankutty, N., Foley, J.A. 2012. Comparing the yields of organic and conventional agriculture. *Nature*, 485, 229–232.

Seufert, V. 2019. Comparing yields: Organic versus conventional agriculture. In: *Encyclopedia of Food Security and Sustainability.* Ferranti, E, Berry, E.M., Anderson, J.P., Eds., Elsevier, pp. 196–208.

Shabetya, O.N., Kotsareva, N.V., Nasser, A.M., Katskaya, A.G., Al-Maidi, A.A.H. 2020. Biochemical composition of eggplant and its change during storage. *Plant Arch.*, 20, 385–388.

Sikora, M., Hallmann, E., Rembiałkowska, E. 2009. The content of bioactive compounds in carrots from organic and conventional production in the context of health prevention. *Roczniki Pan'stwowego Zakadu Higieny*, 60, 217–220.

Sink, N., Mikulic-Petkovsek, M., Veberic, R., Kacjan Marsic, N. 2017. Chemical composition and morphometric traits and yield of carrots grown in organic and integrated farming systems. *Turk. J. Agric. For.*, 41, 452–462.

Smith, T.A., Lin, B.H., Huang, C.L. 2009. Growth and development in the U.S. retail organic food sector. *Sustainability,* 1, 573–591.

Smith-Spangler, C., Brandeau, M., Hunter, G.E., Bavinger, J., Pearson, M., Eschbach, P.J., Sundaram, V., Lui, H., Schirmer, P., Stave, C., Olkin, I., Bravata, D.M. 2012. Are organic foods safer or healthier than conventional alternatives? A systematic review. *Ann. Intern. Med.,* 157, 348–366.

Smolen, S. & Sady, W. 2009. The effect of various nitrogen fertilization and foliar nutrition regimes on the concentrations of sugars, carotenoids and phenolic compounds in carrot (*Daucus carota* L.). *Sci. Hortic.,* 120, 315–324.

Szafirowska, A. & Elkner, K. 2008. Yielding and fruit quality of three sweet pepper cultivars from organic and conventional cultivation. *Veg. Crops Res. Bull.*, 69, 135–143.

Suojala, T. 2000. Variation in sugar content and composition of carrot storage roots at harvest and during storage. *Sci. Hortic.*, 85, 1–19.

Tasiopoulou, S., Chiodini, A.M., Vellere, F., Visentin, S. 2007. Results of the monitoring program of pesticides in organic food of plant origin in Lombardy (Italy). *J. Environ. Sci. Health B,* 42, 835–841.

Teasdale, J.R. & Mohler, C.L. 2000. The quantitative relationship between weed emergence and the physical properties of mulches. *Weed Sci.*, 48, 385–392.

Tejada, M., Gonzalez, J.L., García-Martínez, A.M., Parrado, J. 2008. Application of a green manure composted with beet vinasse on soil restoration: effects on soil properties. *Bioresour. Technol.*, 99, 4949–4957.

Testani, E., Ciaccia, C., Campanelli, G., Leteo, F., Salvati, L., Canali, S. 2019. Mulch-based no-till effects of weed community and management in an organic vegetable system. *Agronomy*, 9, 594.

Thorup-Kristensen, K., Dresbøll, D.B., Kristensen, H.L. 2012. Crop yield, root growth, and nutrient dynamics in a conventional and three organic cropping systems with different levels of external inputs and N re-cycling through fertility building crops. *Eur. J. Argon.*, 37, 66–82.

Tian, J., Lou, Y., Fang, H., Liu, S., Xu, M., Blagodatskaya, E., Kuzyakov, Y. 2017. Response of soil organic matter fractions and composition of microbial community to long-term organic and mineral fertilization. *Biol. Fertil. Soils*, 53, 523–532.

Tilman, D., Cassman, K.G., Matson, P.A., Naylor, R., Polasky, S. 2002. Agricultural sustainability and intensive production practices. *Nature,* 418, 671–677.

Tonitto, C., David, M.B., Drinkwater, L.E. 2006. Replacing bare fallows with cover crops in fertilizer-intensive cropping systems: a meta-analysis of crop yield and N dynamics. *Agric. Ecosyst. Environ.* 112, 58–72.

Trevisan, S., Francioso, O., Quaggiotti, S., Nardi, S. 2010. Humic substances biological activity at the plant-soil interface: from environmental aspects to molecular factors. *Plant Signal. Behav.*, 5, 635–643.

Tuomisto, H.; Hodge, I.; Riordan, P.; Macdonald, D. 2012. Does organic farming reduce environmental impacts? - A meta-analysis of European research. *J. Environ. Manage.*, 112, 309–320.

Turbas, E., Oll, Ü. 1969. Agrokeemia laboratoorne praktikum [*Practical analyses of agrochemistry*]. Tallinn, Estonia.

U.S. Department of Agriculture, Agricultural Research Service. 2020. USDA Food and Nutrient Database for Dietary Studies 2017-2018. Food Surveys Research Group Home Page. Available online: http://www.ars.usda.gov/nea/bhnrc/fsrg (accessed on 1 Feb 2021).

U.S. Food and Drug Administration. Pesticide Residue Monitoring Program. Fiscal year 2017 Pesticide Report. FDA Pesticide Residue Monitoring Program Reports and Data; 2019. Available online: www.fda.gov/food/pesticides/pesticide-residue-monitoring-2017-report-and-data (accessed on 29 May 2021).

Vaitkevičiene, N., Jariene, E., Kulaitiene, J., Danillcenko, H., Cerniauskiene, J., Aleinikoviene, J., Srednicka-Tober, D., Rembiałkowska, E. 2020. Influence of agricultural management practices on the soil properties and mineral composition of potato tubers with different colored flesh. *Sustainability,* 12, 9103.

Vincent-Caboud, L., Casagrande, M., David, C., Ryan, M.R., Silva, E.M., Peigne, J. 2019. Using mulch from cover crops to facilitate organic no-till soybean and maize production. A review. *Agron. Sustain. Dev.*, 39, 45.

Vinha, A.F., Barreira, S.V.P., Costa, A.S.G., Alves, R.C., Oliveira, M.B.P.P. 2014. Organic versus conventional tomatoes: influence on physicochemical parameters, bioactive compounds and sensorial attributes. *Food Chem. Toxicol.*, 67, 139–144.

Vorontsov, I.E., Kulakovskiy, I.V., Makeev, V.J. 2013. Jaccard index based similarity measure to compare transcription factor binding site models. *Algorithms Mol. Biol.* 8, 23.

Warman, P.R. & Havard, K.A. 1997. Yield, vitamin and mineral contents of organically and conventionally grown carrots and cabbage. *Agric., Ecosyst. Environ.*, 61, 155–162.

Warman, P.R. & Havard, K.A. 1996. Yield, vitamin and mineral content of four vegetables grown with either composted manure or conventional fertilizer. *J. Veg. Crop Prod.*, 2, 13–25.

Wayman, S., Cogger, C., Benedict, C., Burke, I., Collins, D., Bary, A. 2015. The influence of cover crop variety, termination timing and termination method on mulch, weed cover and soil nitrate in reduced-tillage organic systems. Renew. Agric. Food Syst., 30, 450–460.

Weber, J.F., Kunz, C., Peteinatos, G.G., Zikeli, S., Gerhards, R. 2017. Weed control using conventional tillage, no-tillage, and cover crops in organic soybean. Agriculture, 7, 43.

Wezel, A., Casagrande, M., Celette, F., Vian, J.-F., Ferrer, A., Peigné, J. 2014. Agroecological practices for sustainable agriculture. A review. Agron. Sustain. Dev., 34, 1–20.

Wierzbowska, J, Cwalina-Ambroziak, B., Głosek, M., Sienkiewicz, S. 2017. Yield and mineral content of edible carrot depending on cultivation and plant protection methods. *Acta Sci. Pol. Hortorum Cultus*, 16, 75–86.

Winter, C.K. & Davis, S.F. 2006. Organic foods. *J. Food Sci.*, 1, 117–124.

Woëse, K., Lange, D., Boess, C., Bogl, K.W. 1997. A comparison of organically and conventionally grown foods – results of a review of the relevant literature. *J. Sci. Food and Agric.,* 74, 281–293.

Worthington, V. 2001. Nutritional quality of organic versus conventional fruits, vegetables and grains. *J. Altern. Compl. Med.*, 7, 161–173.

Wunderlich, S.M., Feldman, C., Kane, S., Hazhin, T. 2008. Nutritional quality of organic, conventional, and seasonally grown broccoli using vitamin C as a marker. *Int. J. Food Sci. Nutr.,* 59, 34–45.

Yuan, Y., Chen, C., Zheng, C., Wang, X., Yang, G., Wang, Q., Zhang, Z. 2014. Residue of chlorpyrifos and cypermethrin in vegetables and probabilistic exposure assessment for consumers in Zhejiang Province, China. *Food Control*, 36, 63–68.

Zakir, H.M., Sultana, M.N., Saha, K.C. 2012. Influence of commercially available organic vs inorganic fertilizers on growth yield and quality of carrot. *J. Environ. Sci. Nat. Resour.*, 5, 39–45.

Zhou, Z.-Y., Wang, M.-J., Wang, J.-S. 2000. Nitrate and nitrite contamination in vegetables in China. *Food Reviews Int.*, 16, 61–76.

Zicari, G., Soardo, V., Cerrato, E., Rivetti, D. 2011. Results from the monitoring of pesticide residues in fruits and vegetables marketed in Piedmont (Italy), 2000-2008. *Ig Sanita Pubbl.*, 67, 149–168.

SUMMARY IN ESTONIAN

MAHEVILJELUSE MEETODITE MÕJU PORGANDI SAAGILE JA KVALITEEDILE NING UMBROHTUDELE

Sissejuhatus

Kogu maailmas kasvab mahetoidu, sealhulgas maheköögivilja tootmine ja nõudlus selle järele (Smith *et al.*, 2009; Niggli, 2015; IFOAM, 2018; Rahman *et al.,* 2021). Tarbijad eelistavad mahetoitu, pidades seda tervislikumaks ja keskkonda vähem saastavamaks, kuna mahetoitu toodetakse sünteetilisi pestitsiide ja väetiseid kasutamata (Tuomisto *et al.*, 2012; Orsini *et al.*, 2016; Bosona ja Gebresenbet, 2018; Gomiero, 2018; Massey *et al.*, 2018; Ditlevsen *et al.*, 2019).

Mahetootmisest saadakse väiksemaid saake võrreldes tavatootmisega ja see on tõsiseks probleemiks. Täiustades aga mahetootmise agrotehnoloogiat, on võimalik saagikust tõsta ja vähendada mahajäämust tavatootmise saakidest (Badgley *et al.*, 2007; de Ponti *et al.*, 2012; Seufert *et al.*, 2012; Ponisio *et al.*, 2015; Reganold ja Wachter, 2016). Teatavasti on mahetootmisel positiivne mõju mulla omadustele ja mahemuldades on suurem orgaanilise aine sisaldus kui tavatootmise muldades, mis on aga eelduseks mahesaakide kasvule (Bulluck, *et al.* 2002; Mäder *et al.*, 2002; Mondelaers *et al.*, 2009; Reeve *et al.*, 2016; Bai *et al.*, 2018; FiBL, 2018; Vaitkevičiene *et al.*, 2020).

Paljud varasemad teadusartiklid on jõudnud järeldusele, et mahe- ja tavatootmises kasvatatud köögiviljade, sealhulgas porgandi toitainete sisaldus ei erine teineteisest oluliselt (Dangour *et al.*, 2009; Hoefkens *et al.*, 2009; Smith-Spangler *et al.* 2012). Samas aga tuuakse välja maheköögiviljade vähene saastatus nitraatide ja pestitsiididega (Giuseppina *et al.* 2011). Uuemad uuringud (nt Hurtado-Barroso *et al.* 2019) on lisaks sellele väitnud, et mahetoit sisaldab rohkem bioaktiivseid ühendeid, nagu polüfenoole, C-vitamiini, karotenoide jt.

Köögiviljade toitainete sisaldust mõjutavad geneetilised ja keskkonnast tingitud faktorid, nagu kasvuaegne ilmastik, õhu saastatus ja küpsuse faas koristuse ajal, mis on sõltumatud tootmisviisist (Gobbo-Neto ja Lopes, 2007). Ainult need faktorid, mis mahe- ja tavatootmises süstemaatiliselt erinevad, saavad põhjustada rangelt järjekindlaid erinevusi toodangu koostises (Brandt *et al.*, 2011). Sageli on mahe- ja tavatootmises kasvatatud köögiviljade saagi ja kvaliteedi kohta toodud vastukäivaid ja ebajärjekindlaid tulemusi, mis on olnud seotud metodoloogiliste probleemidega läbiviidud katsete rajamisel (Fjelkner-Modig *et al.*, 2000; Dangour *et al.*, 2009; Seljåsen *et al.*, 2013; Bernacchia *et al.*, 2016; EPRS, 2016; Reeve *et al.*, 2016). Tüüpiliseks probleemiks on olnud tavatootmise suuremad väetamisnormid peamiste toitainete osas võrreldes mahetootmisega (EPRS, 2016). Seda probleemi aitab lahendada suuremate orgaanilise aine koguste lisamine mahetootmissüsteemi. Orgaanilise aine juurdeandmine parandab mulla tervist ja tõstab seeläbi mulla samale toitainete sisalduse tasemele kui tavasüsteemiski (Tejada *et al.*, 2008; Diacono ja Montemurro, 2010; Reeve *et al.*, 2016; Bai *et al.*, 2018). Kirchmann'i *et al.* (2016) järgi peaks tava- ja mahekatsete võrdlemisel olema täidetud vähemalt kolm kriteeriumi, et tulemusi korrektselt interpreteerida. Need tingimused on järgmised: 1) katse alguses peab muld katselappidel olema ühesugune, 2) võrdlemiseks tuleb kasvatada sama kultuuri, 3) väetiskogused igas süsteemis peavad olema võrdsustatud. Käesoleva uuringu üks peamisi eesmärke oli katsetada eelnevaid kriteeriume arvesse võttes porgandit samal mullal ja võrdsete lämmastikunormide juures nii tava- kui ka maheviljeluses, et võrrelda viljelusviiside mõju porgandi saagile ja kvaliteedile.

Mahetootmises on umbrohutõrje tõsiseks probleemiks. Agro-ökoloogilistel kultuuridel (ASC), sealhulgas vahekultuuridel, on umbrohutõrjes oluline roll. Nad suruvad alla umbrohtusid ja samal ajal parandavad mulla kvaliteeti (Gallandt, 2014). Kõige levinum viis on agro-ökoloogiliste kultuuride purustamine ja mulda viimine enne põhikultuuri külvamist või istutamist. Vähelevinud on minimeeritud harimisviis vahekultuuri kasvu lõpetamiseks muljur-rulli abil (Peigné *et al.*, 2016). Siiski on viimasel ajal Euroopa talupidajate seas kasvanud huvi rullimis-muljumistehnoloogia (ILRC) vastu (Casagrande *et al.*, 2016; Vincent-Caboud *et al.*, 2019). ILRC tehnoloogia võimaldab agro-ökoloogilistest kultuuridest muljur-rulli abil moodustada maapinnale tiheda multšikihi, mis takistab umbrohtude tärkamist ja levimist. Seda meetodit on köögiviljakasvatuses veel vähe uuritud ja kasutatud. Eestis katsetati nimetatud meetodit esmakordselt EL projekti SoilVeg (2015 – 2018) raames. ILRC meetodi rakendamine vajab veel edasisi uuringuid.

Doktoritöö hüpoteesid olid järgmised:

1. Porgandi kaubanduslik ja mittekaubanduslik saak on mahe- ja tavatootmise tingimustes optimaalsete lämmastiku normide kasutamisel samal tasemel ja jääb mahetingimustes madalamaks optimaalsest väiksemate N normide korral (**I, II, III**).

2. Maheporganditel on suurem suhkrute, vitamiin C ja kuivaine sisaldus võrreldes tavatingimustes kasvanud porganditega (**I, II, III**).

3. Tavaviljeluses kasvatatud porgandid sisaldavad rohkem lämmastikku ja nitraate kui maheporgandid ning nendes sisaldub pestitsiidijääke (**I, II, III**).

4. Rullimis-muljumistehnoloogia kasutamine agro-ökoloogiliste kultuuride kasvu lõpetamiseks maheköögiviljakasvatuses vähendab umbrohtude tihedust, liigirikkust ja muudab umbrohtude liigilist koosseisu võrreldes haljasväetise meetodiga (**IV**).

Doktoritöö eesmärgid olid järgmised:

- hinnata porgandi kaubandusliku ja mittekaubandusliku saagi osatähtsust mahe- ja tavatootmises optimaalsete N normide kasutamise ja optimaalsest väiksemate N koguste korral maheviljeluses (**I, II, III**);

- välja selgitada suhkrute, C-vitamiini ja kuivaine sisaldus mahe- ja tavatootmise porgandis (**I, II, III**);

- kindlaks määrata lämmastiku ja nitraatide tase mahe- ja tavaporgandis (**I, II, III**);

- välja selgitada pestitsiidijääkide esinemine tavaporgandis (**I, II, III**);

- fikseerida rullimis-muljumistehnoloogia mõju umbrohtude tihedusele, liigirikkusele ja umbrohtude liigilisele koosseisule Eestis läbiviidud katsete põhjal (**IV**).

Katsematerjal ja metoodika

Doktoritöö raames viidi läbi katsed porgandiga (sort 'Jõgeva Nantes') selle saagi ja kvaliteedi uurimiseks kahel katseperioodil: aastatel 2011–2014 (TP1) (**I**) ja 2008–2009 (TP2) (**II, III**) Eesti Taimekasvatuse Instituudis, Jõgeval. Rullimis-muljumistehnoloogia mõju uuriti aastatel 2015–2017 kahes katsetsüklis: 2015/2016 (Y1) ja 2016/2017 (Y2). Katsed viidi läbi ühel ja samal mullal. Porgand külvati mai lõpus ja koristati kas oktoobri algul (2008, 2009, 2011 ja 2012) või septembri keskel (2013 ja 2014).

Perioodil TP1 (**I**) oli katse kolmes korduses, iga kordus eraldi blokis, milles neli varianti, nendest kolm tava – CON5, CON3 ja CON1 – ning üks mahe – ORG. Katselapi suurus oli 10 m^2. Tavavariantides väetati kõiki variante sünteetilise mineraalväetise Cropcare 8-12-23 ühesuguse normiga, millega anti N 80 kg ha^{-1}. Tavavariandid erinesid üksteisest sünteetiliste pestitsiididega pritsimise arvu poolest, CON5 pritsiti viis korda, CON3 kolm korda ja CON1 üks kord (tabel 1). Mahevarianti väetati Matogard OÜ hobusesõnnikukompostiga, 8 t ha^{-1} (N 1–2%, P 0,1–0,3% ja K 0,6–0,9%, tootja andmetel), millega anti tavavariandiga vähemalt samal tasemel lämmastikku (N 80 kg ha^{-1}).

Perioodil TP2 (**II, III**) oli katse neljas korduses kahe variandiga, tava (C) ja mahe (O). Katselapi suurus oli 25 m^2. Tavavarianti väetati põhiväetisena mineraalväetisega Cropcare 8-12-23, millega anti N 65 kg ha^{-1}. Kasvuaegse väetisena kasutati ammooniumnitraati (N 50 kg ha^{-1}) ja leheväetisega Folicare 18-18-18 (N 4 kg ha^{-1}). Mahevarianti väetati taimsetest jäätmetest valmistatud kompostiga 2 t ha $^{-1}$ (N 24 kg ha^{-1} 2008 ja N 20 kg ha^{-1} 2009). Kasvuaegse väetisena kasteti porgandit humiin- ja fulvohapete vedela kontsentraadi Humistar lahusega 1:20. Tavavariandi porgandeid pritsiti sünteetiliste pestitsiididega viis korda (tabel 1).

Tabel 1. Tavavariantides (CON5, CON3, CON1 ja C) kasutatud sünteetilised pestitsiidid, pestitsiidiklass (h – herbitsiid, i – insektitsiid, f – fungitsiid), toote nimi ja kasutatud normid kahel katseperioodil (TP1 ja TP2) 2008 – 2014.

Kasutatud pestitsiidi t.aine* ja klass	**Toote nimi**	**Variant**	**Kasutusnorm, publikatsiooni nr.**
Aclonifen (h)	Fenix	CON5, CON3, CON1	2,0 l ha^{-1} , **I**
		C	2,5 l ha^{-1}, **II, III**
Propaquisafop (h)	Agil 100 EC	CON5, C	1 l ha^{-1}, **I, II, III**
Cypermethrin (i)	Fastac 50	CON5, CON3	0,15 l ha^{-1}, **I**
		C	0,3 l ha^{-1}, **III**
Tiametoksam (i)	Actara 25 WG	C	120 g ha^{-1}, **II**
Boscalid + pyraclostrobin (f)	Signum	C	0,75 kg ha^{-1}, **II, III**
Chlorothalonil (f)	Bravo 50SC	CON5, CON3	3,0 l ha^{-1}, **I**

* t.aine – toimeaine

Kogusaagist eraldati kaubanduslik ja mittekaubanduslik saak, mille moodustasid valdavalt lõhenenud, harunenud või väikesed porgandid (läbimõõt < 2 cm). Kaubandusliku saagi porgandites määrati suhkrute, C-vitamiini, kuivaine, lämmastiku ja nitraatide sisaldus. Kuna enne katsete rajamist tehtud mullaanalüüsist ei leitud pestitsiidijääke, siis pestitsiidide jääkide sisaldust analüüsiti ainult tavavariantide porgandis. Porgandit analüüsiti Põllumajandusuuringute Keskuse, Maaülikooli ja Eesti Taimekasvatuse Instituudi laboratooriumides.

Projekti SoilVeg raames viidi läbi 14 agro-ökoloogiliste kultuuride muljumis-rullimiskatset viies Euroopa riigis (Eesti, Hispaania, Itaalia, Sloveenia ja Taani), nendest kaks katseseeriat Eesti Taimekasvatuse Instituudis Jõgeval. Igas riigis toimunud katsed olid erinevates klimaatilistes tingimustes, katsed oli erineva katseplaaniga ja erinev oli ka saagikultuur. Kõigis katsetes oli ühiseks osaks see, et võrreldi omavahel agro-ökoloogiliste kultuuride kasvu lõpetamise kaht tehnoloogiat: 1) traditsiooniline purustamine ja sellele järgnev ASC muldaviimine (GM), 2) rullimis-muljumistehnoloogia (ILRC). Jõgeva katsetes külvati agro-ökoloogiliste kultuuridena rukis (*Secale cereale* L.) ja itaalia raihein (*Lolium multiflorum* Lam.) augusti lõpus 2015. a (Y1) ning rukis ja tritikale (x *Triticosecale blaringhemii* A. Camus) septembri alguses 2016. a (Y2).

Peale ASC talvitumist taimik purustati ja künti mulda või muljuti-rulliti ASC õitsemise faasis juuni keskel. Saagikultuuriks olnud valge peakapsas istutati kohe peale ASC muljumist-rullimist, et saagikultuuri istutamine liiga hiljaks ei jääks.

Neli umbrohtude tiheduse ja ASC biomassi proovi (raamid mõõtudega 0,5 x 0,5 m ja 1 x 1 m, vastavalt) võeti igalt katselapilt enne ASC kasvu lõpetamist juuni esimestel päevadel. Teine umbrohuproovide võtmine toimus kapsa varases kasvu faasis, mis oli 69 päeva (Y1) ja 37 (Y2) päeva peale istutamist. Umbrohtude tiheduse (taimi m^{-2}), liigirikkuse (liiki proovi kohta) ja liigilise koostise andmete saamiseks loendati nii tärganud kui ka uuesti kasvama hakanud taimed ja määrati liigid. Esimesel katseaastal tuvastati umbrohuproovides 45 ja teisel katseaastal 43 liiki.

Tulemused ja arutelu

Uurimistulemuste põhjal selgus, et katses, kus maheviljeluse variandis kasutati väetamisel vähemalt sama suurt N normi (N 80 kg ha^{-1}) kui tavaviljeluses (TP1), oli porgandi kaubanduslik saak mahevariandis 14,5% suurem (**I**). Siin oli tõenäoliselt suurema mahesaagi põhjuseks orgaaniline väetis kompostina, millel on eelised mineraalväetise ees. Orgaaniline väetis suurendab mulla orgaanilise aine sisaldust, aktiveerib mullaorganisme ja suurendab mulla ensümaatilist aktiivsust ning selle tulemusena suureneb taimedele kättesaadavate toitainete hulk (Henneron et al., 2015; Lesur-Dumoulin et al., 2017; Tian et al., 2017; Bai et al., 2018; Schrama et al., 2018; Eremeev et al., 2019; Vaitkevičiene et al., 2020).

Hüpoteesile vastupidiselt oli kaubanduslik saak teisel katseperioodil (TP2) nii mahe- kui ka tavaviljeluses võrdne. Tulemuse selgitamiseks selged tõendid puuduvad. Võib vaid oletada, et maheviljeluses kasutatud katteloor ning humiin- ja fulvohapete lahusega kastmine koos kompostiga võisid luua mahevariantide mullas toitainete parema kättesaadavuse porganditaimedele võrreldes tavavariandiga, mida väetati ainult sünteetiliste mineraalväetistega. Seda oletust on kinnitanud eelnevad uuringud, kus on esile toodud katteloori eelised taimedele soodsama mikrokliima loomisel ja selle kaudu suurema saagi saamisel (Gimenez et al., 2002; Rekika et al., 2009; Kołota ja Adamczewska-Sowińska, 2011; Kalisz et al., 2014; Goldwater et al., 2018). Mitmed uuringud on tõestanud Humistari positiivset mõju taimede abiootilise stressi vähendajana, mulla keemiliste ja füüsikaliste omaduste parandajana, taimedele toitainete ja vee parema kättesaadavuse tagajana ning juurte massi suurendajana

(Trevisan et al., 2010; Canellas et al., 2015; Nardi et al., 2016; Rouphael ja Colla, 2018; Bulgari et al., 2019; Drobek et al., 2019).

Mittekaubandusliku saagi osatähtsus kogusaagis oli tavavariandis usutavalt suurem nii katseperioodil TP1 kui ka TP2 (10,0% ja 12,9%, vastavalt) (**I, II, III**). Sellist tulemust toetas tõenäoliselt soodsam mulla olukord ja väiksem lämmastiku kättesaadavus mahevariantides.

Suhkrute ja kuivaine sisaldust porgandis viljelusviis ei mõjutanud. Sarnase tulemuseni on jõutud ka varasemates uuringutes (Rosenfeld *et al.* 1998; Brandt *et al.*, 2011; Gąstoł *et al.*, 2011; Bach *et al.*, 2015; Hlisnikovský et al., 2021).

C-vitamiini sisaldus maheviljeluse porgandis oli tavaviljeluse porgandist suurem ainult suurema kompostinormiga katseperioodi (TP1) puhul (I). TP1 katseperioodil lämmastikusisalduses viljelusviiside vahelised erinevused puudusid. TP2 katseperioodil oli mahevariandis väiksema lämmastiku sisaldusega katsetes maheporgandi lämmastikusisaldus oluliselt väiksem (II, III). Nitraatide sisaldus oli aga mõlema katseperioodi puhul tavaporgandis oluliselt suurem kui maheporgandis (I, II, III).

Aasta mõjutas kõiki eelnimetatud porgandi saagi- ja kvaliteedinäitajaid katseperioodil TP1.

Tavaporgandis leiti analüüsitud seitsmest pestitsiidijäägist viit: aclonifeni, boscalidi, chlorothalonili, cypermethrini ja pyraclostrobini. Herbitsiid aclonifen ja fungitsiid chlorothalonil jääki leiti kõige sagedamini, neljal aastal. Herbitsiid propaquizafop ja insektitsiid thiamethoxam jääki aga ei esinenud porgandis ühelgi katseaastal. Kõik pestitsiidijäägid porgandis esinesid koguses, mis jäid allapoole maksimaalset lubatud normi.

Mõlemal katseaastal oli ILRC tehnoloogia kasutamisel selge efekt umbrohtude tihedusele, liikide arvukusele ja liigilisele koostisele põhikultuuri kasvu varases faasis (**IV**). Analüüsides mõlema katseaasta keskmisi, vähendas ILRC meetod umbrohtude tihedust 69,9% ($p \leq 0{,}01$). Liikide arvukus vähenes samuti usutavalt. Mõlemal katseaastal muutus liigiline koosseis, mille iseloomustamiseks kasutati käesolevas töös Jaccard'i sarnasuse koefitsienti (Jaccard Distance, JaccD). Kahe katseaasta andmete summeerimisel saadud kogumi 10 enamesinenud umbrohu JaccD GM ja ILRC vahel oli 0,52.

Kokkuvõte

1. Doktoritöö üks olulisemaid tulemusi oli vastupidiselt hüpoteesile see, et optimaalse lämmastikuga väetamise puhul saadi mahetootmises suurem kaubanduslik saak kui tavatootmises (TP1) ja väiksema lämmastikuga väetamise puhul oli võimalik saada mahetootmises sama kõrget saaki võrreldes tavatootmisega (TP2). Mõlema väetamisvariandi puhul oli mittekaubandusliku saagi osatähtsus tavatootmises suurem kui mahetootmises.

2. Hüpotees, et mahetoodetes on kõrgem suhkrute, C-vitamiini ja kuivaine sisaldus, leidis osaliselt kinnitust. Doktoritöö tulemused näitasid, et C-vitamiini sisaldus oli 10% kõrgem ainult katseperioodi TP1 maheporgandis. Väiksema lämmastikunormiga väetamise korral mahevariandis olid suhkrute, C-vitamiini ja kuivaine sisaldused samal tasemel mõlemas viljelusviisis (TP2).

3. Lämmastikusisaldus tavaporgandis oli suurem ainult katseperioodil, mille mahevarianti oli väiksema lämmastikunormiga väetatud (TP2). Nitraatide sisaldus oli aga mõlemal katseperioodil (TP1 ja TP2) tavaporgandis suurem.

4. Tavaporgandis esines erinevaid pestitsiidijääke.

5. Rullimis-muljumistehnoloogia agro-ökoloogiliste kultuuride kasvatamisel võrreldes traditsioonilise purustamise ja sissekünni meetodiga põhikultuuri varases faasis vähendas umbrohtude tihedust, liigirikkust ja muutis liigilist koosseisu.

ACKNOWLEDGEMENTS

I wish to express my gratitude to my supervisior prof. emer. Anne Luik for her long term mentoring, support and advice which helped me to complete the thesis. My supervisors assoc. prof. Evelin Loit and senior researcher Ilmar Tamm made a decisive contribution in the crucial situations during the preparation of the thesis. My greatest respect and thanks to them!

My deepest and heartfelt gratitude belongs to my colleague senior researcher Anne Ingver for the constant support throughout the long years of my work. Anne, your professional advice, corrections, encouragement and friendship has helped enhance the value of the thesis and get me through several moments of crisis.

I am thankful to Dr Liina Talgre, Dr Karin Kauer and Dr Liina Edesi for peer-reviewing the manuscript of my thesis and providing valuable recommendations.

I would like to thank all co-authors for their substantial contribution to publications presented in this research.

I would like to express sincere thanks to the Estonian Research Institute director Andre Veskioja who created several favorable conditions for conducting of my research to achieve my goal.

Special thanks to helpful colleague Sirje Tamm for her valuable technical assistance and always positive attitude. I am grateful to Piret Rääbus for English language editing. I am also thankful to Ülle Tamm and Reet Bender for Estonian language editing of the thesis.

I greatly appreciate the support of vegetable working group members Ülle Ratassepp (†), Eve Somelar, Ave Leppik, Taavi Piiskoppel, Siiri Margens, Larissa Sirel and Ele Malm for their help on daily experiments. Without your significant help and experience, it would be difficult to run all the experiments.

I am very thankful to all the members of my family who have been with me, always supported and inspired me on my long way towards this achievement.

This research was supported by contract 8-2/T1003PKAI of the Estonian Ministry of Rural Affairs; Estonian Science Foundation Grant No 7515; target financed project of the Estonian University of Life Sciences No PK 9003 and the project SoilVeg funded by ERA-Net CORE Organic Plus Funding Bodies partners of the European Union's FP7 research and innovation program under the grant agreement no. 618107.

I

ORIGINAL PUBLICATIONS

Bender, I., Edesi, L., Hiiesalu, I., Ingver, A., Kaart, T., Kaldmäe, H., Talve, T., Tamm, I., Luik, A. 2020. Organic carrot (*Daucus carota* L.) production has an advantage over conventional in quantity as well as in quality. *Agronomy*, 10, 1420.

agronomy

Article

Organic Carrot (*Daucus carota* L.) Production Has an Advantage over Conventional in Quantity as Well as in Quality

Ingrid Bender [1,*], Liina Edesi [2], Inga Hiiesalu [3], Anne Ingver [1], Tanel Kaart [4], Hedi Kaldmäe [5], Tiina Talve [2], Ilmar Tamm [1] and Anne Luik [6]

1 Department of Jõgeva Plant Breeding, Estonian Crop Research Institute, J. Aamisepa 1, 48309 Jõgeva alevik, Estonia; anne.ingver@etki.ee (A.I.); ilmar.tamm@etki.ee (I.T.)
2 Department of Agrotechnology, Estonian Crop Research Institute Estonian Crop Research Institute, J. Aamisepa 1, 48309 Jõgeva alevik, Estonia; liina.edesi@etki.ee (L.E.); tiina.talve@etki.ee (T.T.)
3 Institute of Ecology and Earth Sciences, University of Tartu, Vanemuise 46, 51003 Tartu, Estonia; inga.hiiesalu@ut.ee
4 Institute of Veterinary Medicine and Animal Sciences, Estonian University of Life Sciences, Fr. Kreutzwaldi 62, 51014 Tartu, Estonia; tanel.kaart@emu.ee
5 Polli Horticultural Research Centre, Estonian University of Life Sciences, Uus 2, 69108 Polli küla, Estonia; hedi.kaldmaee@emu.ee
6 Research Centre of Organic Farming, Estonian University of Life Sciences, Fr. Kreutzwaldi 5, 51014 Tartu, Estonia; anne.luik@emu.ee
* Correspondence: ingrid.bender@etki.ee; Tel.: +372-7766909

Received: 27 August 2020; Accepted: 16 September 2020; Published: 18 September 2020

Abstract: Organic production is one of the fastest growing food sectors globally. However, average yield in organic vegetable production is up to 33% lower than in conventional production. This difference could be due to higher fertilization rates in conventional, compared to organic, farming. We aimed to compare yield and quality characteristics of carrots produced under equal nitrogen fertilization rates over four years in organic and conventional conditions. We found a 14.5% higher marketable, and 10.0% lower discarded, yield in the organic compared to the average conventional treatments. In addition, carrots managed organically had 14.1% lower nitrate and 10.0% higher vitamin C content than carrots managed conventionally. There were no convincing effects of cultivation system on the nitrogen, total sugar, or dry matter content of carrots. Organically managed carrots were free of pesticide residues, while several residues were found in carrots managed conventionally. Our study reveals that organic management of carrots may exceed that of conventional methods in yield and several quality characteristics, while being free of pesticide residues. Organic fertilizer gave an advantage over mineral fertilizer, when equal rates of nitrogen were used in both production systems.

Keywords: carrot; organic and conventional yield; nitrate; vitamin C; total sugars; dry matter; pesticide residues; organic fertilizer

1. Introduction

Organic production continues to be one of the fastest growing food sectors globally [1], and is often promoted as a sustainable alternative to conventional agriculture [2]. The organic vegetable market is being largely driven by increased consumer demand for organic food [3–6], as it is perceived to be healthier and safer for the environment [5,7,8]. Although the area of organic vegetable production has increased more than six-fold worldwide during recent decades [9], the performance and benefits of organic agriculture need further research.

It is a general notion that, although organic production reduces environmental impacts due to the restricted use of synthetic fertilizers and pesticides, it often results in lower yields, making the (economic) sustainability of organic farming questionable [10]. The yield gap in horticulture has been shown to vary a lot between experiments comparing organic and conventional systems [7,11–14]. Two global meta-analyses concluded that across all crops the average yield of organic production is 20–25% lower than conventional production, whereas vegetables can have up to even 33% lower yields in an organic system [15,16]. In addition to lower yields, organic production can have a relatively high yield variability [2,17].

Consumers expect organic food to have a higher nutritional value, while being free of chemical residues [5]. Seufert and Ramankutty [2] concluded in their review that organically produced food in general tends to contain a higher amount of secondary metabolites, vitamins, and various mineral nutrients, but that these results vary greatly between studies. Pesticides on the other hand are potentially toxic to humans, and can have both acute and chronic health effects, depending on the quantity and way in which a person is exposed to them [18]. Pesticides have been applied across the world for almost a century, creating a build-up of adverse pollution in our environment [1]. A recent European-wide study detected pesticide residues in over 80% of the tested agricultural soils [19]. Therefore, synthetic pesticide residues in vegetables have become a special concern, not only due to potential negative influences on soil microorganisms and human health, but also in terms of consumer expectations [20,21]. According to Seufert and Ramankutty [2] the majority of studies have found that, compared to conventional production, organically produced food, indeed, has reduced contamination from pesticide residues.

Yield and quality of crops depend mainly on the type and applied rates of fertilizers, locality or soil type, and climatic conditions during the year of harvest [22–24]. However, it has been pointed out that studies comparing the yield and quality of organic versus conventional vegetables have often provided inconsistent results, due to methodological problems in experimental design [24–29]. The typical problem is that fertilization rates of the main plant nutrients are higher in conventional than organic crop production [28]. For example, according to Swedish national statistics, for all crops harvested in 2013, the average nitrogen (N) fertilization was 64 kg ha^{-1} in organic and 115 kg ha^{-1} in conventional production [28]. This problem can be overcome by increasing the addition of organic matter in the organic system, thereby improving soil health and reaching the same levels of nutrients as in the conventional system [29–32]. Kirchmann et al. [33] have stressed that at least three criteria should be followed to ensure correct interpretation of comparative studies of organic vs. conventional production: the initial soil fertility must be similar between plots, ideally only the same type of crop production is compared, and rates of nutrient input to each system must be quantified. By taking the above-mentioned criteria into account, we compared the yield and quality indicators of carrots produced in an organic and in a conventional system, with the same initial soil fertility, and with equal nitrogen fertilization rates.

We hypothesized that: (1) The yield of carrot production does not differ between conventional and organic systems with equal levels of nitrogen fertilization; (2) Organically produced carrots have better quality than conventional carrots in terms of various quality indicators and a lack of pesticide residues.

2. Materials and Methods

2.1. Field Experiment Design

The study was carried out at the Estonian Crop Research Institute, Jõgeva, Estonia (58°76′24′′ N, 26°39′76′′ E) in the Nemoral climatic zone [34] from 2011 to 2014. Weather conditions during the experimental years are described below (see section weather conditions). The experimental area had been out of intensive use for at least 30 years, and for the last four years had been managed according to organic farming practice (no use of synthetic fertilizers and pesticides). Soil at the site is clay loam classified as Endogleyc Luvisol (FAO 2014) [35]. A pooled topsoil sample was analyzed before the establishment of the experiment, and the following results were obtained: pH_{HCl} 6.4, P 356 mg kg^{-1}, K 220 mg kg^{-1}, Ca 2067 mg kg^{-1}, Mg 210 mg kg^{-1}, Cu 4.0 mg kg^{-1}, Mn 117 mg kg^{-1}, B 0.08 mg kg^{-1}, and C_{org} 2.0%. Hence, the nutritional status of the soil was satisfactory and soil acidity favorable for carrot cultivation. No pesticide residues were present in the soil. The trial area was divided into four fields and carrot was grown in a different field with a different precrop each year. The preceding crops before carrot experiments were as follows: barley (*Hordeum vulgare* L.) in 2011; a mixture of phacelia (*Phacelia tanacetifolia* Benth.), mustard (*Sinapis alba* L.), and crimson clover (*Trifolium incarnatum* L.) in 2012; red clover (*Trifolium pratense* L.) in 2013 and 2014.

The experimental layout was a randomized complete block design with four experimental plots (5.0 m × 2.0 m each) per block, in three replications. In each block, three plots had conventional production treatment (CON5, CON3, and CON1) and one plot had organic treatment (ORG). Conventional production treatments differed in the types of pesticides and number of sprayings during the growing period: CON5 was sprayed five times, receiving two herbicides, the same insecticide twice, and one fungicide; CON3 was sprayed three times, receiving one of each pesticide; and CON1 was sprayed once, receiving one herbicide (Table 1). The ORG treatment received no pesticides, according to EU regulations on organic production (Council Regulation No. 843/2007).

Table 1. Used synthetic pesticides in treatments, classification by target organisms, and growth stages of carrot [36] when spraying was carried out in the conventional cultivation from 2011 to 2014.

No.	Treatment	Used Pesticides a.s.	Pesticide Category	Application Rates of a.s.	Growth Stages
5	CON5	aclonifen	herbicide	2.0 l ha^{-1}	07
		propaquizafop	herbicide	1.0 L ha^{-1}	14
		cypermethrin	insecticide	0.15 L ha^{-1}	10 and 20
		chlorothalonil	fungicide	3.0 L ha^{-1}	44
3	CON3	aclonifen	herbicide	2.0 L ha^{-1}	07
		cypermethrin	insecticide	0.15 L ha^{-1}	20
		chlorothalonil	fungicide	3.0 L ha^{-1}	44
1	CON1	aclonifen	herbicide	2.0 L ha^{-1}	07

a.s. = active substance; No. is the number of sprayings.

Synthetic pesticides were applied according to the recommended mean doses to control weeds, insects (carrot psyllid, *Trioza viridula* Zetterstedt and carrot fly, *Psila rosae* Fabricius), and diseases (black rot of carrots, *Alternaria radicina* Meier Drechsler et Eddy). Before sowing, conventional plots were fertilized by applying 1 t ha^{-1} of Cropcare 8-12-23 (N_8, P_5, K_{19} plus micronutrients), whereas organic plots received 8 t ha^{-1} of horse manure bio-compost (N_1, $P_{0.3}$, $K_{0.8}$, plus micronutrients), so that both systems received 80 kg N ha^{-1}. We used a local old middle-ripening orange-colored carrot variety "Jõgeva Nantes" (on the variety list since 1952), which is the only carrot variety of Estonian origin, and well adapted to local conditions and popular among organic growers. Seeds of the carrots were sown at the end of May at a seeding density of 100 seeds m^{-1}. The seeds were sown in a pair of rows, 20 cm between the rows and 50 cm between each pair of rows. To control weeds all experimental plots, including the conventional treatment were weeded twice by hand and hoeing.

2.2. Yield and Chemical Analyses

The carrots were harvested by hand at the beginning of October in 2011 and 2012, and at the end of September in 2013 and 2014. Two yield fractions, marketable and discarded yield, were quantified in both production systems. Discarded yield consisted mainly of cracked, but also of forked and small roots (diameter < 2 cm). A randomly selected sample of marketable yield of 8 kg was taken from each plot. From this a random 600 g sample was taken for laboratory analyses the following day. Total sugar content was determined following the modified Bertrand method, as described by Turbas and Oll [37]: the extract was treated with Fehling solution and the Cu_2O sediment obtained filtered, dissolved in $Fe_2(SO_4)_3$, and the quantity of reducing sugars calculated from the results of titration with $KMnO_4$. Non-reducing sugars were hydrolyzed at 60 °C with the addition of sulfuric acid before analysis.

Ascorbic acid (vitamin C) content was determined according to ISO 6557/2:1984, using the modified Tillman method by titration of ascorbic acid with 2.6-dichloroindophenol under acid conditions. Dry matter (DM) content was determined according to EVS-EN 12,145:2000 by determination of loss of mass during drying at 70 °C in the vacuum oven. Total N content was determined by the copper catalyst Kjeldahl method, and nitrate content by flow injection analysis, using Fiastar 5000 (ISO 13395).

Residues of the applied pesticides were tested from the carrots (aclonifen, chlorothalonil, cypermethrin and propaquizafop) using a multi-residue QuEChERS method combining gas (aclonifen, chlorothalonil, and cypermethrin) and liquid (propaquizafop) chromatography following the acetonitrile extraction of the sample and clean-up by dispersive solid phase extraction, as described in the European Standard EVS-EN 15,662:2008, and validated according to the requirements of SANCO/10684/2009. One sample of pesticide residues per treatment was analyzed each year, except for CON1 in 2013 and 2014 (were not measured). Testing of carrots in ORG provided an opportunity to state with certainty that these treatments did not contain pesticide residues.

2.3. Weather Conditions

Data of air temperatures and precipitation from May to October 2011–2014 were obtained from the closest meteorological station. In summary, monthly average air temperature was higher and the amount of precipitation was lower than the long term averages (LTA) during the growing seasons of 2011 and 2013, whereas the summer of 2011 was extremely dry (Table 2). The vegetation period of 2012 was characterized by higher than LTA precipitation and close to average temperature. Rain was frequent in June on twenty-two days out of thirty. The distribution of precipitation in 2014 was irregular: June and August were wetter, whereas July and September were drier than the LTA.

Table 2. Long-term monthly average of air temperature, sum of precipitation, and deviations from the average.

Month	Temperature (°C)					Precipitation (mm)				
		Deviation					Deviation			
	LTA	2011	2012	2013	2014	LTA	2011	2012	2013	2014
May	10.3	0.7	1.2	4.0	1.2	50	–15	12	33	14
June	14.5	3.0	–1.1	3.3	–1.4	69	–30	41	–31	89
July	16.8	3.7	1.1	0.8	2.4	79	–45	6	–44	–31
August	15.4	0.9	–0.6	1.3	1.2	89	–14	41	–19	34
September	10.6	2.0	1.6	0.4	1.0	66	–13	–7	–34	–39
October	5.3	1.9	0.5	1.3	–0.2	66	7	6	–8	–18

LTA = Long term average (1922–2015).

2.4. Statistical Analyses

Two-way analysis of variance (ANOVA) was used to determine the effects of treatment and year, and their interactions, on carrot yield and quality parameters. Two different analyses were performed: at first all four treatments (CON5, CON3, CON1, and ORG) were compared, and second an average of the three conventional production treatments (CON-AV) was calculated and only two treatment groups (CON-AV and ORG) were compared. The pairwise differences between treatments within years and overall, as well between years within treatments, were tested with the Tukey-Kramer (HSD) test. These statistical analyses were performed using JMP 5.0.1.2 software SAS, 2002 (SAS Institute, Inc., Cary, NC, USA).

Principal component analysis (PCA) was used to discover the common patterns in carrot yield parameters, and to visualize their dependency on treatment and year. Data were log-transformed and centered before the PCA. Spearman rank correlation analysis was used to assess pairwise relationships between measured carrot yield parameters. PCA and Spearman correlation analyses were conducted in R version 3.5.2, 2018 (R Core Team, Vienna, Austria).

3. Results

3.1. Yield

The results of ANOVA showed that the marketable yield and the share of discarded yield were both significantly affected by treatment ($p = 0.012$ and $p = 0.023$, respectively) (CON-AV vs. ORG) and year (both $p < 0.001$; Table 3). Additionally, discarded yield was significantly affected by the interaction between treatment and year (Trm*Year, $p = 0.008$). Across four trial years the average marketable yield of organic production was significantly higher than CON-AV (14.5%). In addition, the percent of discarded yield was significantly lower in ORG compared to CON-AV (10.0%). Generally, marketable yield was higher in ORG compared to CON-AV in all trial years, however, this difference was significant only in 2012. In contrast, the effect of treatment on the share of discarded yield depended on year; in 2011–2013 discarded yield was generally lower in ORG (although significantly so only in 2012), but in 2014 it was lower in CON-AV (although the difference remained non-significant). The hot and extremely dry growth period in 2011 resulted in week germination of seeds, and caused the significantly lowest marketable, and the highest discarded, yields across all four treatments (both $p < 0.001$) (Table S1).

Table 3. Marketable and discarded yield and content of nitrogen, nitrates, vitamin C, sugars, and dry matter (DM) in conventional (average of three conventional treatments, CON-AV) and organic (ORG) treatments (mean ± standard error); fold change indicates the change of ORG with respect to CON-AV (ORG/CON-AV) and p-value shows the statistical significance of the difference between CON-AV and ORG (significant *p*-values <0.05 are presented in bold). For each variable results of two way analysis of variance (F-statistics and *p*-values) of the factors treatment (Trm), year, and treatment by year interaction (Trm*Year) are also presented.

Variable	Year	CON-AV	ORG	Fold Change (*100%)	*p*-Value
Marketable yield, t ha^{-1}	Trm: $F_{1,40} = 6.9$, $p = 0.012$; Year: $F_{3,40} = 94.8$, $p < 0.001$; Trm*Year: $F_{3,40} = 0.9$, $p = 0.442$				
	2011	6.3 ± 1.2 ^{A}	8.2 ± 0.8 ^{A}	130.5	0.380
	2012	24.0 ± 3.5 ^{B}	29.2 ± 3.8 ^{B}	121.6	**0.020**
	2013	22.0 ± 1.8 ^{B}	25.7 ± 3.8 ^{B}	116.9	0.091
	2014	25.8 ± 4.9 ^{B}	26.3 ± 3.8 ^{B}	102.0	0.818
	Average	19.5 ± 8.5	22.4 ± 9.1	114.5	**0.012**
Percent of discarded yield, %	Trm: $F_{1,40} = 5.6$, $p = 0.023$; Year: $F_{3,40} = 182.6$, $p < 0.001$; Trm*Year: $F_{3,40} = 4.5$, $p = 0.008$				
	2011	68.0 ± 5.5 ^{A}	65.1 ± 3.3 ^{A}	95.7	0.419
	2012	47.5 ± 7.9 ^{B}	32.9 ± 4.3 ^{B}	69.2	**<0.001**
	2013	32.2 ± 4.7 ^{C}	30.0 ± 4.4 ^{B,C}	93.2	0.531
	2014	18.1 ± 3.4 ^{D}	21.2 ± 2.2 ^{C}	117.0	0.384
	Average	41.5 ± 19.5	37.3 ± 17.7	90.0	**0.023**
N, %	Trm: $F_{1,40} = 0.1$, $p = 0.707$; Year: $F_{3,40} = 35.9$, $p < 0.001$; Trm*Year: $F_{3,40} = 1.7$, $p = 0.183$				
	2011	2.5 ± 0.2 ^{A}	2.3 ± 0.1 ^{A}	94.0	0.260
	2012	2.1 ± 0.2 ^{B}	2.1 ± 0.1 ^{A}	99.1	0.840
	2013	1.6 ± 0.2 ^{C}	1.6 ± 0.1 ^{B}	101.3	0.891
	2014	2.0 ± 0.3 ^{B}	2.3 ± 0.2 ^{A}	113.0	0.056
	Average	2.1 ± 0.4	2.1 ± 0.3	101.3	0.707

Table 3. *Cont.*

	Trm: $F_{1,40}$ = 6.2, p = 0.017; Year: $F_{3,40}$ = 181.2, p < 0.001; Trm*Year: $F_{3,40}$ = 2.3, p = 0.088				
NO_3, mg kg^{-1}	2011	283.3 ± 36.7 ^{A}	292.3 ± 10.6 ^{A}	103.2	0.603
	2012	107.5 ± 26.0 ^{B}	99.7 ± 4.2 ^{B}	92.7	0.650
	2013	66.7 ± 16.1 ^{C}	24.6 ± 5.4 ^{C}	36.9	**0.019**
	2014	194.4 ± 27.9 ^{D}	150.0 ± 29.3 ^{B}	77.1	**0.013**
	Average	163.0 ± 88.6	141.7 ± 103.0	86.9	**0.017**
	Trm: $F_{1,40}$ = 5.3, p = 0.026; Year: $F_{3,40}$ = 99.1, p < 0.001; Trm*Year: $F_{3,40}$ = 1.6, p = 0.213				
Vitamin C, mg $100g^{-1}$	2011	1.5 ± 0.2 ^{A}	2.0 ± 0.3 ^{A}	134.2	**0.046**
	2012	2.7 ± 0.1 ^{B}	3.0 ± 0.2 ^{B}	113.5	0.168
	2013	3.4 ± 0.3 ^{C}	3.2 ± 0.4 ^{B}	94.9	0.503
	2014	4.1 ± 0.7 ^{D}	4.6 ± 0.0 ^{C}	111.1	0.074
	Average	2.9 ± 1.1	3.2 ± 1.0	110.0	**0.026**
	Trm: $F_{1,40}$ = 3.4, p = 0.072; Year: $F_{3,40}$ = 14.7, p < 0.001; Trm*Year: $F_{3,40}$ = 3.8, p = 0.018				
Sugars, %	2011	6.4 ± 0.7 ^{A,B}	6.4 ± 0.5 ^{A}	98.9	0.859
	2012	5.8 ± 0.5 ^{A}	5.9 ± 0.5 ^{A}	102.1	0.763
	2013	6.9 ± 0.2 ^{B}	8.5 ± 0.0 ^{B}	122.3	**<0.001**
	2014	6.0 ± 1.0 ^{A}	5.9 ± 0.4 ^{A}	98.3	0.807
	Average	6.3 ± 0.8	6.7 ± 1.2	105.9	0.072
	Trm: $F_{1,40}$ = 0.4, p = 0.512; Year: $F_{3,40}$ = 64.8, p < 0.001; Trm*Year: $F_{3,40}$ = 3.0, p = 0.044				
Dry matter, %	2011	10.5 ± 0.6 ^{A}	9.9 ± 0.1 ^{A}	93.7	0.063
	2012	10.4 ± 0.5 ^{A}	11.0 ± 0.4 ^{B}	106.5	0.058
	2013	13.1 ± 0.4 ^{B}	12.6 ± 0.3 ^{C}	96.4	0.184
	2014	10.9 ± 0.7 ^{A}	10.8 ± 0.1 ^{A,B}	99.9	0.990
	Average	11.2 ± 1.2	11.1 ± 1.0	99.0	0.512

Mean values without common uppercase letters (A,B,C,D) within treatment (in columns) are statistically significantly different (p < 0.05, Tukey–Kramer (HSD) test); Average = average of 2011–2014.

3.2. Nitrogen and Nitrate

The results of ANOVA showed that the carrot nitrogen content was not significantly affected by management system, whilst the opposite was true for nitrate content (Table 3). Both N and NO_3 were significantly influenced by the trial year. The average N content across all trial years was equal for both CON-AV and ORG. N content was significantly lower in 2013 than in other trial years. Nitrate content was significantly lower in ORG than in CON-AV in two trial years out of four (2013 and 2014), and also remained significantly lower as an average across all years. When considering all four treatments separately, nitrate content was significantly higher in the drought year of 2011 than in the other trial years (Table S1).

3.3. Vitamin C

Vitamin C content in carrots varied statistically significantly depending on treatment and year (Supplementary Table S1), based on ANOVA analyses. Vitamin C content was significantly higher in ORG than in CON-AV as an average across all trial years (Table 3). However, the highest difference between cultivation systems was in the drought year of 2011 (34.2%). At the same time, vitamin C content remained significantly lowest in all treatments in 2011, compared to other trial years (Table S1).

3.4. Total Sugars

According to the results of ANOVA, the total sugar content in the carrots was not influenced by treatment, but depended significantly on year, and treatment by year interaction (Table 3). Out of all trial years the average total sugar content was the highest in 2013 in both management systems, and the only significant difference between ORG and CON-AV appeared in this year (22.3%). In spite of this, as an average of all trial years total sugar content did not differ significantly between management systems, nor between different conventional treatments (Table S1).

3.5. Dry Matter

The ANOVA results showed that carrot DM content was not influenced by treatment, but depended significantly on year, and treatment by year interaction (Table 3). The average DM content did not differ significantly between ORG and CON-AV across all trial years, nor were there any differences within single trial years. DM content was highest in 2013 in both management systems. When studying all four treatments separately it was evident that as an average across all trial years DM was slightly but significantly higher in CON1 than in other treatments (Table S1).

3.6. Principal Component Analyses

The first two principal components explained 80.5% of the total variance of the studied carrot yield and quality parameters. The strongest pattern (PC1 54.7%) indicated that if the higher marketable yield was achieved, also the vitamin C and DM content of carrots were higher, and the nitrogen and nitrate content, as well the discarded yield, were lower (Figure 1). These results are in accordance with the results of the correlation analysis (Table S2), where a significantly positive correlation was found between marketable yield and vitamin C content ($r = 0.58$, $p < 0.001$), as well as negative correlations between DM content and nitrogen and nitrate contents ($r = -0.59$, $p < 0.001$ and $r = -0.61$, $p < 0.001$, respectively), and between vitamin C content and discarded yield ($r = -0.90$, $p < 0.001$).

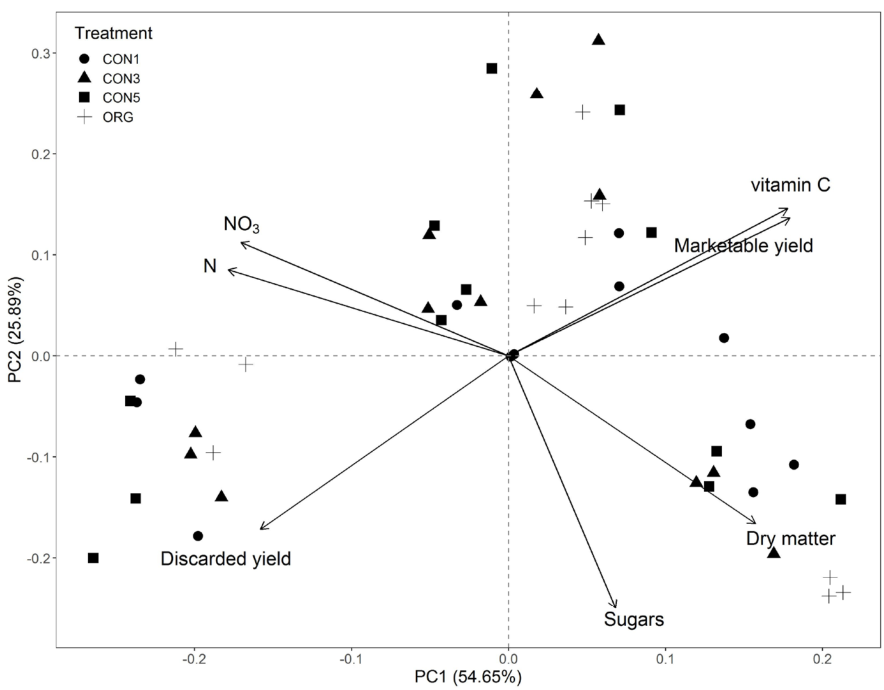

Figure 1. Biplot of principal component analysis by treatments. Vectors indicate the direction of increase of the carrot yield and quality parameters respective to the first two principal components; symbols distinguished by treatments mark the location of single samples in the PC1-PC2-plane.

The second strongest pattern (PC2 25.9%) mainly separates samples with higher and lower content of total sugars, where the samples with higher sugar content also tend to have higher DM content, and lower nitrogen and nitrate content. These results are also partly evident from the correlation analyses (Table S2), where there is a significant positive relationship between sugar content and DM ($r = 0.53$, $p < 0.001$), and a significantly negative relationship between sugar and nitrogen content ($r = -0.30$, $p < 0.05$).

The analysis of principal component (PC) scores by treatment did not reveal any clear patterns (Figure 1), while PC scores by years showed clear between-year differences (Figure 2). In 2011 the samples had higher values of discarded yield, and lower values of marketable yield and vitamin C content, while in 2013 the samples had the highest DM content, and samples from 2014 had the highest vitamin C content.

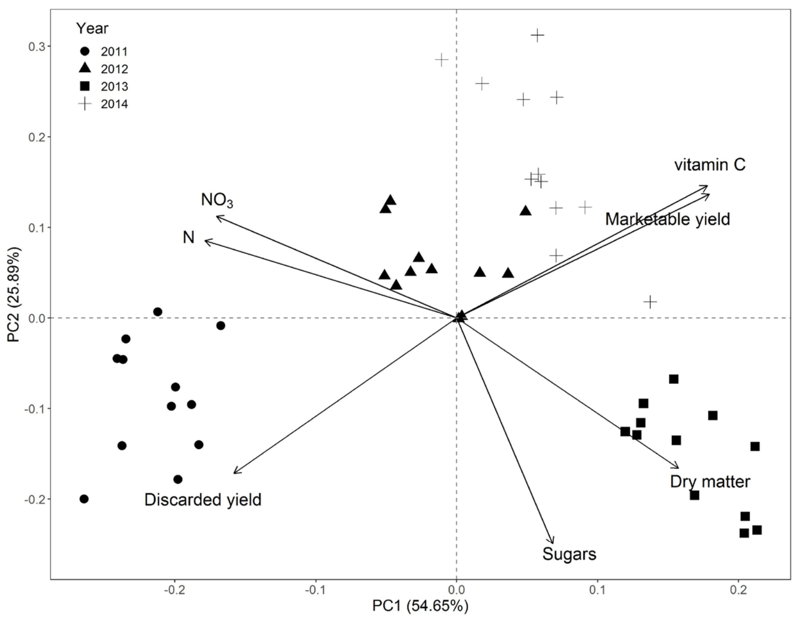

Figure 2. Biplot of principal component analysis by year. Vectors indicate the direction of increase of the carrot yield and quality parameters respective to the first two principal components; symbols distinguished by year mark the location of single samples in the PC1-PC2-plane.

3.7. Pesticide Residues

Out of the four analyzed pesticides, residues of three (aclonifen, chlorothalonil, and cypermethrin) were detected in all trial years except 2012 (Table 4). Residues of the herbicide (propaquizafop) were not detected in any of the trial years. The fungicide chlorothalonil was detected in CON5 in three years and in CON3 only in 2013, although it was applied in these treatments in each trial year. The herbicide aclonifen was detected in two treatments out of three; in CON5 in two years and in CON1 only in 2011. The insecticide cypermethrin was found only in CON5 in 2014, despite being used in two treatments in each trial year. The content of all detected residues was below the allowed maximum residue levels (aclonifen 0.08; propaquizafop 0.2; cypermethrin 0.05; chlorothalonil 0.3 mg kg^{-1}) by the EC Regulation No 396/2005 [38]. No pesticide residues were found in the organic carrots.

Table 4. Pesticide active substances, found in conventionally produced carrots.

Treatment	Used Pesticides a.s.	2011		2013		2014	
		Pesticide Residue	Content, mg kg^{-1}	Pesticide Residue	Content, mg kg^{-1}	Pesticide Residue	Content, mg kg^{-1}
CON5	aclonifen propaqui. cyperm. chlorot.	aclonifen chlorot.	<0.01 0.013	chlorot.	0.223	aclonifen cyperm. chlorot.	0.008 0.028 0.007
CON3	aclonifen cyperm. chlorot.	No residues	No residues	chlorot.	0.080	aclonifen	<0.01
CON1	aclonifen	aclonifen	<0.01	-	-	-	-

a.s. = active substances; propaqui. = propaquizafop; cyperm. = cypermethrin; chlorot. = chlorothalonil; "-" No analyses have been performed.

4. Discussion

The results of our study show that organic management can have an advantage over the conventional system in both yield and quality of carrots at equal N levels. In particular, we found higher marketable and lower discarded yield, and better quality characteristics of carrots (lower nitrate and higher vitamin C content), in organic compared to conventional management. For a few quality characteristics (nitrogen, total sugar, and DM content) there were no convincing differences between the management treatments of carrots. In addition, carrots from organic management were free of pesticide residues, whereas several residues were found in carrots from conventional management.

Contrary to expectations we found that organically grown carrots had on average 14.5% higher yield and 10% lower discarded yield compared to conventionally grown carrots. Previous research comparing organic and conventional vegetable productions have found up to 33% lower yields from organic production [15,16]. One of the main factors limiting organic yield has typically been lower nutrient availability, while fertilization rates are higher in conventional systems [39]. One important reason for higher yield of organically grown carrots in our experiment was the fact that in the ORG treatment we applied compost with a N rate equal to that in the conventional treatments. Organic fertilizer is known to have advantages over mineral fertilizers since it increases total organic carbon content, soil organic matter, stimulates the activity of microorganisms, and increases enzymatic activity in soil, and thus increases the availability of nutrients for the plants [14,32,40–42].

Another important factor influencing crop yield is the prevailing weather during the growing period. Lotter et al. [43] found that under severe drought conditions organically managed farms produced higher yields than their conventional counterparts. This could be explained by increased organic matter level in soil making the organic farming system less susceptible to extreme drought events [42]. In our case, there was a shortage of precipitation in three trial years out of four, and the results overall followed the above-mentioned tendency towards higher yield in organic management compared to conventional. However, our results showed that significantly higher yields with organic management appeared when the weather conditions were more favorable for carrot production, as in 2012. This was also accompanied by significantly lower discarded yield in the ORG treatment. In contrast, the highest discarded yield was found in the drought year of 2011. This is in accordance with Thorup-Kristensen et al. [44], who found that the highest percentage of discarded yield in both organic and conventional production systems was produced in the year with the lowest amount of precipitation. However, in contrast to our experiment, the study by Thorup-Kristensen et al. [44] did not reveal a management effect on the discarded yield of carrot.

In our experiment the discarded yield in all treatments was formed mostly due to physiological disorders of carrots. Notably, there was a low pressure of insects and diseases due to the lack of other carrot production fields in the neighboring area, from where carrot damaging pests and diseases could have been transmitted to the trial. Another reason for the low occurrence of carrot pests and diseases might be due to the use of old local variety "Jõgeva Nantes", which according to our previous experience has been disease-free even without the use of fungicides (I. Bender, pers. obs.). Old varieties can be genetically heterogeneous and might have specific adaptation traits relevant for organic conditions [45–47]. This could also explain why application of pesticides and fungicides in the CON treatments did not result in lower discarded yield than in the ORG.

Nitrogen content in the carrots did not differ between management treatments. According to some previous studies, significantly higher concentration of nitrogen was detected in conventional carrots than in organic, which can be explained by lower N fertilization rates in the organic system [48–50]. In our experiment, the lack of differences in N content is likely a result of applying fertilization, so that N levels were equal in the two treatments. However, there was a significant year effect on the N content of carrots, being lower in 2013 than in other trial years, probably caused by shortage of precipitation in June–September. Nitrate content on the other hand was significantly influenced both by treatment and year, being lower in the ORG than in the CON-AV treatment, and highly variable across all trial years. The nitrate content of the carrots was highest in the extremely dry 2011. Some earlier studies have also shown that organic carrots contain less nitrate than conventional carrots [24,48,49,51,52], and that the year of production can have a significant effect [53]. Gennaro and Quaglia [54] concluded in their review, that lower nitrate levels in organic vegetables seem to be due to differences in N fertilization level. However, we found lower nitrate content in ORG at equal N fertilization levels in both systems. Mineral fertilizer used in CON treatments directly provides nitrate, while compost is slowly decomposable and nitrogen releases gradually [55]. In general, carrot is classified as a vegetable with a low nitrate content, with the average being 200–500 mg kg^{-1} [56]. The content of nitrate in our experiment was even lower, except in 2011.

We found that as an average of all trial years, carrots in ORG had significantly higher vitamin C content compared to CON-AV, being as much as 34% higher in the drought year of 2011. This is in line with previous research, reporting higher vitamin C content in vegetables in organic production [57–60]. However, a few studies have found no differences in vitamin C content between these management systems for carrots and other vegetables [25,61]. Vitamin C content in vegetables depends on several factors, such as genotype, maturity at harvest, fertilizer type, pre-harvest weather conditions, and soil type [62,63]. As all mentioned factors except fertilizer type were the same in our study for carrots in CON and ORG treatments, we assume that the differences in the content of vitamin C could have been due to different fertilizer type; compost was used in the organic, whereas mineral fertilizer was used in the conventional treatments.

The management system in our study did not influence the total sugar content in carrots, except in 2013, where significantly more sugars were found in ORG compared to CON-AV. Some earlier studies have similarly found that the production method did not affect the total sugar content in carrots [48,49,64]. However, several studies have concluded that organic vegetables, including carrots, contain more sugars than conventional ones [58,65–68]. Total sugar content in carrots could be affected more by climate-related factors than by management methods [69]. Bach et al. [64] found that higher temperatures, in particular, resulted in higher total sugar content. Indeed, the total sugar content of carrots in our trial was up to 8.5%, in the warmer than LTA year of 2013, whereas for the variety "Jõgeva Nantes" the sugar content is typically between 6.5–7.5% (unpublished data).

According to our results DM content did not differ significantly between organic and conventional carrots, which is in accordance with earlier studies [48,57,64,67], but contradict others which have reported higher DM content in organically cultivated carrots than in conventional carrots [49,52,61,65,66]. However, DM in our trial was influenced by the weather conditions of the trial years, being significantly higher in both management systems in the warmer than LTA year of 2013 than in the other trial years. These results indicate that the effect of weather conditions on DM overshadowed that of cultivation methods.

We found no pesticide residues in organic carrots, whereas residues of three out of four of the pesticides used were detected in the conventional carrots. In general organic food is reported to contain fewer or no residues [20,70–73]. In the summer of 2012, the amount of precipitation during the main spraying period was high, and therefore the chemical control measures were not successful which resulted in the absence of pesticide residues in carrot samples. Chlorothalonil and aclonifen were the most frequently detected pesticide residues in conventional carrots. Chlorothalonil is a broad-spectrum fungicide with low aqueous solubility. This residue has often been found in conventionally grown vegetables [74–78]. The substance group of systemic and selective herbicide aclonifen is not highly soluble in water, but is in many organic solvents, being moderately persistent in soil [79]. Persistence of the insecticide cypermethrin in the environment varies from 14.6 to 76.2 days (half-life), depending on the physicochemical properties of the soil [80]. Cypermethrin was detected only once in our carrot samples. Nevertheless, pesticide residues detected in conventional carrots might pose a threat to the environment and consumers. Even legislatively determined "safe" levels of residues, in case of simultaneous exposure of multiple chemical substances, may have synergistic effects, causing unknown adverse health issues [81].

5. Conclusions

The results of our four-year comparison of organic and conventional carrot production show that organic management can have advantages over the conventional system in both yield and quality, at equal N fertilization level. In particular, we found a higher marketable yield, lower discarded yield, and higher quality of carrots (lower nitrate and higher vitamin C content) in organic compared to conventional management. This can be explained by the higher quality of organic compost compared to the mineral fertilizer. Besides treatment effects, these variables were also influenced by the weather conditions of the trial years. Our study suggests that organic management of carrots can exceed conventional management in yield and quality, when N fertilization levels are equivalent.

Supplementary Materials: The following are available online at http://www.mdpi.com/2073-4395/10/9/1420/s1, Table S1: Marketable and discarded yield and content of nitrogen, nitrates, vitamin C, sugars and dry matter (mean ± standard error) in conventional (CON5, CON3, CON1) and organic (ORG) treatments from 2011 to 2014 For each variable results of two way analysis of variance (F-statistics and p-values of factors treatment (Trm), year and treatment by year interaction (Trm*Year)) are presented; Table S2: Spearman rank correlation coefficients between studied carrot yield and quality parameters.

Author Contributions: Conceptualization, I.B. and A.L.; methodology, I.B. and A.L.; software, T.K.; validation, I.B., I.H., A.I. and I.T.; formal analysis, I.B., L.E. and T.K.; investigation, I.B.; resources, I.B. and A.L.; data curation, I.B., L.E. and H.K.; writing—original draft preparation, I.B., I.H., A.I. and I.T.; writing—review and editing, I.B., I.H., A.I. and I.T.; visualization, T.K. and T.T.; supervision, A.L. and I.T.; project administration, I.B. and I.T.; funding acquisition, A.L. and I.T. All authors have read and agreed to the published version of the manuscript.

Funding: This research was supported by the Personal Research Grant (PUT1170) of the Estonian Ministry of Education and contracts 8-2/T1003PKAI of the Estonian Ministry of Rural Affairs.

Acknowledgments: The authors would like to thank Ingrid Williams for the language correction and Sirje Tamm, Ülle Ratassepp, Taavi Piiskoppel, Larissa Sirel, Siiri Margens for their excellent technical assistance.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. IFOAM. *Consolidated Annual Report of IFOAM-Organics International*; IFOAM: Bonn, Germany, 2018.
2. Seufert, V.; Ramankutty, N. Many shades of gray—The context-dependent performance of organic agriculture. *Sci. Adv.* **2017**, *3*, e1602638. [CrossRef] [PubMed]
3. Niggli, U. Sustainability of organic food production: Challenges and innovations. *Proc. Nutr. Soc.* **2015**, *74*, 83–88. [CrossRef] [PubMed]
4. Apaolaza, V.; Hartmann, P.; D'Souza, C.; López, C.M. Eat organic–Feel good? The relationship between organic food consumption, health concern and subjective wellbeing. *Food Qual. Prefer.* **2018**, *63*, 51–62. [CrossRef]

5. Ditlevsen, K.; Sandøe, P.; Lassen, J. Healthy food is nutritious, but organic food is healthy because it is pure: The negotiation of healthy food choices by Danish consumers of organic food. *Food Qual. Prefer.* **2019**, *71*, 46–53. [CrossRef]
6. European Comission. Organic farming in EU. A fast growing sector. *EU Agric. Markets. Briefs* **2019**, *13*. Available online: https://ec.europa.eu/info/sites/info/files/food-farming-fisheries/farming/documents/market-brief-organic-farming-in-the-eu_mar2019_en.pdf (accessed on 16 September 2020).
7. Tuomisto, H.; Hodge, I.; Riordan, P.; Macdonald, D. Does organic farming reduce environmental impacts? A meta-analysis of European research. *J. Environ. Manag.* **2012**, *112*, 309–320. [CrossRef]
8. Orsini, F.; Maggio, A.; Rouphael, Y.; de Pascale, S. "Physiological quality" of organically grown vegetables. *Sci. Hortic.* **2016**, *208*, 131–139. [CrossRef]
9. Willer, H.; Lernoud, J. Vegetables. In *The World of Organic Agriculture*; Willer, H., Lernoud, J., Eds.; FiBL & IFOAM—Organics International: Frick, Switzerland, 2019; pp. 125–128.
10. Connor, D.J. Organic agriculture cannot feed the world. *Field Crop Res.* **2008**, *106*, 187–190. [CrossRef]
11. Ponisio, L.C.; M'Gonigle, L.K.; Mace, K.C.; Palomino, J.; de Valpine, P.; Kremen, C. Diversification practices reduce organic to conventional yield gap. *Proc. R. Soc. B Biol. Sci.* **2014**, *282*, 1396. [CrossRef]
12. Kniss, R.K.; Savage, S.D.; Jabbour, R. Commercial crop yields reveal strengths and weaknesses for organic agriculture in the United States. *PLoS ONE* **2016**, *11*, e0161673. [CrossRef]
13. Reganold, J.P.; Wachter, J.M. Organic agriculture in the twenty-first century. *Nat. Plants* **2016**, *2*, 5221. [CrossRef] [PubMed]
14. Lesur-Dumoulin, C.; Malézieux, E.; Ben-Ari, T.; Langlais, C.; Makowski, D. Lower average yields but similar yield variability in organic versus conventional horticulture. A meta-analysis. *Agron. Sustain. Dev.* **2017**, *37*, 45. [CrossRef]
15. De Ponti, T.; Rijk, B.; van Ittersum, M.K. The crop yield gap between organic and conventional agriculture. *Agric. Syst.* **2012**, *108*, 1–9. [CrossRef]
16. Seufert, V.; Ramankutty, N.; Foley, J.A. Comparing the yields of organic and conventional agriculture. *Nature* **2012**, *485*, 229–234. [CrossRef] [PubMed]
17. Smith, O.M.; Cohen, A.L.; Rieser, C.J.; Davis, A.G.; Taylor, J.M.; Adesanya, A.W.; Jones, M.S.; Meier, A.R.; Reganold, J.P.; Orpet, R.J.; et al. Organic farming provides reliable environmental benefits but increases variability in crop yields: A global meta-analysis. *Front. Sustain. Food Syst.* **2019**, *3*, 82. [CrossRef]
18. WHO. Pesticide Residues in Food (19 February 2018). Available online: https://www.who.int/news-room/fact-sheets/detail/pesticide-residues-in-food (accessed on 29 July 2020).
19. Silva, V.; Mol, H.G.J.; Zomer, P.; Tienstra, M.; Ritsema, C.J.; Geissen, V. Pesticide residues in European agricultural soils—A hidden reality unfolded. *Sci. Total Environ.* **2019**, *653*, 1532–1545. [CrossRef]
20. Gomiero, T. Food quality assessment in organic vs. conventional agricultural produce: Finding and issues. *Appl. Soil Ecol.* **2018**, *123*, 714–728. [CrossRef]
21. Seljåsen, R.; Kristensen, H.L.; Kretzschmar, U.; Birlouez-Aragon, I.; Paoletti, F.; Lauridsen, C.; Wyss, G.S.; Busscher, N.; Mengheri, E.; Sinesio, F.; et al. How to understand the complexity of product quality and the challenges in differentiating between organically and conventionally grown products—Exemplified by fresh and heat-processed carrots (*Daucus carota* L.). *Org. Agric.* **2016**, *6*, 31–47. [CrossRef]
22. EFSA (European Food Safety Authority). Opinion of the Scientific Panel on Contaminants in the Food chain on a request from the European Commission to perform a scientific risk assessment on nitrate in vegetables. *EFSA J.* **2008**, *6*, 689. [CrossRef]
23. Jørgensen, H.; Bach Knudsen, K.E.; Lauridsen, C. Influence of different cultivation methods on carbohydrate and composition and digestibility of energy of fruits and vegetables. *J. Sci. Food Agric.* **2012**, *92*, 2876–2882. [CrossRef]
24. Seljåsen, R.; Kristensen, H.L.; Lauridsen, C.; Wyss, G.S.; Kretzschmar, U.; Birlouez-Aragone, I.; Kahl, J. Quality of carrots as affected by pre- and postharvest factors and processing. *J. Sci. Food. Agric.* **2013**, *93*, 2611–2626. [CrossRef] [PubMed]
25. Fjelkner-Modig, S.; Bengtsson, H.; Stegmark, R.; Nyström, S. The influence of organic and integrated production on nutritional, sensory and agricultural aspects of vegetable raw materials for food production. *Acta Agric. Scand. Sect. B Plant Soil Sci.* **2000**, *50*, 102–113. [CrossRef]
26. Dangour, A.D.; Dodhia, S.K.; Hayter, A.; Allen, E.; Lock, K.; Uauy, R. Nutritional quality of organic foods: A systematic review. *Am. J. Clin. Nutr.* **2009**, *90*, 680–685. [CrossRef] [PubMed]

27. Bernacchia, R.; Preti, R.; Vinci, G. Organic and conventional foods: Differences in nutrients. *Ital. J. Food Sci.* **2016**, *28*, 565–578.
28. EPRS (European Parliamentary Research Service). Human Health Implications of Organic Food and Organic Agriculture. 2016. Available online: https://www.europarl.europa.eu/RegData/etudes/STUD/2016/581922/EPRS_STU(2016)581922_EN.pdf (accessed on 29 July 2020).
29. Reeve, J.R.; Hoagland, L.A.; Villalba, J.J.; Carr, P.M.; Atucha, A.; Cambardella, C.; Davis, D.R.; Delate, K. Organic farming, soil health, and food quality: Considering possible links. In *Advances in Agronomy, 137*; Sparks, D.L., Ed.; Academic Press: Chennai, India, 2016; Volume 137, pp. 319–368. [CrossRef]
30. Tejada, M.; Gonzalez, J.L.; García-Martínez, A.M.; Parrado, J. Application of a green manure composted with beet vinasse on soil restoration: Effects on soil properties. *Bioresour. Technol.* **2008**, *99*, 4949–4957. [CrossRef]
31. Diacono, M.; Montemurro, F. Long-term effects of organic amendments on soil fertility. A review. *Agron. Sustain. Dev.* **2010**, *30*, 401–422. [CrossRef]
32. Bai, Z.; Caspari, T.; Gonzalez, M.R.; Batjes, N.H.; Mäder, P.; Bünemann, E.K.; de Goede, R.; Brussard, L.; Minggang, X.; Ferreira, C.S.S.; et al. Effects of agricultural management practices on soil quality: A review of long-term experiments for Europe and China. *Agric. Ecosyst. Environ.* **2018**, *265*, 1–7. [CrossRef]
33. Kirchmann, H.; Kätterer, T.; Bergström, L.; Börjesson, G.; Bolinder, M.A. Flaws and criteria for design and evaluation of comparative organic and conventional cropping systems. *Field Crop Res.* **2016**, *186*, 99–106. [CrossRef]
34. Metzger, M.J.; Bunce, R.G.; Jongman, R.H.; Mücher, C.A.; Watkins, J.W. A climatic stratification of the environment of Europe. *Glob. Ecol. Biogeogr.* **2005**, *14*, 549–563. [CrossRef]
35. FAO. *World Reference Base for Soil Resources 2014. International Soil Classification System for Naming Soils and Creating Legends for Soil Maps World Soil Resources*; Report 106; FAO: Rome, Italy, 2015. Available online: http://www.fao.org/3/a-i3794en.pdf (accessed on 16 September 2020).
36. Meier, U. *Growth Stages of Mono- and Dicotyledonous Plants. BBCH Monograph*; Open Agrar Repositorium: Quedlinburg, Germany, 2018. [CrossRef]
37. Turbas, E.; Oll, Ü. *Agrokeemia Laboratoorne Praktikum [Practical Analyses of Agrochemistry]*; Valgus: Tallinn, Estonia, 1969.
38. Regulation (EC) No 396/2005. Available online: https://ec.europa.eu/food/plant/pesticides/eu-pesticides-database (accessed on 14 September 2020).
39. Kirchmann, H.; Bergström, L.; Kätterer, T.; Andrén, O.; Andersson, R. Can organic crop production feed the world. In *Organic Crop Production—Ambitions and Limitations*; Kirchmann, H., Bergström, L., Eds.; Springer: Dordrecht, The Netherlands, 2008; pp. 39–72.
40. Henneron, L.; Bernard, L.; Hedde, M.; Pelosi, C.; Villenave, C.; Bertrand, M.; Girardin, C.; Blanchart, E. Fourteen years of evidence for positive effects of conservation agriculture and organic farming on soil life. *Agron. Sustain. Dev.* **2015**, *35*, 169–181. [CrossRef]
41. Tian, J.; Lou, Y.; Fang, H.; Liu, S.; Xu, M.; Blagodatskaya, E.; Kuzyakov, Y. Response of soil organic matter fractions and composition of microbial community to long-term organic and mineral fertilization. *Biol. Fertil. Soils* **2017**, *53*, 523–532. [CrossRef]
42. Scharma, M.; de Haan, J.J.; Kroonen, M.; Verstegen, H.; van der Putten, W.H. Crop yield cap and stability in organic and conventional farming system. *Agric. Ecosyst. Environ.* **2018**, *256*, 123–130. [CrossRef]
43. Lotter, D.W.; Seidel, R.; Liebhardt, W. The performance of organic and conventional cropping systems in an extreme climate year. *Am. J. Altern. Agric.* **2003**, *18*, 146–154. [CrossRef]
44. Thorup-Kristensen, K.; Dresbøll, D.B.; Kristensen, H.L. Crop yield, root growth, and nutrient dynamics in a conventional and three organic cropping systems with different levels of external inputs and N re-cycling through fertility building crops. *Eur. J. Argon.* **2012**, *37*, 66–82. [CrossRef]
45. Finckh, M.R. Integration of breeding and technology into diversification strategies for disease control in modern agriculture. *Eur. J. Plant Pathol.* **2008**, *121*, 399–409. [CrossRef]
46. Dawson, J.C.; Murphy, K.M.; Huggins, D.R.; Jones, S.S. Evaluation of winter wheat breeding lines for traits related to nitrogen use under organic management. *Org. Agric.* **2011**, *1*, 65–80. [CrossRef]
47. Cortés-Olmos, C.; Leiva-Brondo, M.; Roselló, J.; Raigón, D.M.; Cebolla-Cornejo, J. The role of traditional varieties of tomato as sources of functional compounds. *J. Sci. Food Agric.* **2014**, *94*, 2888–2904. [CrossRef]
48. Bender, I.; Ess, M.; Matt, D.; Moor, U.; Tõnutare, T.; Luik, A. Quality of organic and conventional carrots. *Agron. Res.* **2009**, *7*, 572–577.

49. Bender, I.; Moor, U.; Luik, A. The effect of growing systems on the quality of carrots. *Res. Rural Dev.* **2015**, *1*, 118–123.
50. Søltoft, M.; Nielsen, J.; Holst Laursen, K.; Husted, S.; Halekoh, U.; Knuthsen, P. Effects of organic and conventional growth systems on the content of flavonoids in onions and phenolic acids in carrots and potatoes. *J. Agric. Food Chem.* **2010**, *58*, 10323–10329. [CrossRef]
51. Pussemier, L.; Larondelle, Y.; Pethegem, C.; Huyghebaert, A. Chemical safety of conventionally and organically produced foodstuffs: A tentative comparison under Belgian conditions. *Food Control* **2006**, *17*, 14–21. [CrossRef]
52. Lairon, D. Nutritional quality and safety of organic food. A review. *Agron. Sustain. Dev.* **2009**, *30*, 33–41. [CrossRef]
53. Ilić, Z.S.; Šunić, L. Nitrate content of root vegetables during different storage conditions. *Acta Hortic.* **2015**, *1079*, 659–665. [CrossRef]
54. Gennaro, L.; Quaglia, G.B. Food safety and nutritional quality of organic vegetables. *Acta Hortic.* **2003**, *614*, 675–680. [CrossRef]
55. Matallana González, M.C.; Martínez-Tome, M.J.; Torija Isasa, M.E. Nitrate and nitrite content in organically cultivated vegetables. *Food Addit. Contam. B* **2010**, *3*, 19–29. [CrossRef]
56. Santamaria, P. Nitrate in vegetables: Toxicity, content, intake and EC Regulation. *J. Sci. Food Agric.* **2006**, *86*, 10–17. [CrossRef]
57. Brandt, K.; Leifert, C.; Sanderson, R.; Seal, C.J. Agroecosystem management and nutritional quality of plant foods: The case of organic fruits and vegetables. *Crit. Rev. Plant Sci.* **2011**, *30*, 177–179. [CrossRef]
58. Hallmann, E. The influence of organic and conventional cultivation systems on the nutritional value and content of bioactive compounds in selected tomato types. *J. Sci. Food Agric.* **2012**, *92*, 2840–2848. [CrossRef]
59. Oliveira, A.B.; Moura, C.F.H.; Gomes-Filho, E.; Marco, C.A.; Urban, L.; Miranda, M.R.A. The impact of organic farming on quality of tomatoes is associated to increased oxidative stress during fruit development. *PLoS ONE* **2013**, *8*, e56354. [CrossRef]
60. Vinha, A.F.; Barreira, S.V.P.; Costa, A.S.G.; Alves, R.C.; Oliveira, M.B.P.P. Organic versus conventional tomatoes: Influence on physicochemical parameters, bioactive compounds and sensorial attributes. *Food Chem. Toxicol.* **2014**, *67*, 139–144. [CrossRef]
61. Bender, I.; Ingver, A. The influence of production methods on yield and quality of carrots and swedes. *Acta Hortic.* **2012**, *960*, 293–298. [CrossRef]
62. Mozafar, A. *Plant Vitamins: Agronomic, Physiological and Nutritional Aspects*; CRC Press: Boca Raton, FL, USA, 1994.
63. Lee, S.K.; Kader, A.A. Preharvest and postharvest factors influencing vitamin C content of horticultural crops. *Postharvest Biol. Technol.* **2000**, *20*, 207–220. [CrossRef]
64. Bach, V.; Kidmose, U.; Kristensen, H.L.; Edelenbos, M. Eating quality of carrots (*Daucus carota* L.) growing in one conventional and three organic cropping systems over three years. *J. Agric. Food Chem.* **2015**, *63*, 9803–9811. [CrossRef] [PubMed]
65. Rembiałkovska, E.; Hallmann, E. Influence of cultivation method (organic vs. conventional) on selected quality attributes of carrots (*Daucus carota*). *Zyvienie Czovieka Metab.* **2007**, *34*, 550–556.
66. Rembiałkovska, E.; Średnicka, D. Organic food quality and impact on human health. *Agron. Res.* **2009**, *7*, 719–727.
67. Gąstoł, M.; Domagała-Świątkiewicz, I.; Krośniak, M. Organic versus conventional—A comparative study on quality and nutritional value of fruit and vegetable juices. *Biol. Agric. Hortic.* **2011**, *27*, 310–319. [CrossRef]
68. Pereira, F.O.; Pereira, R.S.; Rosa, L.S.; Teodoro, A.J. Organic and conventional vegetables: Comparison of the physical and chemical characteristics and antioxidant activity. *Afr. J. Boitechnol.* **2016**, *15*, 1746–1755. [CrossRef]
69. Rosenfeld, H.J.; Samuelsen, R.T.; Lea, P. Relationship between physical and chemical characteristics of carrots grown at northern latitudes. *J. Hortic. Sci. Biotechnol.* **1998**, *73*, 65–73. [CrossRef]
70. Hoogenboom, L.A.P.; Bokhorst, J.G.; Northolt, D.M.; van de Vijver, L.P.L.; Broex, N.J.G.; Mevius, D.J.; Meijs, J.A.C.; van der Roest, J. Contaminants and microorganisms in Dutch organic food products: A comparison with conventional products. *Food Addit. Contam. Part A* **2008**, *25*, 1195–1207. [CrossRef]
71. Lima, G.P.P.; Vianello, F. Review on the main differences between organic and conventional plant-based foods. *Int. J. Food Sci. Technol.* **2011**, *46*, 1–13. [CrossRef]

72. Barański, M.; Średnicka-Tober, D.; Volakakis, N.; Seal, C.; Sanderson, R.; Stewart, G.B.; Benbrook, C.; Biavati, B.; Markellou, E.; Giotis, C.; et al. Higher antioxidant and lower cadmium concentration and lower incidence of pesticide residues in organically grown crops: A systematic literature review and meta-analyses. *Br. J. Nutr.* **2014**, *5*, 794–811. [CrossRef] [PubMed]
73. EFSA (European Food Safety Authority). The 2017 European Union report on pesticide residues in food. *EFSA J.* **2019**, *17*. [CrossRef]
74. Yuan, Y.; Chen, C.; Zheng, C.; Wang, X.; Yang, G.; Wang, Q.; Zhang, Z. Residue of chlorpyrifos and cypermethrin in vegetables and probabilistic exposure assessment for consumers in Zhejiang Province, China. *Food Control* **2014**, *36*, 63–68. [CrossRef]
75. Ahoudi, H.; Gnandi, K.; Tanouayi, G.; Ouro-Sama, K.; Yorke, J.; Creppy, E.; Moesch, C. Assessment of pesticides residues contents in the vegetables cultivated in urban area of Lome (southern Togo) and their risks on public health and the environment Togo. *Int. J. Biol. Chem. Sci.* **2018**, *12*, 2172–2185. [CrossRef]
76. Divakara, J.; Sharma, D. Dissipation of chlorothalonil in leafy vegetables accelerated by use of biofertilizer. *Pest Manag. Hortic. Ecosyst.* **2019**, *25*, 109–115.
77. U.S. Food and Drug Administration. Pesticide Residue Monitoring Program. Fiscal year 2017 Pesticide Report. FDA Pesticide Residue Monitoring Program Reports and Data; 2019. Available online: www.fda.gov/food/pesticides/pesticide-residue-monitoring-2017-report-and-data (accessed on 29 July 2020).
78. Office of Environmental Health Hazard Assessment. Proposition 65. Interpretive Consumption of Chlorothalonil Residues in Certain Foods. Interpretive Guidelines No. 2019-01—2019-09; 2019. Available online: Oehha.ca.gov/media/downloads/crnr/chlorothalonilig111519.pdf (accessed on 29 July 2020).
79. Onder Erguven, G.; Byhan, H.; Demir, G.; Ikizoglu, B.; Kanat, G. Monitoring aclonifen remediation in soil with a laboratory-scale research. *J. Chem.* **2016**. [CrossRef]
80. Chen, S.; Geng, P.; Xiao, Y.; Hu, M. Bioremediation of β-cypermethrin and 3-phenoxybenzaldehyde contaminated soils using Streptomyces aureus HP-S-01. *Appl. Microbiol. Biotechnol.* **2012**, *94*, 505–515. [CrossRef]
81. Nicolopoulou-Stamati, P.; Maipas, S.; Kotampasi, C.; Stamatis, P.; Hens, L. Chemical pesticides and human health: The urgent need for a new concept in agriculture. *Front. Public Health* **2016**, *4*. [CrossRef]

II

Bender, I., Ess, M., Matt, D., Moor, U., Tõnutare, T., Luik, A. 2009. Quality of organic and conventional carrots. *Agronomy Research*, 7, 572−577.

Agronomy Research **7**(Special issue II), 572–577, 2009

Quality of organic and conventional carrots

I. Bender[1], M. Ess[1], D. Matt[2], U. Moor[2], T. Tõnutare[2] and A. Luik[2]

[1]Jõgeva Plant Breeding Institute, Aamisepa 1, 48309 Jõgeva alevik, Estonia;
e-mail: Ingrid.Bender@jpbi.ee
[2]Institute of Agricultural and Environmental Sciences, Estonian University of Life Sciences,
Kreutzwaldi 64, 51014 Tartu, Estonia

Abstract. At Jõgeva Plant Breeding Institute, cultivation of the Estonian carrot variety 'Jõgeva Nantes' conventionally (with application of mineral fertilizers: N 115, P 40 and K 152 kg ha^{-1} and pesticides: Fenix, Actara 25 WG, Agil and Signum) and organically (compost, Humistar, agryl cover) was compared. Marketable yield of organic carrots was 11% higher than that of conventionally grown carrots. Conventional carrots contained pesticide residues and had significantly higher nitrate concentration than organic carrots. Contents of dry matter, total sugars, soluble solids, phosphorus, potassium, calcium and magnesium did not significantly differ between carrots between cultivation systems. The contents of ß-carotene, vitamin C and nitrogen were significantly lower in organically grown than in conventionally grown carrot.

Key words: agryl cover, ß-carotene, calcium, dry matter, magnesium, nitrogen, phosphorus, potassium, soluble solids, total antioxidant capacity, total sugars, vitamin C, yield

INTRODUCTION

In Estonia, as in other European countries, targets have been set to upgrade domestic organic production, including that of vegetables. This is driven by consumer demand to buy organic food primarily for health-related reasons. Preferred products are organic vegetables and fruits (Pehme et al., 2007). Therefore the quality of raw products is an important aspect. Quality of locally produced organic vegetables is still very poorly studied. Therefore the aim of the present study was to evaluate how the yield and quality of carrots is affected by production methods – organic versus conventional, according to principles of good agricultural practice.

MATERIALS AND METHODS

The field experiment was carried out at Jõgeva Plant Breeding Institute (26°24'E, 58°44'N) in 2008. Carrots were cultivated under conventional and organic conditions on plots of 100 m^2, with four replications of each treatment. For two years before the experiment, cereals were cultivated on the area according to the EU regulations on organic production (Council Regulation No. 843/2007). Soil at the site was classified as soddy-podzolic sandy loam. A soil sample was analysed before establishment of the experiment using the following methods: pH – ISO 10390, P, K, Ca, Mg, Cu, Mn – Mehlich III, B – by Berger and Truogi and C_{org} – by NIRS. The following results were obtained: pH_{HCl} 6.1, P 65 mg kg^{-1}, K 121 mg kg^{-1}, Ca 1930 mg kg^{-1}, Mg 164 mg kg^{-1}, Cu 1.4 mg kg^{-1}, Mn 79 mg kg^{-1}, B 0.72 mg kg^{-1} and C_{org} 1,7%. Hence the nutritional status of the soil was satisfactory and soil acidity favourable for carrot cultivation. No pesticide residues, as measured by the method prEN 15662: 2007 NIRS, were present in the soil. Both soil samples were analysed in Laboratory of Agrochemistry at the Estonian Agricultural Research Centre in Saku. For basic fertilization, 800 kg ha^{-1} of Cropcare 8-12-23 (N 65, P 40, K 152 plus micronutrients) was applied to the conventional plot and 200 kg ha^{-1} of compost (analysed by the Laboratory of Agrochemistry at the Estonian Agricultural Research Centre to have N 1,2%, P 0,26%, K 0,8%, pH_{HCl} 6,99) was applied to the organic plot. During the growing period conventional carrot plants were fertilized by ammonium nitrate (N 50 kg ha^{-1}) and sprayed with Folicare 18-18-18 (4 kg ha^{-1}), resulting in a total supply of 0.7 kg N, 0.3 kg P and 0.6 kg K ha^{-1}. Organic carrot plants were fertigated at a rate of 1 litre per meter of row with humic acids solution (fertilizer Humistar diluted by 1:20), resulting in a total supply of 1.4 kg K ha^{-1}. Carrot seeds of the Estonian variety 'Jõgeva Nantes' were sown on 27 May. The organic plot was covered after seed sowing for two months with non-woven polypropylene agryl cover to control carrot psyllid (*Trioza viridula*) and carrot fly (*Psila rosae*). The insecticide Actara 25 WG was sprayed at 120 g ha^{-1} on 13 June and 30 July on the conventionally grown carrots. The soil of the conventional plot was treated with the herbicide Fenix at 2.5 l ha^{-1} two days before the sprouting of carrots and 18 days after seed sowing against couch grass with a herbicide Agil 100 EC at 1.0 l ha^{-1}. The fungicide Signum 0.75 kg ha^{-1} was used on 12 August to control black rot (*Alternaria radiciana).* The organic plot was weeded twice by hand and hoeing. The crops were harvested manually on 10 October. The following analyses were performed on one sample of raw carrot roots from each of the replicate organic and conventional plots: pesticide residues were analysed by gas chromatography in the Laboratory of Agrochemistry at the Estonian Agricultural Research Centre. Dry matter (DM), sugars and vitamin C were determined in the same laboratory; DM by 71/393 EEC method, total sugars using a method described by Faithfull (2002), vitamin C by a Murri's method as described by Turbas & Oll (1969). Soluble solids content (SSC) (°Brix) was measured using the digital refractometer ATAGO CO., Ltd., Japan. Total N was determined by Copper Catalyst Kjeldahl Method, (984.13); phosphorus by Stannous Chloride method, ISO/FDIS 15681, AN 5242; calcium by o-Cresolphthalein Complexone method, ISO 3696, AN 5260 in Kjeldahl Digest by Fiastar 5000; magnesium by Fiastar 5000, ASTN90/92 by Titan Yellow method; potassium by Flame Photometric Method, (956.01); nitrates by Fiastar 5000, AN 5201 (nitrate - N, Cd-reduction, ISO 13395), Foss Tecator AB, 2001 (Helrich, 1990). Total N, phosphorus, calcium, magnesium, potassium and nitrates were determined in the Plant Biochemistry Laboratory of Estonian University of Life Sciences. β-carotene was determined in the Health Protection Inspectorate Tartu Laboratory, using T44- HPLC method. Total antioxidant capacity (TAC) was determined using the 1.1-diphenyl-2-picrylhydrazyl (DPPH) discoloration assay described by Brand-Williams et al. *(*1995) with some modifications. Results of TAC are reported as Trolox equivalents (TE) mg 100 FW^{-1}. Significant differences of data between cultivation techniques were tested by one-way analysis of variance at significance level of $P \leq 0.05$. In the Figures mean values followed by the same letter are not significantly different at $P \leq 0.05$.

RESULTS AND DISCUSSION

The seed sowing and germination period was dry resulting in uneven establishment of carrot plants. A rainy period started on 10 June but did not alleviate the situation. This explains the low carrot yields. The marketable yield of organic carrots (10.9 t ha^{-1}) was 11% higher than conventional (9.7 t ha^{-1}), because of the higher proportion of damaged (cracked) carrots produced conventionally. Warman & Havard (1996), Fjelkner–Modig et al., (2000) and Rembialkowska (2000) have reported that, as a rule, organic yield is lower than conventional. Improved thermal regime and maintained humidity under the agryl cover probably raised the organic marketable yield. Earlier studies on broccoli (Kunicki et al., 1996) and carrot (Gimenez et al., 2002) have demonstrated the same effects of agryl cover. The applied humic acids fertilizer Humistar might be another contributor to the better yield of organic carrots. It is well established that humid acids improve soil chemical and physical quality and, in general, enhance root growth and development (Tan & Nopamornbodi, 1979; Bidegain et al., 2000; Canellas et al., 2002; Arancon et al., 2003). From the five analysed pesticide residues, two were detected in the conventionally grown carrots and none in organically grown carrots. These results concur with those of Rembialkowska & Hallmann (2007), who also found that organic vegetables were free of pesticide residues. Contaminants were determined as follows: boscalid 0.320 mg kg^{-1} and pyraclostrobin 0.090 mg kg^{-1}. According to EU regulation No 149/2008, the residues found did not exceed permitted levels but may be hazardous to consumers due to synergy between the two residues.

No significant differences were found between organic and conventional cultivation in content of total sugars (6.5% and 6.0% respectively), P (0.3% and 0.3% respectively), K (1.7% and 1.7% respectively), Ca (0.4% and 0.4% respectively) and Mg (0.9% and 1.0% respectively). However, contradictory results have been reported. According to Polish scientists organic carrots contain more total sugars than conventional (Rembialkowska, 2003; Rembialkowska & Hallmann, 2007), but the content of K, Ca and Mg were similar in organic and conventional carrots (Rembialkowska, 2003). Warman & Havard (1996) also observed minor differences in mineral content between the organic and conventional management systems. Yet, Worthington (2001) has found that organic crops contain significantly more Mg and P than do conventional crops.Our organically and conventionally grown carrots did not differ significantly in their DM content (10.9% and 10.8%, respectively). According to earlier studies by Leszczyn'ska (1996) and Fjelkner-Modig et al. (2000) organically grown crops (including carrot) had higher DM content compared with conventional ones. Kaack et al. (2002) found that DM content decreased linearly with increasing amount of nitrogen applied.SSC of organically grown carrots ranged from 8.6 to 9.2°Brix and of conventionally grown from 8.5 to 9.1°Brix. The average SSC of both carrots was 8.9° Brix and was not affected by cultivation technology. Vitamin C content in carrots harvested from the organic plot was significantly lower than that of conventional plot (5.0 and 6.2 mg %, respectively) (Fig. 1). Vitamin content of a plant depends on a number of factors such as climate, genetic properties, fertilizer and soil (Mozafar, 1994). Contradictory results have been reported by Worthington (2001), i.e. organic crops (among them carrot) contain significantly more vitamin C than conventional crops. However, several scientists (Warman & Havard, 1996; Warman & Havard, 1997; Fjelkner-Modig et al., 2000) could not verify significant differences in vitamin C content caused by different cultivation systems.The average β-carotene content in organically grown carrots was 4908 μg 100g FW^{-1} and in conventionally grown carrots 5186 μg $100gFWg^{-1}$(Fig. 1). These are a bit lower than found by Dutta et al. (2005), who reported β-carotene content of fresh carrots to be 84 μg g^{-1} and a bit higher than reported by Yen et al. (2008), who found β-carotene content in carrots to range from 0.11 to 0.28 mg g^{-1}. In our experiment conventional cultivation significantly increased β-carotene content in carrots. β-carotene is widely known as provitamin A and is reported to protect against cancer, cardiovascular disease (Breithaupt & Bamedi, 2001) and to enhance immune responses (Kurilich et al., 1999). However, these presumed benefits are highly contested, since all epidemiological studies of β-carotene intake were confounded with intake of the cancer-preventing compound falcarinol (Kobaek-Larsen et al., 2005), which is mainly found in carrots, and rodents metabolise β-carotene differently from humans (Wang et al., 1991). The role of β-carotene as an antioxidant has been widely reported (Terao, 1989; Palozza & Krinsky, 1992), however, tests of high doses (>10 mg day^{-1}) of this and other antioxidants consistently increased mortality (Bjelacovic et al., 2008).

In our experiment, TAC of organically-grown carrots was 24.5 TE $mg100gFW^{-1}$ and of conventionally grown carrots 25.7 TE $mg100gFW^{-1}$. Cultivation technology did not affect TAC significantly.

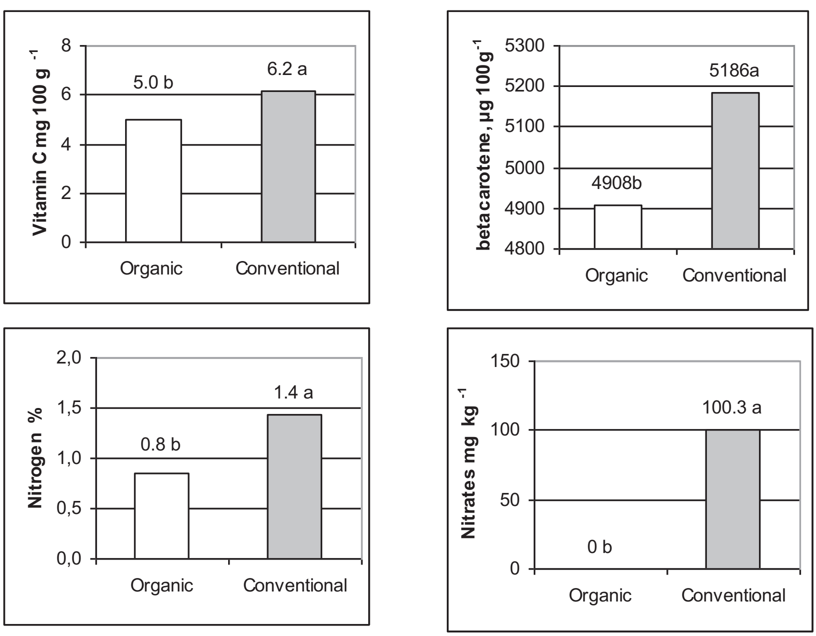

Fig. 1. Vitamin C, β-carotene, nitrogen and nitrates content of organically and conventionally grown carrots.

Nitrogen content was significantly higher in conventional vs. organic carrots (1.4 and 0.8%, respectively) (Fig. 1). Nitrates were not detected in organically grown carrots, whereas conventional carrots contained 100.3 mg kg^{-1} of nitrates (Fig. 1). Several studies have affirmed that organic carrots consist significantly less nitrogen and nitrate than do conventional (Leclerc et al., 1991; Leszczyn'ska, 1996; Warman & Havard, 1997; Rembialkowska, 2000; Rembialkowska, 2003; Rembialkowska & Hallmann, 2007; Zdravkovic et al., 2007).

CONCLUSIONS

Organic production of the carrot variety 'Jõgeva Nantes' increased marketable yield compared with conventional production. Cultivation technology did not significantly influence the contents of dry matter, mineral compounds, total sugars and TAC value, but the quality of conventional carrots was significantly decreased by their high nitrate and pesticides residue content, both absent from the organic carrots, while the organic ones had lower contents of vitamin C (-24%) and β-carotene (-6%).

ACKNOWLEDGEMENTS**.** Current research was supported by Estonian Science Foundation Grant No 7515 and by target financed project of the Estonian University of Life Sciences No PK 9003.

REFERENCES

Arancon, N. Q., Lee, S., Edwards, C. A. & Atiyeh, R. 2003. Effects of humic acids derived from cattle, food and paperwaste vermicomposts on growth of greenhouse plants. *Pedobiologia* **47,** 741–744.

Bidegain, R. A., Kaemmerer, M., Guiresse, M., Hafidi, M., Rey, F., Morard, P. & Revel, J. C. 2000. Effects of humic substances from composted or chemically decomposted poplar sawdust on mineral nutrition of ryegrass. *The J. of Agr. Sc.***134**, 259–267.

Bjelakovic G, Nikolova D, Gluud LL, Simonetti RG, Gluud C. 2008. Antioxidant supplements for prevention of mortality in healthy participants and patients with various diseases. *Cochrane Database of Systematic Reviews 2008*, Issue 2. Art. No.: CD007176. DOI: 10.1002/14651858.CD007176.

Brand-Williams, W., Cuvelier, M.E., & Berset, C. 1995. Use of a free radical method to evaluate antioxidant activity. *Food Sci. and Techn*. **28,** 25–30.

Breithaupt D. E., & Bamedi, A. 2001. Carotenoid esters in vegetables and fruits: a screening with emphasis on b-cryptoxanthin esters. *J. of Agric. and Food Chem*. **49**, 2064– 2067.

Canellas, L. P., Olivares, F. L., Okorokova-Facanha, A. L & Facanha, A. R. 2002. Humic acids isolated from earthworm compost enhance root elongation, lateral root emergence and plasma membrane H^+-ATPase activity in maize roots. *Plant Physiology* **130**, 1951–1957.

Dutta, D., Raychaudhuri, U. & Chakraborty, R. 2005. Retention of β-carotene in frozen carrots under varying conditions of temperature and time of storage. *Afric J.of Biot.*.**4,** 102–103.

Faithfull, N. T. 2002. *Methods in Agricultural Analysis: A Practical Handbook.* CABI Publishing, 292 pp.

Fjelkner-Modig, S., Bengtsson, H., Stegmark, R. & Nystrom, S. 2000. The influence of Organic and Integrated Production on Nutritional, Sensory and Agricultural Aspects of Vegetable Raw Materials for Food Production. *Acta Agric. Scand., Sect. B, Soil and Plant Sci.* **50**, 102–113.

Gimenez, C., Otto, R. F. & Castilla, N. 2002. Productivity of leaf and root vegetable crops under direct cover. 2002. *Sci. Hort.* **94**, 1–11.

Helrich K, ed. 1990. *Official Methods of Analysis of the AOAC*, 15th ed. Arlington, VA, USA: Association of Official Analytical Chemists, 1400 pp.
Kaack, K, Nielsen, M., Christensen, L. P & Thorup-Kristensen, K. 2002. Nutritionally Important Chemical Constitutients and Yield of Carrot (*Daucus carota* L.) Roots Grown Organically Using Ten Levels of Green Manure. *Acta Agric. Scand., Sect. B, Soil and Plant Sci.* **51**, 125–136.
Kobæk-Larsen, M., Christensen, L. P., Vach, W., Ritskes-Hoitinga, J. and Brandt, K. 2005. Inhibitory effects of feeding with carrots or (-)-falcarinol on development of azoxymethane-induced preneoplastic lesions in the rat colon. *J. of Agric. and Food Chem.* **53**, 1823–1827.
Kunicki, E., Cebula, S, Libik, A. & Siwek, P. 1996. The influence of row cover on the development and yield of broccoli in spring production. *Acta Horticulture* **407**, 377–384.
Kurilich, A. C., Tsau, G. J., Brown, A., Howard L., Klein, B. P. & Jeffery, E. H. 1999. Carotene, tocopherol, and ascorbate contents in subspecies of *Brassica oleracea*. *J. of Agric. and Food Chem.* **47**, 1576–1581.
Leclerc, C., Miller, M., Joliet, E. & Roquelin, G. 1991. Vitamin and mineral contents of carrot and celeric grown under mineral or organic fertilization. *Biol. Agr. & Hort.* **7**, 339–348.
Leszczyn'ska, T. 1996. Nitrates and nitrites in vegetables from conventional and ecological cultures. *Bromatologia I Chemia Toksykologiczna* **29**, 289–293.
Mozafar, A. 1994. Plant vitamins: agronomic, Physiological and nutritional aspects. *CRC Press Inc*., Florida.
Palozza, P. & Krinsky, N.I. 1992. Communication. β-carotene and α- tocopherol are synergistic antioxidants. *Arch. Biochem. Biophys*. **297**, 184–187.
Pehme, S., Luik, A. & Liivaauk, P. 2007. http://orgprints.org/9930/
Rembialkovska, E. & Hallmann, E. 2007. Influence of cultivation method (organic vs. conventional) on selected quality attributes of carrots (*Daucus carota*). *Zyvienie Czovieka I Metabolizm* **34**, 550–556.
Rembialkovska, E. 2000. The nutritive and sensory quality of carrots and cabbage from organic and conventional farms. In *IFOAM 2000: The world grows organic*. *Proceedings 13th International IFOAM Scientific Conference.* Zurich, 297.
Rembialkovska, E. 2003. Organic farming as a system to provide better vegetable quality. *Acta Hort.* **604**, 473–479.
Tan, K. H. & Nopamornbodi, V. 1979. Effect of different levels of humic acids on nutrient content and growth of corn (*Zea mays* L.). *Plant and Soil* **51**, 283–287.
Terao, J. 1989. Antioxidant activity of β-carotene related carotenoids in solution. *Lipids* **24** (7), 659–661.
Turbas, E. & Oll, Ü. 1969. *Agrokeemia laboratoorne praktikum.* Tallinn (in Estonian), 276 pp.
Wang, X. D., Tang, G. W., Fox, J. G., Krinsky, N. I. & Russell, R. M. 1991. Enzymatic conversion of β-carotene into beta-apo-carotenals and retinoids by human, monkey, ferret, and rat tissue. *Arch. Biochem. Biophys*. **285**, 8–16.
Warman, P. R. & Havard, K. A. 1996. Yield, vitamin and mineral content of four vegetables grown witheither composted manure or conventional fertilizer. *J. of Veg. Crop Prod.* **2**(1), 13–25.
Warman, P. R. & Havard, K. A. 1997. Yield, vitamin and mineral contents of organically and conventionally grown carrots and cabbage. *Agric., Ecosyst. & Environ.* **61**, 155–162.
Worthington, V. 2001. Nutritional quality of organic versus conventional fruits, vegetables and grains. *J. of Altern. and Compl. Medicine* **7**, 161–173.
Yen, Y-H., Shih, C-H. & Chang, C.-H. 2008. Effect of adding ascorbic acid and glucose on the antioxidative properties during storage of dried carrot. *Food Chem*. **107**, 265–272.
Zdravkovic, M., Damjanovic, D. & Zdravkovic, J. 2007. Effects of fertilizers on nutritive characteristics of carrot. *Acta Horticulture* **729**, 361–365.

III

Bender, I., Moor, U., Luik, A. 2015. The effect of growing systems on quality of carrots. *Research for Rural Development* 2015, 1, 118−123.

THE EFFECT OF GROWING SYSTEMS ON THE QUALITY OF CARROTS

Ingrid Bender[1], Ulvi Moor[2], Anne Luik[2]

[1]Estonian Crop Research Institute, Estonia, Ingrid.Bender@etki.ee
[2]Estonian University of Life Sciences, Estonia

Abstract

The aim of the research was to evaluate how the quality of carrots is affected by organic and conventional production system. The experiment was carried out at the Estonian Crop Research Institute in 2009. Conventional treatment received following amount of nutrients via mineral fertilizers: N 115, P 40 and K 152 kg ha^{-1}. For plant protection, following pesticides were used: Fenix, Fastac 50, Agil and Signum. In organic cultivation system compost and humic acids solution Humistar were used for fertilization and polypropylene non-woven fabric Agryl P-17 for plant protection. Marketable yield of organic carrots was 8% lower compared to conventional carrots. Conventional carrots contained pesticide residues and had significantly higher nitrate concentration than organic carrots. Contents of total sugars, phosphorus, potassium, calcium and magnesium did not differ significantly between carrots from different cultivation systems. At harvest, dry matter (DM) content of organically grown carrots was significantly higher, whereas vitamin C and ß-carotene content was significantly lower in organically grown carrots. However, after 5-months of storage, organic carrots had significantly higher total soluble solids (TSS) and β-carotene content compared to conventional ones indicating that organically grown carrots were less susceptible to storage conditions.

Key words: β-carotene, conventional, *Daucus carota,* nitrates, organic, yield

Introduction

The interest of consumption of organic food, including that of vegetables have been steadily increasing during the last decade in Estonia and also in other countries (Winter and Davis, 2006; Pehme et al., 2007; Dangour et al., 2009; Smith et al., 2009; Matallana González et al., 2010). Vegetables and fruits are the important sources of vitamins, minerals, trace elements, dietary fibre and a large variety of beneficial phytochemicals, which might decrease the risk of certain age-related and cardiovascular diseases. Therefore the dietary guidelines recommend eating at least five portions of fruits and vegetables a day. Several factors are affecting the quality of raw products and cultivation system is one of them. The composition of organically and conventionally produced vegetables has been studied for years, but further research is still recommended due to insufficient data (Hoefkens et al., 2009; Seljåsen et al., 2013). To add knowledge to mentioned topic, the aim of the present research was to evaluate how the quality of carrots (both at harvest and after storage) is affected by organic and conventional production system.

Materials and Methods

The field experiment was carried out at the Estonian Crop Research Institute at Jõgeva (26°24'E, 58°44'N) in 2009 and was a repetition of the experiment done one year earlier (Bender et al., 2009). Carrots (*Daucus carota*) were cultivated under conventional and organic conditions on plots of 100 m^2 altogether, with four replications per treatment.

For two years before the experiment, cereals were cultivated on the area according to the EU regulations on organic production (Council Regulation No. 843/2007). Soil at the sites was sandy loam. The soil samples were analysed before establishment of the experiment using the following methods: pH – ISO 10390, P, K, Ca, Mg, Cu, Mn – Mehlich III, B – by Berger and Truogi and C_{org} – by NIRS. The nutritional status of the soil was satisfactory and soil acidity favourable for carrot cultivation (Table 1). No pesticide residues, as measured by the method prEN 15662: 2007 NIRS, were present in the soil. All soil samples were analysed in the Laboratory of Agrochemistry at the Estonian Agricultural Research Centre in Saku.

Table 1

Soil pH and nutrient status before experiment establishment in 2009

pH_{KCl}	P(ppm)	K(ppm)	Ca(ppm)	Mg(ppm)	Cu(ppm)	Mn(ppm)	B(ppm)	C_{org}(ppm)
7.0	79	105	2800	128	1.9	66	1.15	2.0

For basic fertilization, 800 kg ha^{-1} of Cropcare 8-12-23 (N 65, P 40, K 152 plus micronutrients) was applied to the conventional plot and 12 t ha^{-1} of green waste compost (analysed by the Laboratory of Agrochemistry at the Estonian Agricultural Research Centre to have N 1.0 g $100g^{-1}$, P 0.20 g $100g^{-1}$, K 0.3 g $100g^{-1}$, pH_{HCl} 6.76) was applied to the organic plot. During the growing period conventional carrot plants were fertilized by ammonium nitrate (N 50 kg ha^{-1}) and sprayed with Folicare 18-18-18 (4 kg ha^{-1}), resulting in a total supply of 0.7 kg N, 0.3 kg P and 0.6 kg K ha^{-1}. Organic carrot plants were fertigated at a rate of 1 litre per meter of row with humic acids solution (fertilizer Humistar diluted by 1:20), resulting in a total supply of 1.4 kg K ha^{-1}.

Carrot seeds of orange colored cv. Jõgeva Nantes were sown on 27 May. After seed sowing the organic plots were covered with polypropylene non-woven fabric Agryl P-17 for two months to control carrot psyllid (*Trioza viridula*) and carrot fly (*Psila rosae*). In conventional system, the insecticide Fastac 50 was sprayed at 0.3 l ha^{-1} at 15 June and 28 July . The fungicide Signum 0.75 kg ha^{-1} was used on 12 August to control black rot (*Alternaria radiciana).* The soil of the conventional plots was treated with the herbicide Fenix at 2.5 l ha^{-1} two days before the sprouting of carrots and 18 days after seed sowing against couch grass with a herbicide Agil 100 EC at 1.0 l ha^{-1}. The organic plots were weeded twice by hand and hoeing. The crop was harvested manually on 8 October. Crop yield was calculated per hectare.

For postharvest experiment, 5 kg of carrots from both treatments from each replicate (all together 20 kg carrots per treatment) were stored in plastic boxes for recording postharvest loss. Additional two boxes (10 kg) of carrots from both treatments were stored for analyses. Carrots were stored for five months in coolstore of Estonian University of Life Sciences. Storage temperature ranged from 2 to 4 °C and RH was 85 to 90%. Postharvest loss (weight of carrots with decay or growth symptoms) was recorded monthly. The storage period finished in spring 2010. Quality analyses were performed at harvest and after 5-months of storage.

After harvest carrot composition and amount of pesticide residues were determined from each of the replicate organic and conventional plots. Pesticide residues were analysed by gas chromatography in the Laboratory of Agrochemistry at the Estonian Agricultural Research Centre. Dry matter (DM), total sugars and ascorbic acid (vitamin C) were determined in the same laboratory; DM by 71/393 EEC methods, total sugars and vitamin C by using the standard methods. Total nitrogen was determined by Copper Catalyst Kjeldahl Method, (984.13); phosphorus by Stannous Chloride method, ISO/FDIS 15681, AN 5242; calcium by o-Cresolphthalein Complexone method, ISO 3696, AN 5260 in Kjeldahl Digest by Fiastar 5000; magnesium by Fiastar 5000, ASTN90/92 by Titan Yellow method; potassium by Flame Photometric Method, (956.01); nitrates by Fiastar 5000, AN 5201 (nitrate - N, Cd-reduction, ISO 13395), Foss Tecator AB, 2001 (Helrich, 1990). Carrot macronutrients were determined at the Laboratory of Plant Biochemistry of the Estonian University of Life Sciences.

Before and after storage, total soluble solids (TSS) content (°Brix) was measured using the digital refractometer ATAGO CO., Ltd., Japan and β-carotene was determined in the Health Protection Inspectorate Tartu Laboratory, using T44- HPLC method.

Significant differences between cultivation systems were tested by one-way analysis of variance and the effect of cultivation system and storage by two- way analysis of variance at significance level of $P \leq 0.05$. Mean values followed by the same letter are not significantly different at $P \leq 0.05$ in Figures.

Results and Discussion

In 2009 the rainy period started on 3 June with low temperature and night frosts. This ameliorated the growth conditions. The marketable yield of conventional carrots (13.4 t ha^{-1}) was 8% higher than of organic carrots in 2009. In 2008, the marketable yield of organic carrots was 11% higher than conventional (Bender et al., 2009). It has been reported earlier that organic yield of vegetable is lower than conventional (Fjelkner–Modig et al., 2000; Mäder et al., 2002). However, Dresbøll et al. (2008) found no differences in carrot yields between the two systems. Improved thermal regime and maintained humidity under the Agryl cover probably raised the organic marketable yield in our experiment in both years. Earlier studies on Chinese cabbage, beetroot and sweet pepper (Moreno et al., 2001; Gimenez et al., 2002; Michalik, 2010) have demonstrated the same effect of non-woven cover. However, Rekika et al. (2008) did not detect the effect of Agryl cover on radish yield at harvest time. In our experiment, the applied humic acids fertilizer Humistar might have been another contributor to the yield of organic carrots. It is well established that humic acids improve soil chemical and physical quality and, in general, enhance root growth and development (Arancon et al., 2003). Although Lada et al. (2004) found that humic acid application to the soil promoted early seedling emergence of carrot, there was no significant yield difference compared to yield from control treatment. Karakurt et al. (2009) demonstrated that soil humic acid treatment can be successfully used for increasing yield and improving fruit quality of organically grown pepper.

From the fore analysed pesticide residues one (α-cypermethrin below 0.01 mg kg^{-1}) was detected in 2009, therefore two in 2008 (Bender et al., 2009) in the conventionally grown carrots and none in organically grown carrots. These results concur with those reported by Rembiałkowska and Hallmann (2007), who also found that organic vegetables were free of pesticide residues. According to EU regulation No 149/2008, the residues found in conventional carrots in our experiment did not exceed permitted levels.

Cultivation system did not affect the content of total sugars, P, K, Ca and Mg of carrots in 2009 (data not shown) and also in 2008 (Bender et al., 2009).

Nitrogen content was significantly higher in conventional vs. organic carrots (1.5 and 1.1 g $100g^{-1}$, respectively) and same result have been indicated in 2008 (Bender et al., 2009). In 2009 organic carrots contained nitrates at low level, significantly lower than conventional ones (26.6 and 149.6 mg kg^{-1}, respectively). In 2008, nitrates were not detected in organically grown carrots (Bender et al., 2009). Several studies have affirmed that organic carrots consist significantly less nitrogen and nitrate than do conventional (Leclerc et al., 1991; Warman and Havard, 1997; Rembiałkowska and Hallmann, 2007; Lairon, 2009; Seljåsen et al., 2013).

DM content of organically grown carrots was significantly higher than that of conventionally grown carrots (10.6 and 10.1 mg 100g^{-1}, respectively), but organically and conventionally grown carrots did not differ significantly in their DM content in 2008 (Bender et al., 2009). Some earlier studies have shown that organic crops (including carrots) contained significantly more DM compared to conventional ones (Rembiałkowska, 2007; Sikora et al., 2009; Bender and Ingver, 2012). However, not all studies have confirmed this phenomenon. Therefore review articles have identified only a trend for higher DM content, for instance no significant differences have been found for organic vegetables (Woëse et al., 1997; Bourn and Prescott, 2002).

TSS content of organically grown carrots was significantly lower than that of conventionally grown carrots (Figure 1). Similarly, conventional carrot samples had higher TSS compared to organic ones in Ireland (Gilsenan et al., 2008). TSS of organically and conventionally grown carrots was not affected by cultivation technology in 2008 (Bender et al., 2009).

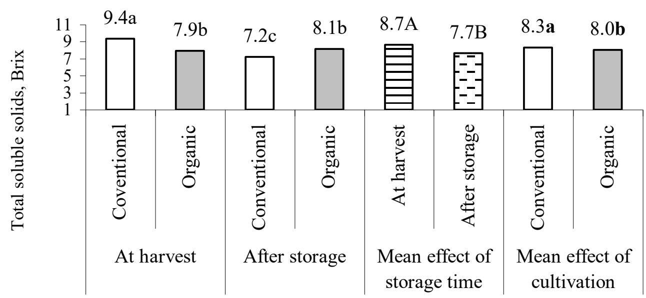

Figure 1. Total soluble solids content of organically and conventionally cultivated carrots cv. Jõgeva Nantes at harvest (October 2009) and after 5-months of storage (March 2010).

No significant differences were found between organic and conventional cultivation in content of vitamin C in carrots in 2009 (5.7 and 5.0 mg 100g^{-1}), therefore was significantly lower in 2008 (Bender et al., 2009). Vitamin content of a plant depends on a number of factors such as climate, genetic properties, fertilizer and soil (Mozafar, 1994). Also according to Lee and Kader (2000) the content of vitamin C in vegetables depends on several factors, among them also preharvest climatic conditions and cultural practices. As reported by Worthington (2001), organic crops (among them carrot) contained significantly more vitamin C than conventional crops. Also Sikora et al. (2009) have found that organic carrots contained significantly more ascorbic acid compared to the conventional ones. However, several scientists (Warman and Havard, 1997; Fjelkner-Modig et al., 2000; Brandt et al., 2011; Bender and Ingver, 2012) could not verify significant differences in vitamin C content caused by different cultivation systems.

In our experiment, no significant differences in β-carotene content were found between organic and conventional carrots (Figure 2), but conventional cultivation system significantly increased β-carotene content of carrots in 2008 (Bender et al., 2009). Rembiałkowska (2003) have demonstrated that organic carrots had less β-carotene. Contrarily, Sikora et al. (2009) reported that organic carrots contained significantly more carotenoids, such as β-carotene and lutein. The same was confirmed by Hoefkens et al. (2009) on literature-based comparison. The Danish scientists Søltoft et al. (2011) and Seljåsen et al. (2013) demonstrated in their reviews that the content of carotenoids in carrot roots was not significantly affected by the agricultural production system. Mentioned results indicates that formation of secondary metabolites is often more dependent on the yearly different weather conditions, and this influence overshadows the possible effect of cultivation system.

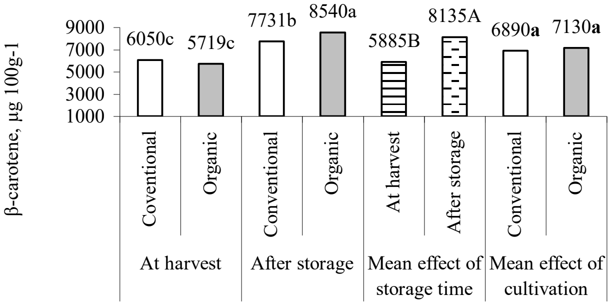

Figure 2. β-carotene content of organically and conventionally cultivated carrots cv. Jõgeva Nantes at harvest (October 2009) and after 5-months of storage (March 2010).

After 5 months of storage, the average postharvest loss of organic carrots was 17% and of conventional carrots 19% (data not shown). Cultivation system had no significant effect on postharvest loss. During storage, TSS content of conventional carrots had significantly decreased, whereas TSS content of organic carrots had remained unchanged (Figure 1). β-carotene content of both organic and conventional carrots had significantly increased during storage (Figure 2). Mentioned result is in agreement with earlier studies reporting that β-carotene content increases at storage temperatures above the freezing point (Howard et al., 1999). It is important to note, that after storage organic carrots had significantly higher TSS and β-carotene content compared to conventional ones.

Conclusions

The yield of the conventionally grown carrots was higher compared to organically grown carrots. Cultivation system did not significantly influence the content of analysed mineral elements and total sugars, but the quality of conventional carrots was significantly decreased by their high nitrate content and some pesticide residues. Organic carrots did not contain pesticide residues and contained nitrates at low level. At harvest, ß-carotene content was significantly lower in organically grown carrots. However, after 5-months of storage, organic carrots had significantly higher TSS and β-carotene content compared to conventional ones indicating that organically grown carrots were less susceptible to storage conditions.

Acnowledgements

Current research was supported by Estonian Science Foundation Grant No 7515 and by target financed project of the Estonian University of Life Sciences No PK 9003.

References

1. Arancon, N.Q., Lee, S., Edwards, C.A., Atiyeh, R. (2003) Effects of humic acids derived from cattle, food and paperwaste vermicomposts on growth of greenhouse plants. *Pedobiologia* 47, pp. 741-744.
2. Bender, I., Ess, M., Matt, D., Moor, U., Tõnutare, T., Luik, A. (2009) Quality of organic and conventional carrots. *Agronomy Research*, 7, pp. 572-577.
3. Bender, I., Ingver, A. (2012) The influence of production methods on yield and quality of carrots and swedes. *Acta Horticulturae,* 960, pp. 293-298.
4. Bourn, D., Prescott, J. (2002) A comparision of nutritional value, sensory qualitites and food safety of organically and conventionally produced foods. *Critical Reviews in Food Science and Nutrition* 42(1), pp. 1-34.
5. Brandt, K., Leifert, C., Sanderson, R., Seal, C.J. (2011) Agroecosystem management and nutritional quality of plant foods: the case of organic fruits and vegetables. *Critical Reviewes in Plant Sciences,* 30(1-2), pp. 177-179.
6. Dangour, A.D., Sakhi, K.D., Arabella, H., Allen, E., Lock, K., Uauy, R. (2009) Nutritional quality of organic foods: a systematic review. *American Journal of Clinical Nutrition*, 90 (3), pp. 680-685.
7. Dresbøll, D.B., Bjørn, G.K., Thorup-Kristensen, K. (2008) Yields and the extent and causes of damage in cauliflower, bulb onion and carrot grown under organic or conventional regimes. *Journal of Horticultural Science and Biotehnology*, 83(6), pp. 770-776.

8. Fjelkner-Modig, S., Bengtsson, H., Stegmark, R., Nystrom, S. (2000) The influence of organic and integrated production on nutritional, sensory and agricultural aspects of vegetable raw materials for food production. *Acta Agriculture Scandinavica, Section B, Soil and Plant Science,* 50, pp. 102-113.
9. Gilsenan, C., Burke, R.M., Barry-Ryan, C. (2008) A comparison of the physical properties and chemical components of Irish grown organic and conventional carrots (*Daucus carota* L.) In: Proceedings 38th Annual Research Conference on Food, Nutrition and Consumer Science, 4th Sept, UCC, Cork, p. 16.
10. Gimenez, C., Otto, R.F., Castilla, N. (2002) Productivity of leaf and root vegetable crops under direct cover. *Scientia Horticulturae,* 94, pp. 1-11.
11. Helrich, K., (ed) (1990) *Official Methods of Analysis of the AOAC*, 15th ed. Arlington, VA, USA: Association of Official Analytical Chemists, 1400 p.
12. Hoefkens, C., van Dekinderen, I., de Meulenaer, B., Devlieghere, F., Baert, K., Sioen, I., de Henauw, S., Verbeke, W., van Camp, J. (2009) A literature-based comparision of nutrient and contaminant contents between organic and conventional vegetables and potatoes. *British Food Journal*, 111(10), pp. 1078-1097.
13. Howard, L.A., Wong, A.D., Perry, A.K., Klein, B.P. (1999). β-carotene and ascorbic acid retention in fresh and processed vegetables. *Journal of Food Science*, 64, pp. 929–936.
14. Karakurt, Y., Unlu, H., Padem, H. (2009) The influence of foliar and soil fertilization of humic acid on yield and quality of pepper. *Acta Agriculture Scandinavica, Section B, Soil and Plant Science,* 59, pp. 233-237.
15. Lada, R., Stiles, A., Surette, M.A., Caldwell, C., Nowak, J., Sturz, A.V., Blake, T.J. (2004) Stand establishment technologies for processing carrots. *Acta Horticulturae*, 631, pp. 105-116.
16. Lairon, D. (2009) Nutrional quality and safety of organic food. A review. *Agronomy of Sustainable development*, 30, pp. 33-41.
17. Leclerc, J., Miller, M.L., Joliet, E., Rocquelin, G. (1991) Vitamin and mineral contents of carrot and celeriac grown under mineral or organic fertilization. *Biological Agriculture and Horticulture*, 7(4), pp. 339-348.
18. Lee, S.K., Kader, A.A. (2000) Preharvest and postharvest factors influencing vitamin C content of horticultural crops. *Postharvest Biology and Technology,* 20, pp. 207-220.
19. Matallana Gonzalez, M.C., Martinez-Tome, M.J., Torija Isasa, M.E. (2010) Nitrate and nitrite content in organically cultivated vegetables. *Food Additives and Contaminants*: Part B, 1, pp. 19-29.
20. Michalik, L. (2010) The effect of non-wovwn PP fabric covers on the yielding and the fruit quality of field-grown sweet peppers. Acta Scientiarum Polonorum-Hortorum Cultus, 9(4), pp. 25-32.
21. Moreno, D.A., Lopez-Lefebre, L.R., Villora, G., Ruiz, J.M., Romero, L. (2001) Floating row covers affect Pb and Cd accumulation and antioxidant status in Chinese cabbage. *Scientia Horticulturae*, 89 pp. 85-92.
22. Mozafar, A. (1994) *Plant vitamins: agronomic, physiological and nutritional aspects.* CRC Press Inc., Florida, 412 p.
23. Mäder, P., Fliessbach, A., Dubois, D., Gunst, L., Fried, P., Niggli, U. (2002) Soil fertility and biodiversity in organic farming. *Science,* 296, pp. 1694-1697.
24. Pehme, S., Luik, A., Liivaauk, P. (2007) Estonian consumers attitudes to organic food. Available at: http://orgprints.org/9930/, 27 February 2015.
25. Rekika, D., Stewart, K.A., Boivin, G., Jenni, S. (2008) Reduction of insect damage in radish with floating row covers. *International Journal of Vegetable Science,* 14(2), pp. 177-193.
26. Rembiałkowska, E. (2003) Organic farming as a system to provide better vegetable quality. *Acta Horticulturae*, 604, pp. 473-479.
27. Rembiałkowska, E. (2007) Quality of plant products from organic agriculture. Review. *Journal of the Science of Food and Agriculture,* 87, pp.2757-2762.
28. Rembiałkowska, E., Hallmann, E. (2007) Influence of cultivation method (organic vs. conventional) on selected quality attributes of carrots (*Daucus carota*). *Zyvienie Czovieka I Metabolizm*, 34, pp. 550-556.
29. Seljåsen, R., Kristensen, H.L., Lauridsen, C., Wyss, G.S., Kretzschmar, U., Birlouez-Aragone, I., Kahl, J. (2013) Quality of carrots as affected by pre- and postharvest factors and protsessing. *Journal of the Science of Food and Agriculture,* 93, pp. 2611-2626.
30. Sikora, M., Hallmann, E., Rembiałkowska, E. (2009) The content of bioactive compounds in carrots from organic and conventional production in the context of health prevention. *Roczniki Pan'stwowego Zakadu Higieny,* 60(3), pp. 217-220.
31. Smith, T.A., Lin, B.H., Huang, C.L. (2009) Growth and development in the U.S. retail organic food sector. *Sustainability*, 1(3), pp. 573-591.
32. Søltoft, M., Bysted, A., Madsen, K.H., Mark A.B., Bügel, S.G., Nielsen J., Knuthsen, P. (2011) Effects of organic and conventional growth systems on the content of carotenoids in carrot roots, and on intake

and plasma status of carotenoids in humans. *Journal of the Science of Food and Agriculture,* 91(4), pp. 767-775.
33. Warman, P.R., Havard, K.A. (1997) Yield, vitamin and mineral contents of organically and conventionally grown carrots and cabbage. *Agriculture, Ecosystems and Environment,* 61, pp. 155-162.
34. Winter, C.K., Davis, S.F. (2006) Organic foods. *Journal of Food Science*, 1 (9), pp. 117-124.
35. Woëse, K., Lange, D., Boess, C., Bogl, K.W. (1997) A comparison of organically and conventionally grown foods – Results of a review of the relevant literature. *Journal of the Science of Food and Agriculture,* 74, pp. 281-293.
36. Worthington, V. (2001) Nutritional quality of organic versus conventional fruits, vegetables and grains. *Journal of Alternative and Complementary Medicine*, 7, pp. 161-173.

IV

Navarro-Miró, D., Blanco-Moreno, J.M., Ciaccia, C., Chamorro, L., Testani, E., Kristensen, H.L., Hefner, M., Tamm, K., **Bender, I.**, Jakop, M., Bavec, M., Védie, H., Lepse, L., Canali, S., Sans, F.X. 2019. Agroecological service crops managed with roller crimper reduce weed density and weed species richness in organic vegetable systems across Europe. *Agronomy for Sustainable Development*, 39, 55.

Agronomy for Sustainable Development (2019) 39: 55
https://doi.org/10.1007/s13593-019-0597-8

RESEARCH ARTICLE

Agroecological service crops managed with roller crimper reduce weed density and weed species richness in organic vegetable systems across Europe

David Navarro-Miró[1] · José M. Blanco-Moreno[1] · Corrado Ciaccia[2] · Lourdes Chamorro[1] · Elena Testani[2] · Hanne Lakkenborg Kristensen[3] · Margita Hefner[3] · Kalvi Tamm[4] · Ingrid Bender[5] · Manfred Jakop[6] · Martina Bavec[6] · Hélène Védie[7] · Līga Lepse[8] · Stefano Canali[2] · F. Xavier Sans[1]

Accepted: 22 September 2019 / Published online: 18 November 2019

Abstract

Agroecological service crops are introduced into the vegetable crop rotation to provide agroecosystem services, and are a key strategy for weed management in organic systems. Organic farmers across Europe usually terminate these crops before cultivation of the subsequent cash crop, using them as green manure. Recently, the in-line tillage-roller crimper has attracted interest across Europe. It allows flattening the agroecological service crops and creates a narrow furrow that facilitates the fertilization and transplantation of organic vegetables. In Europe, most of the research on this technology has been carried out in Italy, and no studies are available analyzing its effect on weed density, weed species richness, and community composition in different vegetable crops, soils, and climatic conditions across Europe. We compared the effects of the usage of in-line tillage-roller crimper versus green manure on the weed abundance, species richness, and community composition in fourteen original datasets from five countries over 2 years. The support for a common effect of in-line tillage-roller crimper across trials was tested by means of a meta-analytic approach based on a weighted version of Stouffer's method. Our results indicate that in-line tillage-roller crimper management reduced weed density by 35.1% on average in comparison with green manure, and this trend was significant across trials. Moreover, we document a significant reduction of weed species richness under this technique and significant but, in general, minor changes in the weed community composition across the trials. Therefore, this study provides for the first time a solid evidence of the effectiveness of this management technique to reduce weed density at the early stages of crop growth across a wide range of vegetable systems and production conditions in Europe. Nonetheless, it is important to note that the effect of this technology can be strongly affected by variations in cropping conditions.

Keywords Agroecological service crops · In-line tillage · Mulch · Community composition

✉ David Navarro-Miró
david.danami@gmail.com

[1] Agroecosystems Research Group; Biodiversity Research Institute (IRBio); and Section of Botany and Mycology, Department of Evolutionary Biology, Ecology and Environmental Sciences, Faculty of Biology, University of Barcelona, Av. Diagonal 643, 08028 Barcelona, Spain

[2] Council for Agricultural Research and Economics, Research Centre for Agriculture and Environment (CREA-AA), Rome, Italy

[3] Department of Food Science, Aarhus University, Aarhus, Denmark

[4] Department of Agrotechnology, Estonian Crop Research Institute, Jõgeva, Estonia

[5] Department of Jõgeva Plant Breeding, Estonian Crop Research Institute, Jõgeva, Estonia

[6] Institute for Organic Farming, Faculty of Agriculture and Life Sciences, University of Maribor, Ho??e, Maribor, Slovenia

[7] Groupe de Recherche en Agriculture Biologique (GRAB), Avignon, France

[8] Institute of Horticulture, Latvian University of Agriculture, Dobeles novads, Latvia

1 Introduction

Agroecological service crops (ASCs) are sown in cropping systems to provide or promote agroecosystem services, independent of their position in the crop rotation and the method used to terminate them. This term includes catch crops, cover crops, and complementary crops (Canali et al. 2015). In vegetable systems, ASCs are usually grown during the cold rainy season. However, some authors have also highlighted the potential applicability of summer ASCs in southern Mediterranean regions of Europe, although their implementation is still limited (Canali et al. 2015).

In organic systems, ASCs are considered a key strategy for managing weeds (Gallandt 2014). To this end, numerous organic producers terminate the ASCs before the subsequent cash crop to avoid competition and reduce weed emergence. Nevertheless, some authors have noted that weed control effectiveness strongly depends on the termination technique selected (Canali et al. 2013; Ciaccia et al. 2016). Among European organic farmers, the most widespread management technique consists of chopping the ASCs and incorporating them into the soil by noninversion tillage (but sometimes plowing) as green manure (GM), while no-till methods are hardly used (Peigné et al. 2016). Despite the benefits of no-till practices for improving the quality of the soil (Sapkota et al. 2012), their adoption in organic systems is still limited because of important constraints mainly related to weed control (Casagrande et al. 2016).

However, in recent years, the no-till roller crimper (RC) for ASC management has attracted the interest of organic farmers and researchers across Europe (Casagrande et al. 2016; Vincent-Caboud et al. 2017). The RC allows flattening of the ASCs and creates a dense layer of plant residues (i.e., mulch) connected to the soil by the roots. The presence of mulch has physical and chemical effects, which can limit weed germination and seedling emergence. It has been shown that the extracts of some ASC species residues inhibit weed germination both in bioassays and open-field conditions (Ciaccia et al. 2015). The physical effect of the mulch might reduce weed density both by modifying the environmental conditions of the soil surface and by acting as a physical barrier that obstructs the development of the seedlings (Altieri et al. 2011). The flattened ASC modifies the soil temperature, surface daily temperature range, and soil water content (Altieri et al. 2011; Canali et al. 2013), which affects weed potential germination (Guillemin et al. 2013). Additionally, it reduces the light intensity that arrives at the soil surface (Teasdale and Mohler 2000), affecting the dormancy release and germination of many weed species (Batlla and Benech-Arnold 2014). Weed germination and emergence is also strongly conditioned by the mulch biomass and the specific weather conditions (i.e., temperature, rainfall) of the year. In general, the quantity of residues is more important than the type of residues, and the increase of the mulch biomass present on the soil surface decreases weed emergence exponentially (Teasdale and Mohler 2000). The specific weather conditions of the year can have an influence on both the ASC biomass production and the potential subsequent weed germination and emergence during the cash crop production (Carr et al. 2012; Canali et al. 2013).

Opposite results have been observed for the effect of mulch on weed species richness (Campiglia et al. 2010; Radicetti et al. 2013). Similarly, it is unclear how physical and allelopathic effects of mulch determine which species can germinate and emerge (Moonen and Bàrberi 2004). Mirsky et al. (2012) suggested that weed control by the mulch is species-specific and depends on both the sufficient quantity of mulch when a species is germinating and the energy reserves of propagules (i.e., big versus small seeds). Conversely, Campiglia et al. (2010) affirmed that the mulch acts to a greater extent on the number of individual plants irrespective of weed species. Furthermore, it is also important to note that some studies have reported shifts in the weed community composition in response to mulch presence (Campiglia et al. 2010; Radicetti et al. 2013).

The limited implementation and research on the no-till RC approach might be related to the predominant humid temperate climate of Europe (Mäder and Berner 2012). Additionally, in vegetable cropping systems, some agronomic difficulties, such as transplanting and fertilization of the vegetable crop, have hindered the adoption of this technique by organic famers (Luna et al. 2012; Canali et al. 2013). To overcome these limitations and facilitate the adaptation of this technology to organic European vegetable systems, the RC was modified by adding in-line tillage (in-line tillage/roller crimper, hereafter ILRC) (Canali et al. 2013). This modification, based on vertical sharpened discs and coulters arranged in line at the rear of the RC, allows flattening the ASC and simultaneously creating a narrow transplanting furrow without disturbing the surrounding mulch (Fig. 1).

Since its development, the research has mainly focused on analyzing the effect of cold rainy season ASCs managed with ILRC on weed abundance in zucchini and melon cash crops, and all these experiments have been carried out in the long-term MOVE trial located in Italy (Canali et al. 2013; Ciaccia et al. 2015, 2016). Moreover, most of the research focused on flattening the ASCs has been mainly focused on optimizing the RC design, selecting the best cold rainy season ASC composition, identifying changes in the abundance of perennial species, and analyzing the effect on cash crop development

Fig. 1 Pepper plant transplanted into a narrow furrow created by the ILRC after flattening the ASCs in Spain. Author: Alejandro Pérez-Ferrer

and production (Mirsky et al. 2012; Carr et al. 2012; Canali et al. 2013; Frasconi et al. 2019). However, to the best of our knowledge, only one study has focused on the effect of RC management on weed species richness (Halde et al. 2015), and another one has discussed, but not tested, its influence on weed community composition (Ciaccia et al. 2016). It therefore appears that the currently available information does not yet show robust evidence of the effectiveness of ILRC for weed control and the effect of this management technique on weed species richness and community composition across different vegetable crops, soils, and climatic conditions in European organic vegetable systems.

To fill this knowledge gap and investigate the potential for a wider adoption of this technology, this study aims to evaluate whether ASC management (GM vs. ILRC) affects the structural parameters of weed assemblages (weed density, species richness, and community composition). Moreover, we also evaluate the magnitude of the effects of ILRC compared with those of GM, and whether this effect is reliable or, on the contrary, depends on the variations in cropping conditions, and the ASC biomass produced. For these purposes, we analyzed fourteen original datasets on weed assemblages from five European countries over 2 years. The datasets are the result of a joint effort within the framework of the SoilVeg project, which aimed to analyze the applicability of ILRC to European vegetable agroecosystems. We hypothesized that (i) ILRC reduces weed density and species richness and modifies the community composition in comparison with GM ASC management, and (ii) the benefits of ILRC are strongly affected by variations in cropping conditions caused by interannual deviations in weather and in timing and effectiveness of field operations, as well as differences in relation to changing the area within the field. However, since we have not investigated these factors in detail, we consider that differences between years summarize these effects.

2 Materials and methods

2.1 Locations and trials

The organic vegetable field trials were located in Denmark (DK), Estonia (EE), Italy (IT), Slovenia (SI), and Spain (ES) for two consecutive years (Table 1). The locations were selected to cover a wide range of vegetable production conditions under different climatic zones of Europe (Metzger 2005). The trial established in DK represents the Atlantic North European climatic zone under the influence of the Atlantic Ocean, and it is characterized by cold winters and mild summers. The EE trial was located in the Nemoral zone, which is characterized by late spring and summer with high temperatures and abundant precipitation. The trial of SI represents the Alpine South zone characterized by the environmental conditions of the high mountains. The trials of ES and IT were located in the Mediterranean North zone, characterized by winters with maximum precipitation events and dry summers.

All partners (DK, EE, IT, SI, ES) grew the ASCs in the cold rainy season followed by a spring-summer cash crop. In parallel trials, in the Mediterranean countries (IT and ES), summer ASCs (warm-dry season) were also cultivated before the autumn-winter cash crop. Herein, IT-SCC and ES-SCC are used to refer to the main trials, and IT-ACC and ES-ACC are used for the parallel trials. Thus, in total, fourteen original datasets were analyzed (i.e., seven field experiments during two consecutive years) (Table 1).

2.2 Experimental design, management, and sampling methods of each trial

Cash crop management varied among partners depending on the climatic conditions, available machinery, and requirements of the selected vegetable crop. The experiment was repeated on the same plots in both years in ES. In all the other trials, the plots were moved to an adjacent area of the same experimental field. Each partner had a different experimental layout and management, but the comparison between ASCs' management was common to all (ILRC vs. GM). ILRC management consists of (i) several rapid passes of a roller crimper to flatten the ASCs, followed by (ii) a slower operation with an ILRC to create a narrow transplanting furrow without disturbing the surrounding mulch. GM management comprises (i) mowing-chopping the ASCs; (ii) incorporating ASCs into the soil by tillage, when the plant residues were dry; and (iii) seedbed preparation.

Each partner assessed weed and ASC species abundance at an early stage of the cash crop. Both germinated and resprouting individuals were counted and identified at the species level prior to weeding operations. These data provided measures of weed density and weed species richness. Weed density (individuals m^{-2}) comprised the total number of

Table 1 Da ta on the environmental conditions, ASCs, range of total dry biomass, cash crop, and weed sampling details of the seven trials included in this study

Country	Cash crop period	Temperature rainfall (annual mean)	Soil type	ASC	Range of total dry biomass (t/ha ASC+weeds)	Weed proportion of the total biomass (%)	Cash crop	Weed sampling (samples per plot)	Timing of sampling (days after transplanting)	Explanatory variables in the models
Denmark	SCC	1Y: 9.3 °C; 614 mm	Sandy loam	ASC 1–100% VF; ASC 2–100% PS; ASC 3–100% VS	2.32–6.74	7.66 ± 1.14	White cabbage	Four samples of 0.25 m^2	1Y: 26 days 2Y: 22 days	ASC management; total biomass; year
		2Y: 9.1 °C; 673 mm		ASC 4–50% SC + 50% VF; ASC 5–50% SC + 50% PS; ASC 6–50% SC + 50% VS	0.12–9.32	28.98 ± 7.05				
Estonia	SCC	1Y: 6.0 °C; 825 mm	Clay loam	1Y: ASC 1–100% SC; ASC 2–100% LM	3.84–11.20	1.98 ± 0.51	White cabbage	Four samples of 0.25 m^2	1Y: 69 days 2Y: 37 days	ASC management; total biomass; year; fertilization
		2Y: 5.8 °C; 694 mm		2Y: ASC 1–100% SC; ASC 2–100% TR	2.28–11.54	1.07 ± 0.09				
Italy	SCC	1Y: 16.7 °C; 539 mm	Clay	ASC 1–20% HV + 80% VS; ASC 2–20% HV + 80% VF	2.73–12.41	1.29 ± 0.54	Tomato	Four samples of 0.0625 m^2	1Y: 47 days; 2Y: 57 days	ASC management; total biomass; year; fertilization
		2Y: 16.5 °C; 402 mm			1.85–8.74	0.96 ± 0.25				
	ACC	1Y: 16.6 °C; 470 mm		ASC 1–100% VU; ASC 2–70% VU + 30% PG	2.29–6.29	19.02 ± 2.43	Cauliflower	Four samples of 0.0625 m^2	1Y: 28 days 2Y: 30 days	ASC management; total biomass; year
		2Y: 16.7 °C; 539 mm		ASC 3–50% VU + 50% PG; ASC 4–40% VU + 30% PG + 30% RS	1.60–5.44	20.72 ± 3.16				
Slovenia	SCC	1Y: 10.9 °C; 1009 mm	Loam	ASC 1–100% HV; ASC 2–100% TI	4.80–11.20	22.54 ± 1.91	Cauliflower	Two samples of 0.25 m^2	1Y: 43 days; 2Y: 29 days	ASC management; total biomass; year; fertilization
		2Y: 11.1 °C; 961 mm			2.51–11.43	31.24 ± 1.96				
Spain	SCC	1Y: 16.5 °C; 406 mm	Loam	ASC 1–100% CM (81% AB + 19% HV); ASC 2–50% CM + 50% VS	7.16–12.13	0.21 ± 0.04	Green pepper	Eight samples of 0.1 m^2	1Y: 21 days; 2Y: 22 days	ASC management; total biomass; year
		2Y: 16.1 °C; 409 mm			5.04–18.55	0.33 ± 0.06				
	ACC	1Y: 16.1 °C; 344 mm		ASC 1–100% VU; ASC 2–50% VU + 50% SB	2.92–16.35	70.89 ± 3.4	Savoy cabbage	Eight samples of 0.1 m^2	1Y: 30 days; 2Y: 36 days	ASC management; total biomass; year
		2Y: 16.5 °C; 406 mm			0.98–19.23	63.95 ± 4.01				

SCC, spring-summer cash crop; *ACC*, autumn-winter cash crop; *1Y*, first year; *2Y*, second year of experimentation; *VF*, *Vicia faba* var. *equina* Pers.; *PS*, *Pisum sativum* L.; *VS*, *Vicia sativa* L.; *SC*, *Secale cereale* L.; *LM*, *Lolium multiflorum* Lam.; *HV*, *Hordeum vulgare* L.; *VU*, *Vigna unguiculata* (L.) Walp.; *PG*, *Pennisetum glaucum* (L.) R.Br.; *RS*, *Raphanus sativus* L.; *TI*, *Trifolium incarnatum* L.; *CM*, cereal mixture composed by 81% AB + 19% HV; *AB*, *Avena byzantina* K.Koch.; *SB*, *Sorghum bicolor* (L.) Moench; *TR*, × *Triticosecale blaringhemii* A.Camus germinated and resprouting individuals, including weed and ASC species, to account for all the potential competition towards cash crops. On the other hand, weed species richness (number of species/sample) and community composition referred exclusively to weeds germinated at the beginning of the cash crop. In these cases, we analyzed exclusively germinated weeds to isolate the response of weed communities to the different ASC management methods. Weed species abundances were averaged for each plot in all trials, except in ES where the exact locations of samples were taken into account (see below). Weed species richness cannot be standardized to fixed surface and therefore, in each trial, weed species richness referred to the sampling frame.

Specific information on the environmental conditions (i.e., annual mean temperature and rainfall, soil texture), ASC composition, range of total dry biomass, cash crop grown, and weed sampling procedure of the seven trials included in this study is detailed in Table 1.

2.2.1 Denmark

The field experiment was conducted at the research center of the Department of Food Science of Aarhus University located in Årslev (Denmark) (10°27′ E; 55°18′ N). The trial was newly established and the previous crop grown in the area was barley (*Hordeum vulgare* L.). The trial was established on a sandy loamy soil with a 1% carbon in the 0–0.5-m soil layer. The trial had a split-plot randomized complete block experimental design with three replicates, where ASC management (i.e., ILRC vs. GM) was the whole-plot factor, while ASC composition was the subplot factor (i.e., six different ASC compositions) (Table 1). The plot size was 3.2 m × 10 m during the first year and 4.8 m × 10 m during the second year. White cabbage (*Brassica oleracea* var. *capitata* L.) was transplanted on July 1, 2016, and on June 21, 2017. The harvest was carried out on November 11, 2016, and on November 2, 2017. During the first year, all the plots were fertilized prior the ASC plantation (October 5, 2015) with feather meal pellets (26 kg N ha^{-1}) and during the cabbage development (50 kg N ha^{-1}) (August 25, 2016). Cash crop was irrigated two times, on August and September, with sprinklers. During the second year, plots were fertilized with feather meal (26 kg N ha^{-1}) prior to the ASC plantation (October 9, 2016), a week before the cabbage transplantation with feather meal pellets (100 kg N ha^{-1}) and lupine seeds (30 kg N ha^{-1}), and during the cabbage development with feather meal pellets (80 kg N ha^{-1}) (August 24, 2017). In this cash crop cycle, no irrigation was required. Weeds were evaluated in 0.5 m × 0.5 m quadrats randomly distributed on each plot, and one cabbage plant was included in each quadrat. In 2016, weeds were sampled 26 days after transplanting, while in 2017, the sampling was carried out 22 days after transplanting.

2.2.2 Estonia

The field experiment was conducted at the experimental organic research field in eastern Estonia at Jõgeva (Estonia) (58°44′ N; 26°24′ E). The trial was newly established on a certified organic area since 2005. Previously, the area was used for organic arable crop experimentation. Specifically, the previous crop grown was red clover (*Trifolium pratense* L.). The experimental field was located on a clay loamy soil with a 3% organic carbon. The experimental design was a strip-plot design with ASC strips and ASC management crossed with the fertilizing factor (i.e., manure vs. without manure), and three replicates per treatment. The plot size was 6 m × 4 m. White cabbage was transplanted in the first year from the 13th to the 16th of June 2016, and in the second year on June 19, 2017. The harvest was carried out on October 7, 2016, and from October 4 to 6 in 2017. Plots belonging to the fertilization treatment were fertilized before the ASC plantation with the application of 30 t/ha solid cattle manure (153 kg ha^{-1} N, 57 kg ha^{-1} P, and 81 kg ha^{-1} K). During the second year, all plots were fertilized with 12 t ha^{-1} of horse manure compost (12 kg ha^{-1} N, 1.2 kg ha^{-1} P, and 4.8 kg ha^{-1} K). During the first year, cash crop was not irrigated. Conversely, during the second year, all plants were watered one time in mid-July with a humic solution (0.0003 kg ha^{-1} N, 0.0001 kg ha^{-1} P, 0.0002 kg ha^{-1} K). Weeds were evaluated in 0.5 m × 0.5 m quadrats in each plot, placed at 0.5 m from plot borders. During the first year, weeds were sampled 69 days after transplanting, while in the second year, the sampling was carried out 37 days after transplanting.

2.2.3 Italy

The field experiment was conducted in the Experimental Farm of Metaponto belonging to the Consiglio per la Ricerca in Agricoltura e l'Analisi dell'Economia Agraria in Southern Italy (40°24′ N; 16°48′ E). Both parallel field experiments (i.e., spring-summer cash crop (SCC) and autumn-winter cash crop (ACC)) were newly established. The previous crop grown was wheat (*Triticum aestivum* L.) in the ACC trial and fennel (*Foeniculum vulgare* Mill.) in the SCC trial. Soil texture was clay loam and contained on average 1.1% of organic carbon. In both trials, the plot size was 6 m × 4 m. Weed samplings were carried out in four 0.25 m × 0.25 m quadrats randomly distributed in each plot in both trials.

Spring-summer cash crop The experimental design was a split-split-plot with main plots arranged as a randomized complete block design, with three factors and three replications. The main plot was assigned to the ASC factor (i.e., two ASC compositions), the subplot to the ASC management (GM vs. ILRC), and the split-plot to the fertilization factor (three levels). The fertilization factor consisted in (i) no fertilizer,

(ii) commercial organic mineral fertilizer allowed in organic farming, and (iii) anaerobic digestate from cattle residues. The tomato (*Solanum lycopersicum* L.) was transplanted on April 28, 2016, and on May 5, 2017, and harvested from July 7 to August 25 in 2016, and from July 18 to August 25 in 2017. Crop was drip-irrigated weekly. Weed sampling was carried out 47 days after transplanting in the first year, and 57 days after the cash crop transplanting in the second year.

Autumn-winter cash crop The experimental layout was a split-plot with main plots arranged as a randomized complete block design, with two factors and three replications. The main plot was assigned to the ASC composition (four levels) (Table 1) and the subplot was assigned to the ASC management factor levels with two levels (GM vs. ILRC). The ASC was grown in the warm/dry season, followed by cauliflower (*Brassica oleracea* var. *botrytis* L.) as cash crop, which was transplanted on August 3 of both years. The cauliflower harvest was from November 23 to December 15 in 2015, and on November 28, 2016. No fertilization was applied before the ASC sowing. Off-farm animal manure–based organic fertilizer was applied just before the ASC termination, while the second was applied localized on the cauliflower plants during the cash crop plant development. The total fertilizer rate was 150 kg ha^{-1} N, 450 kg ha^{-1} P_2O_5, and 150 kg ha^{-1} K_2O. ASC and cauliflower crops were irrigated on both years of experimentation by micro-sprinklers. ASC was irrigated on the emergence, while cauliflower was watered according to crop requirements each year. Weed sampling was performed in the first year 28 days after transplanting, while in the second year 30 days after transplanting.

2.2.4 Slovenia

The field experiment was conducted at the University of Maribor (Pivola), Faculty of Agriculture and Life Sciences (UM), Slovenia (46°30′ N; 15°37′ E). The trial was newly established in a field in which barley was produced the year before. The soil was characterized by a loam texture with an average of 2.66% of organic carbon in the 0–0.30-m soil layer. The experimental design was a split-split-plot with plots arranged as a randomized complete block design, with three factors (i.e., ASC composition, ASC management, and fertilization) and four repetitions. ASC composition had two levels (Table 1), ASC management had two levels (GM vs. ILRC), and the fertilization factor had two levels (i.e., application of 30 t ha^{-1} of livestock manure before sowing ASC vs. without manure application). The plot size was 2.5 m × 2.5 m. Cauliflower was transplanted in the first year on June 3, 2016, and on May 24, 2017, and harvested on September 29, 2016, and September 5, 2017. During both years of experimentation, all plots were fertilized two times during the cash crop cycle using organic amendments. The first application was carried out at the cash crop transplanting (70 kg ha^{-1} N), while the second fertilization (70 kg ha^{-1} N) was performed during the development of the cash crop. Irrigation was required in the second year of experimentation two times during the cash crop development. Weeds were sampled in four 0.5 m × 0.5 m quadrats randomly placed in each plot. In the first year, weeds were sampled 43 days after transplanting, while in the second year, 29 days after transplanting.

2.2.5 Spain

Spring-summer cash crop and autumn-winter cash crop Field experiments were conducted at the Gallecs Area of Natural Interest (Barcelona, Spain) (41°33′ N; 2°12′ E). The trial was newly established in an area which began the conversion to organic farming in 2005. The previous crop grown in the area was wheat. The trials were characterized by loamy soil texture and the mean proportion of organic carbon is 0.95%. In both parallel trials (i.e., SCC and ACC), the experimental design was a randomized strip-plot with two factors (the ASC composition and ASC management) (Table 1) and four replicates. The different treatments were established in parallel bands randomly distributed, and four plots of 6 m × 4 m were defined within each band. The experimental design was conditioned largely by the need to perform all agricultural works in the same direction and facilitate machinery traffic between plots. In the SCC trial, green pepper (*Capsicum annuum* L.) was transplanted on May 26, 2016, and on June 20, 2017.The last pepper harvest was on October 3, 2016, and on October 2, 2017. In ACC, savoy cabbage (*Brassica oleracea* var. *sabauda* L.) was transplanted on August 4, 2015, and on September 20, 2016. The last savoy cabbage harvest was carried out on December 2, 2015, and on February 22, 2017. In SCC, fertilization was carried out just after transplanting using a commercial organic fertilizer (i.e., 170 kg ha^{-1} N). In ACC, in both years, the fertilizer amount was the same (100 kg ha^{-1} N); however, in the first year, the fertilization was split in two applications (i.e., one just after transplanting and the other during the development of the cabbage), while in the second year, only one fertilization was carried out just after transplanting. In ACC, ASC was irrigated sprinklers in both years, while cabbage was watered according to the crop needs by using drip irrigation. In SCC, only the cash crop was drip-irrigated according to the crop needs. In both trials, eight samples of 0.25 m × 0.40 m were taken per plot. The samples were placed so that the corner of each sample leaned on a cash crop plant, and the longest side was placed perpendicular to the cash crop line.

2.3 Statistical analysis

We did not pool the raw data from different experiments because each trial had its own experimental design; instead, a specific statistical model was used for each trial. Then, we used a meta-analytic approach to test for the overall statistical support for the effect of ASC management on weed density and weed species richness.

Each statistical model included all the experimental variables evaluated in each specific trial (Table 1) to discount their effect in the dependent variable. Only termination (GM and ILRC), year (year 1 and year 2), and total dry biomass were explanatory variables common to all experiments. The first two were included as factors, whereas biomass was included as a covariate. Given the specifics of each trial, the year summarizes the variations in the cropping conditions caused by interannual variations in weather and timing and effectiveness of field operations, as well as differences in relation to changing the area within the field. We pooled the total dry biomass of the different ASCs included in each trial and the weeds present prior to the ASC termination. In the trials which included fertilization, the levels of this factor were defined specifically according to the description in Section 2.1.

In DK, EE, IT, and SI, linear mixed-effects models were used for each partner and year. The specific experimental layout of each trial, described in the previous section, defined the selection of the random effects for these trials.

In ES, the need to facilitate the machinery traffic between plots conditioned the experimental design. Thus, spatial correlation structures were introduced in ES models to account for the lack of independence between samples (Pinheiro et al. 2000). Models including the different classes of spatial correlation structures as well as a model without a spatial correlation structure were compared by likelihood ratio tests and by Akaike's information criterion (AIC) to establish the best model for each dependent variable and year.

When needed, data were transformed to meet the requirements of normality and homoscedasticity. Weed density was transformed applying logarithms (IT-SCC-pooled; ES-ACC-pooled) and square root transformation (SI-SCC-pooled; ES-SCC-pooled). Weed species richness was transformed applying logarithms (EE-SCC-1Y; EE-SCC-2Y). All statistical analyses were performed with R software (R Core Team 2017); for linear mixed-effect models, we used the lme function of the R nlme package (Pinheiro et al. 2017), while for ES models with spatial correlation structures, we used the gls function.

The meta-analytic approach was applied to analyze the effect across trials of the ASC management on weed density and weed species richness. This meta-analytic approach can be nearly as powerful as that based on combining data (Zaykin 2011). We used the weighted Z test, which is essentially a weighted version of Stouffer's method:

$$p_Z = 1 - \Phi\left(\frac{\sum_{i=1}^{k} w_i Z_i}{\sqrt{\sum_{i=1}^{k} w_i^2}}\right)$$

where $Z_i = \Phi^{-1}(1 - p_i)$; p_i is the p value from the ith study out of k studies in total; w_i is the weight selected for the study; and Φ and Φ^{-1} are the standard normal cumulative distribution function and its inverse, respectively. For this study, we weighted the Z_i by the standardized effect size, as suggested by Zaykin (2011):

$$w_i = \frac{|\mu_i|}{SE_i}$$

where μ_i is the coefficient estimate and SE_i is its standard error. For testing the same alternative hypothesis, individual p values were converted to one-sided before combining as follows (Zaykin 2011):

$$p_{one-\text{sided}} = \begin{cases} \frac{p_{two-\text{sided}}}{2}, \text{if the direction of the effect coincides with the alternative hypothesis} \\ 1 - \frac{p_{\text{two-sided}}}{2}, \text{otherwise} \end{cases}$$

Independence among p values is required for the weighted Z test. Thus, we pooled the data from the two consecutive years in each trial to analyze the effect of the termination in each trial.

Community composition shifts were analyzed using permutational multivariate analysis of variance (PERMANOVA). Prior to PERMANOVA, we carried out the steps suggested by Anderson (2001): (i) we transformed the weed abundance measurements into presence/absence data; (ii) we used the Jaccard distance to compute the distances between plots; and (iii) we tested for homogeneity in multivariate dispersion with the betadisper function of the R package vegan (Oksanen et al. 2017). PERMANOVA was performed with the adonis function with the R package vegan (Oksanen et al. 2017). Specifically, it decomposes the variance of the distance matrices and attributes the components of the variance (i.e., measured as partial R^2) to the explanatory variables (i.e., factors and covariates).

The relative importance of the effect size of total dry biomass (ASCs + weeds), year, and termination was also calculated. For weed density and species richness, the estimated coefficient for each explanatory variable was divided by the intercept of the model (Armengot et al. 2015), while for the community composition, the effect size was related to the partial R^2 of each variable for each trail (Koricheva et al. 2013).

3 Results and discussion

3.1 Effect of ILRC management on weed density, species richness, and community composition

The ASC management had a clear effect on weed density, species richness, and community composition at the beginning of the cash crop (Table 2). ILRC management dramatically reduced weed density, and this effect was robust among trials. The mean across experiments showed that ILRC management reduced weed density by 35.1% in comparison with GM. In addition, analyzing both years pooled, the results of the meta-analysis showed that this trend was significant across trials (Fig. 2a). Specifically, ILRC reduced weed density at least in one of the two years in five (DK, EE, ES-SCC, ES-ACC, SI) out of the seven trials, and in two of them (DK, SI), this trend was significant in both years of experimentation (Fig. 2a). Previous field experiments in Italy have also reported a dramatic reduction in weed abundance in ILRC plots, averaging 86% (Canali et al. 2013) and 83.5% (Ciaccia et al. 2016) in comparison with GM. The pattern observed in our study could be related to the presence of mulch, which modifies the light and the temperature at the soil surface (Teasdale and Mohler 2000; Canali et al. 2013), both crucial factors affecting dormancy and germination of many weed species (Guillemin et al. 2013; Batlla and Benech-Arnold 2014).

Weed species richness also had a consistent response to ILRC management during the first 2 years of experimentation across trials (Table 2). ILRC management reduced species richness by 23.8% across trials, and this trend was significant according to the weighted Stouffer test (Fig. 2b). ILRC termination reduced weed species richness in at least one of the years of experimentation in all the countries except Italy, and in three of them (DK, EE, ES-ACC), this trend was significant in both years of experimentation (Fig. 2b). The immediate response observed after the adoption of ILRC management across trials diverged with the only study available so far (Halde et al. 2015), in which a significant response was observed in the fifth year of continuous management in arable rainfed crops. Furthermore, the consistent weed species richness reduction across trials observed in our study contrasts with previous studies. Positive and negative effects have been observed for the effects of tillage intensity (Nichols et al. 2015; Armengot et al. 2015) and the presence of mulch (Campiglia et al. 2010; Radicetti et al. 2013) on weed species richness.

The general pattern observed for weed density and species richness under ILRC across trials contrasts with the local results of the trials carried out in Italy (i.e., ACC and SCC). In these trials, weed density and species richness were not reduced under ILRC management, and even a significant increase of weed density was noticed in the first and second year of experimentation of IT-ACC (Fig. 2a, b). The atypical pattern observed for weed density in IT-ACC trial could be related to the ASC and weed resprouting, while the absence of effect on weed species richness might be a consequence of the low levels of weed density in the experimental field where the trials were carried out (Table 2).

Analyzing weed species from the fourteen datasets, we observed that overall weed communities after the ASC management were dominated by annual and broadleaf species (Table 2). Weed community composition generally had a significant but low response to ASC management (ILRC vs. GM) in most of the trials analyzed. Specifically, in all the trials except in the Italian ACC, the composition of weed communities was significantly affected by the ASC management in both years of experimentation (Fig. 2c). Nonetheless, the percentage of weed community composition variability attributable to termination was generally low and ranged from a minimum value of 8.2% in the second year of the Italian SCC trial ($p = 0.005$) to a maximum of 34.3% in the second year of the trial in Slovenia ($p = 0.001$) (Fig. 2c). On the other hand, the average Jaccard distances between ASC managements (Table 2) indicate that the differences between ILRC plots are similar or even higher than between ILRC and GM plots. In all trials except the Italian ones, the ILRC plots were significantly more variable in weed composition than the GM ones. ILRC reduced drastically weed density and species richness, and this effect was rather unspecific, causing a strong divergence between samples, which means that ILRC does not select some species over others. Previous studies have reported changes in weed community composition produced by both tillage intensity changes (Nichols et al. 2015; Armengot et al. 2015) and mulch presence (Campiglia et al. 2010; Radicetti et al. 2013). However, as far as we know, only one study has considered the effect of ILRC management on weed community composition (Ciaccia et al. 2016). In this study, the authors speculate that ILRC could influence the weed community composition in organic vegetable cropping systems, but they did not statistically compare the differences between ILRC- and GM-managed plots.

In this study, weed density, species richness, and community composition were analyzed only at the early stages of crop growth. Nonetheless, some weed species might emerge later in the crop cycle due to the modifications of the soil

Table 2 Weed density (individuals m^{-2}), weed species richness (species sampling unit^{-1}), weed community composition (EPPO codes), and average Jaccard distances between terminations per year, trial, and ASC management. Weed density and weed species richness are also summarized pooling both years' data

	DK - SCC		EE - SCC		ES - SCC		ES - ACC		IT - SCC		IT - ACC		SI - SCC	
	GM	ILRC	GM	ILRC	GM	ILRC	GM	ILRC	GM	ILRC	GM	ILRC	GM	ILRC
Density														
Year 1	502 ± 32	181 ± 20	159 ± 10	39 ± 3	471 ± 56	257 ± 40	252 ± 11	61 ± 4	52 ± 7	66 ± 11	84 ± 13	114 ± 9	181 ± 16	33 ± 3
Year 2	1057 ± 61	406 ± 35	190 ± 19	66 ± 5	297 ± 20	137 ± 15	1055 ± 43	1032 ± 111	21 ± 3	20 ± 2	130 ± 13	184 ± 24	718 ± 25	250 ± 14
Pooled	780 ± 58	293 ± 27	175 ± 11	57 ± 5	384 ± 31	197 ± 23	653 ± 55	546 ± 82	36 ± 5	43 ± 7	107 ± 10	149 ± 14	449 ± 50	141 ± 21
Species richness														
Year 1	8.2 ± 0.2	5.4 ± 0.3	8.6 ± 0.3	5.2 ± 0.2	5.3 ± 0.2	4.3 ± 0.5	6 ± 0.2	0.7 ± 0.1	1.3 ± 0.1	1.1 ± 0.1	1.2 ± 0.1	1.2 ± 0.1	5.5 ± 0.2	3.2 ± 0.2
Year 2	10.9 ± 0.2	8.7 ± 0.2	11.2 ± 0.6	8.3 ± 0.5	4.9 ± 0.2	3.2 ± 0.2	8.3 ± 0.2	5.7 ± 0.3	1 ± 0.1	1.1 ± 0.1	2.1 ± 0.2	2.4 ± 0.2	6.6 ± 0.2	6.1 ± 0.2
Pooled	9.5 ± 0.3	7.1 ± 0.3	9.9 ± 0.4	7.3 ± 0.5	5.1 ± 0.1	3.8 ± 0.3	7.1 ± 0.2	3.2 ± 0.4	1.1 ± 0.1	1.1 ± 0.1	1.6 ± 0.2	1.8 ± 0.2	6 ± 0.2	4.6 ± 0.3
Community composition														
Year 1														
First more abundant	STEME	VERAR	ARTVU	MATIN	POROL	SOLNI	AMARE	VERPE	CONAR	CONAR	POROL	POROL	GASPA	CAPBP
Second more abundant	VERAR	STEME	ERYCH	LAMPU	SOLNI	POROL	SOLNI	STEME	ECAEL	ECAEL	EPHPT	CONAR	POROL	ECHCG*
Third more abundant	CHEAL	CAPBP	CAPBP	SONAR	AMARE	AMARE	DIPER	SETVE*	SONOL	PHAMI	CONAR	SONAR	AMARE	STEME*
Fourth more abundant	LAMPU	SENVU	LAMPU	MYOAR	HEOEU	SETVE	POROL	AMARE*	SONAR	PHAPA	SONAR	ECHCG	ECHCG	GASPA
Fifth more abundant	CAPBP	LAMPU	CHEAL	AGRRE	AMABL	DIPER	VERPE	CYPRO	POROL	SONOL	ECHCG	EPHPT	POLHY	AMARE
Year 2														
First more abundant	POAAN	VERAR	CHEAL	STEME	AMARE	POROL	STEME	STEME	CONAR	CONAR	CONAR	CONAR	ECHCG	STEME
Second more abundant	POLPE	POAAN	STEME	VIOAR	POROL	AMARE	VERPE	VERPE	ECAEL	ECAEL	SONOL	ECAEL	AMARE	LAMAL
Third more abundant	STEME	STEME	LAMPU	POATR	SOLNI	HEOEU	DIPER	CLDAR	POROL	PICEC*	ECAEL	SONOL	GASPA	AMARE*
Fourth more abundant	LAMPU	LAMPU	VIOAR	MYOAR	HEOEU	SOLNI	POROL	SETVE	EPHPT	BEAVX*	POROL	BEAVX	LAMAL	ECHCG*
Fifth more abundant	VERAR	POLPE	ERYCH	LAMPU	DIPER	CHEAL	SETVE	AMARE	ECHCG	CHEAL*	BEAVX	AMARE	POLHY	GASPA
Jaccard distance														
GM	0.22		0.40		0.54		0.59		0.65		0.50		0.26	
ILRC	0.33	0.37	0.52	0.50	0.53	0.54	0.59	0.60	0.71	0.68	0.50	0.48	0.55	0.54

DK, Denmark; *EE*, Estonia; *IT*, Italy; *SI*, Slovenia; *ES*, Spain; *SCC*, spring-summer cash crop; *ACC*, autumn-winter cash crop; *ILRC*, in-line tillage/roller crimper; *GM*, green manure. EPPO codes followed by an asterisk indicate species that are equally abundant. EPPO codes correspondence can be found in the EPPO Global Database webpage: https://gd.eppo.int/

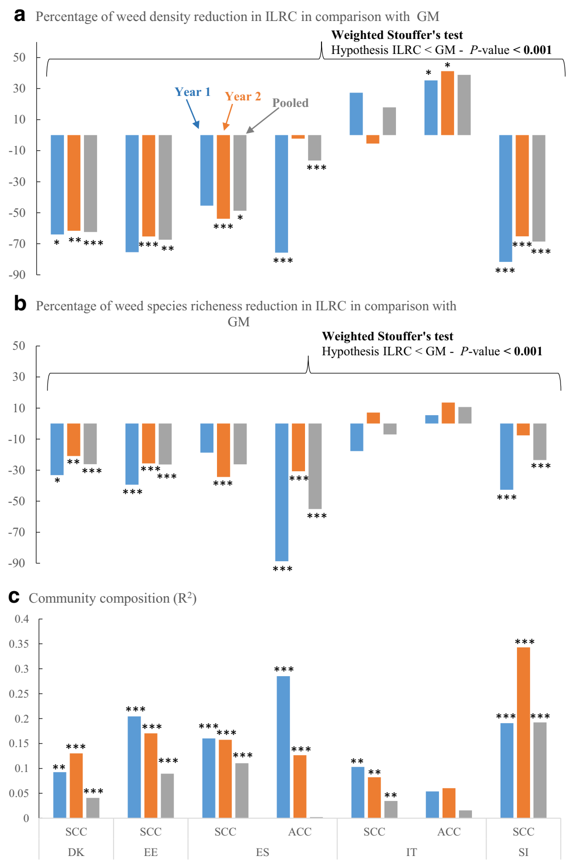

Fig. 2 **a** Percentage of weed density reduction in ILRC in comparison with GM. **b** Percentage of weed species richness reduction in RC in comparison with GM. **c** Community composition (R^2). DK: Denmark, EE: Estonia, IT: Italy, SI: Slovenia, and ES: Spain. SCC: spring-summer cash crop; ACC: autumn-winter cash crop; ILRC: in-line tillage/roller crimper; GM: green manure. Significance codes: $*p \leq 0.05$; $**p \leq 0.01$; $***p \leq 0.001$

surface environment (Guillemin et al. 2013). These weeds could also compete for water and nutrients, and also cause problems during the harvest of some vegetables. Thus, this evaluation should be completed with studies analyzing the weed emergence and growth during the development. Additionally, ILRC long-term studies in vegetable systems are required to provide information on the cumulative effect of this technology over the years. According to previous studies focused on arable crops (Halde et al. 2015), one of the expected cumulative effects is the progressive establishment and proliferation of perennial weed species, which hinder the management of the cropping system and might affect cash crop yield.

3.2 Effect size of the explanatory variables on structural parameters of weed communities

Despite important implications from an agronomic point of view, there are no direct comparisons analyzing the relative importance of the explanatory variables (dry biomass, year, ASC management) in vegetable cropping systems using ASC. To fill this knowledge gap, in our study, we analyzed the effect size of the explanatory variables on structural parameter of weed communities (weed density, species richness, and community composition). We have found that the relative importance of the explanatory variables varied depending on the structural parameter of weed communities and the trial analyzed (Fig. 3).

ASC biomass flattened or chopped and incorporated into the soil is usually considered an important factor for controlling weeds (Radicetti et al. 2013; Canali et al. 2013; Ciaccia et al. 2016). However, in our study, the comparison of the size effects of the explanatory variables on weed density across trials reflected that the relative importance of total dry biomass was low in all cases (Fig. 3) despite the wide ranges of this variable and the different weed proportions in the total dry biomass managed across trials, years, and partners (Table 1). ASC management (ILRC vs. GM) and the variations in the cropping conditions (i.e., year) are more important than the biomass produced by the ASCs for weed density (Fig. 3). Specifically, year had the largest effect size on weed density in four out of the seven trials evaluated. Thus, our results suggest that the reduction of weed density produced by ILRC management can be strongly affected by variations in cropping conditions. Previous studies have noticed a significant effect of both the year and ASC management on weed abundance under ILRC management, but the relative importance of each variable was neither analyzed nor discussed (Canali et al. 2013).

Some authors have suggested that community composition is mainly affected by the tillage intensity, while the weed species richness is a result of both the management and the environmental conditions (Nichols et al. 2015). Our results showed that both community composition and species

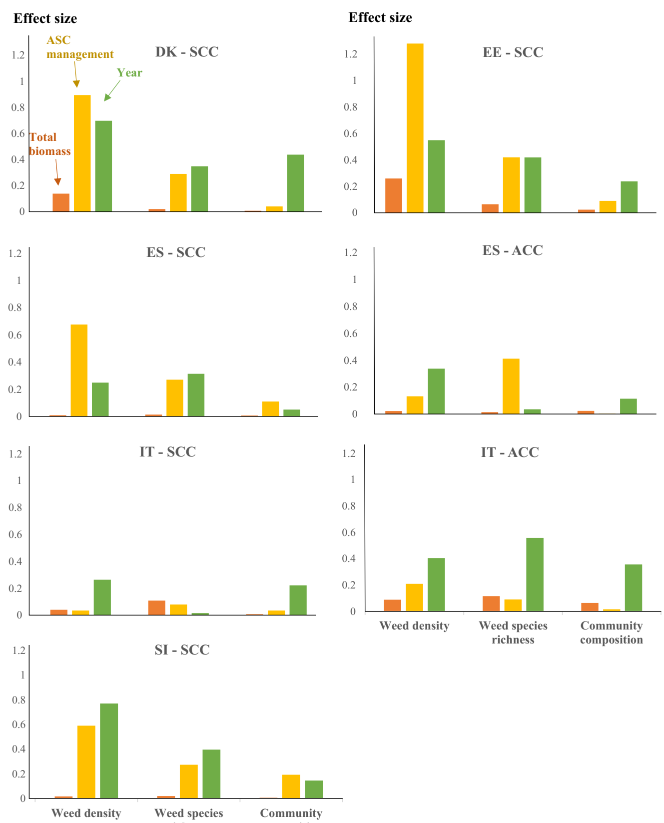

Fig. 3 Relative importance of the total dry biomass prior to ASC termination, the ASC management, and the year on the weed density, species richness, and community composition. For weed density and species richness, the estimate value of each variable was divided by the intercept of the model for each trial. In community composition, the R^2 was calculated for variable for each trial. DK: Denmark, EE: Estonia, IT: Italy, SI: Slovenia, and ES: Spain. SCC: spring-summer cash crop; ACC: autumn-winter cash crop; ILRC: in-line tillage/roller crimper; GM: green manure

richness were influenced by the year and ASC management, and their relative importance varied across trials (Fig. 3). Nonetheless, the year had a larger effect size in more trials than ASC management both for weed species richness and community composition. Total dry biomass presented the lowest relative importance in all trials, except in IT-SCC for weed species richness.

Therefore, our study indicates, for the first time, that the variations in the cropping conditions can strongly affect the outcome of ASC management on the structural parameters of weed communities (weed density, species richness, and community composition). Furthermore, we also note that the effect of the flattened or green manured total dry biomass is less important than the effect of both ASC management and cropping conditions on weed density, species richness, and community composition for most of the trials analyzed.

4 Conclusions

This study, which includes fourteen datasets from five different countries across Europe, provides for the first time solid evidence of the effectiveness of ILRC management for weed control at early stages of crop growth in different vegetable systems, soils, and climatic conditions across Europe. However, most importantly, although the benefits of ILRC management can be strongly affected by variations in cropping conditions (including but not restricted to interannual weather conditions, timing and effectiveness of field operations, variations between fields), our results provide a successful example that can contribute to reduce the reliance on tillage for weed management in organic vegetable systems.

Our multisite study also contributes to reduce the knowledge gap existing in the literature regarding the impact of ILRC management on weed species richness and community composition. We document for the first time a general trend under ILRC management of reduced weed species richness in seven trials across Europe in the transition to this management technique. Additionally, we report a significant but generally low effect of ASC management on weed community composition in most of the trials analyzed. Furthermore, we note that the effect of the total dry biomass, either flattened or used as green manure, is less important than the effect of both ASC management and the yearly conditions on weed density, species richness, and community composition for most of the trails analyzed.

Further research is required to identify the effect of the presence of mulch in ILRC systems on the environmental conditions of the soil surface, in different soils and climatic conditions across Europe, and how it affects the emergence of weeds along the cash crop cycle. Additionally, before this strategy can be suggested to farmers as a continuous management to be followed along the years, long-term studies analyzing the effect of this technology in the weed community composition would be required.

Authors' contributions David Navarro-Miró contributed to the design of the work, collected and analyzed the data, interpreted the results, and drafted the article. José M. Blanco-Moreno contributed to the analysis of data, the interpretation of the results, and the drafting of the article. Corrado Ciaccia contributed to the conception and design of the work and collected and analyzed data. Lourdes Chamorro, Hanne Lakkenborg Kristensen, Margita Hefner, Kalvi Tamm, Elena Testani, Ingrid Bender, Urška Lisec, Martina Bavec, Hélène Vedie, and Līga Lepse contributed to the design and management of the experiments and collection of data in each country. Stefano Canali (SoilVeg project coordinator) conceived the trans-national, multisite, and multi-season dimension of the entire experiment. F. Xavier Sans had a major role in the conception and design of the work, data analysis, and interpretation of the results and contributed to drafting the article. All the authors critically revised the final manuscript.

Funding information The project SoilVeg (http://projects.au.dk/coreorganicplus/research-projects/soilveg/) is funded by ERA-Net CORE Organic Plus Funding Bodies partners of the European Union's FP7 research and innovation program under the grant agreement no. 618107. DNM was funded by a PhD grant from the Ministerio de Educación, Cultura y Deporte from Spain (FPU14/03868).

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflicts of interest.

Disclaimer The findings and conclusions expressed in this paper are those of the authors and do not reflect the views of the Ministerio de Educación, Cultura y Deporte of Spain, or any of the EU funding bodies.

References

Altieri MA, Lana MA, Bittencourt HV et al (2011) Enhancing crop productivity via weed suppression in organic no-till cropping systems in Santa Catarina, Brazil. J Sustain Agric 35:855–869. https://doi.org/10.1080/10440046.2011.588998

Anderson MJ (2001) A new method for non-parametric multivariate analysis of variance. Austral Ecol 26:32–46. https://doi.org/10.1111/j.1442-9993.2001.01070.pp.x

Armengot L, Berner A, Blanco-Moreno JM et al (2015) Long-term feasibility of reduced tillage in organic farming. Agron Sustain Dev 35: 339–346. https://doi.org/10.1007/s13593-014-0249-y

Batlla D, Benech-Arnold RL (2014) Weed seed germination and the light environment: implications for weed management. Weed Biol Manag 14(2):77–87. https://doi.org/10.1111/wbm.12039

Campiglia E, Mancinelli R, Radicetti E, Caporali F (2010) Effect of cover crops and mulches on weed control and nitrogen fertilization in tomato (*Lycopersicon esculentum* Mill.). Crop Prot 29:354–363. https://doi.org/10.1016/J.CROPRO.2009.12.001

Canali S, Campanelli G, Ciaccia C et al (2013) Conservation tillage strategy based on the roller crimper technology for weed control in Mediterranean vegetable organic cropping systems. Eur J Agron 50: 11–18. https://doi.org/10.1016/J.EJA.2013.05.001

Canali S, Diacono M, Campanelli G, Montemurro F (2015) Organic no-till with roller crimpers: agro-ecosystem services and applications in organic Mediterranean vegetable productions. Sustain Agric Res 4: 70. https://doi.org/10.5539/sar.v4n3p70

Carr PM, Anderson RL, Lawley YE et al (2012) Organic zero-till in the northern US Great Plains Region: opportunities and obstacles. Renew Agric Food Syst 27:12–20. https://doi.org/10.1017/S174217051100041X

Casagrande M, Peigné J, Payet V et al (2016) Organic farmers' motivations and challenges for adopting conservation agriculture in Europe. Org Agric 6:281–295. https://doi.org/10.1007/s13165-015-0136-0

Ciaccia C, Canali S, Campanelli G et al (2016) Effect of roller-crimper technology on weed management in organic zucchini production in a Mediterranean climate zone. Renew Agric Food Syst 31:111–121. https://doi.org/10.1017/S1742170515000046

Ciaccia C, Testani E, Campanelli G et al (2015) Ecological service providing crops effect on melon-weed competition and allelopathic interactions. Org Agric 5:199–207. https://doi.org/10.1007/s13165-014-0088-9

Frasconi C, Martelloni L, Antichi D et al (2019) Combining roller crimpers and flaming for the termination of cover crops in herbicide-free no-till cropping systems. PLoS One 14:e0211573. https://doi.org/10.1371/journal.pone.0211573

Gallandt E (2014) Weed management in organic farming. In: Recent advances in weed management. Springer New York, New York, pp 63–85

Guillemin JP, Gardarin A, Granger S et al (2013) Assessing potential germination period of weeds with base temperatures and base water potentials. Weed Res 53:76–87. https://doi.org/10.1111/wre.12000

Halde C, Bamford KC, Entz MH (2015) Crop agronomic performance under a six-year continuous organic no-till system and other tilled and conventionally-managed systems in the northern Great Plains of Canada. Agric Ecosyst Environ 213:121–130. https://doi.org/10.1016/j.agee.2015.07.029

Koricheva J, Gurevitch J, Mengersen KL (2013) Handbook of meta-analysis in ecology and evolution. Princeton University Press ISBN 9781400846184

Luna JM, Mitchell JP, Shrestha A (2012) Conservation tillage for organic agriculture: evolution toward hybrid systems in the western USA. Renew Agric Food Syst 27:21–30. https://doi.org/10.1017/S1742170511000494

Mäder P, Berner A (2012) Development of reduced tillage systems in organic farming in Europe. Renew Agric Food Syst 27:7–11. https://doi.org/10.1017/S1742170511000470

Metzger MJ, Bunce RGH, Jongman RHG et al (2005) A climatic stratification of the environment of Europe. Glob Ecol Biogeogr 14(6): 549–563. https://doi.org/10.1111/j.1466-822x.2005.00190.x

Mirsky SB, Ryan MR, Curran WS et al (2012) Conservation tillage issues: cover crop-based organic rotational no-till grain production in the mid-Atlantic region, USA. Renew Agric Food Syst 27:31–40. https://doi.org/10.1017/S1742170511000457

Moonen AC, Bàrberi P (2004) Size and composition of the weed seedbank after 7 years of different cover-crop-maize management systems. Weed Res 44:163–177. https://doi.org/10.1111/j.1365-3180.2004.00388.x

Nichols V, Verhulst N, Cox R, Govaerts B (2015) Weed dynamics and conservation agriculture principles: a review. Field Crop Res 183: 56–68. https://doi.org/10.1016/j.fcr.2015.07.012

Oksanen J, Blanchet FG, Friendly M, et al (2017) vegan: Community Ecology Package. R package version 2.4-5. https://CRAN.R-project.org/package=vegan

Peigné J, Casagrande M, Payet V et al (2016) How organic farmers practice conservation agriculture in Europe. Renew Agric Food Syst 31:72–85. https://doi.org/10.1017/S1742170514000477

Pinheiro J, Bates D, DebRoy S, Sarkar D and R Core Team (2017). nlme: Linear and Nonlinear Mixed Effects Models. R package version 3.1-131. https://CRAN.Rproject.org/package=nlme

Pinheiro J, Bates D, Douglas M (2000) Mixed-effects models in S and S-PLUS. Springer-Verlag, New York

Radicetti E, Mancinelli R, Campiglia E (2013) Impact of managing cover crop residues on the floristic composition and species diversity of the weed community of pepper crop (*Capsicum annuum* L.). Crop Prot 44:109–119. https://doi.org/10.1016/J.CROPRO.2012.10.017

R Core Team (2017) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna https://www.R-project.org/

Sapkota TB, Mazzoncini M, Bàrberi P et al (2012) Fifteen years of no till increase soil organic matter, microbial biomass and arthropod diversity in cover crop-based arable cropping systems. Agron Sustain Dev 32:853–863. https://doi.org/10.1007/s13593-011-0079-0

Teasdale JR, Mohler CL (2000) The quantitative relationship between weed emergence and the physical properties of mulches. Weed Sci 48:385–392. https://doi.org/10.1614/0043-1745(2000)048[0385:TQRBWE]2.0.CO;2

Vincent-Caboud L, Peigné J, Casagrande M, Silva E (2017) Overview of organic cover crop-based no-tillage technique in Europe: farmers' practices and research challenges. Agriculture 7:42. https://doi.org/10.3390/agriculture7050042

Zaykin DV (2011) Optimally weighted Z-test is a powerful method for combining probabilities in meta-analysis. J Evol Biol 24:1836–1841. https://doi.org/10.1111/j.1420-9101.2011.02297.x

CURRICULUM VITAE

First name: Ingrid
Last name: Bender
Date of birth: 24.04.1954
Position: resercher
Academic degree: MSc in Crop Science, 1992, thesis „Winter hardiness of alfalfa cultivars and breeding numbers in 1982–1992 in Jõgeva“

Education:

2003–(interrupted)	PhD studies, Estonian University of Life Sciences
1980–1985	Estonian Agricultural Academy, educated agronomist
1972–1975	Räpina School of Agriculture, landscaping
1961–1972	Elva Gymnasium

Professional employment:

2013–...	Estonian Crop Research Institute, researcher, vegetable breeder
2008–2013	Jõgeva Plant Breeding Institute, deputy head of vegetable department
1992–1013	Jõgeva Plant Breeding Institute, researcher
1981–1992	Estonian Institute for Scientific Research in Agriculture and Land Improvement, Jõgeva Plant Breeding Station, agronomist
1975–1980	Estonian Research Institute of Agriculture and Land Reclamation (ERIALR), technical assistant in laboratory

Administrative activities:

1992– ...	Member of Estonian Academic Agricultural Society
2003– ...	Member of Estonian Plant Protection Society
2005−...	Member of International Society for Horticultural Science (ISHS)
2005– ...	Member of the Nordic Organization of Agricultural Scientists (NJF)

Research interest:

Tomato and garden pea breeding, maintenance breeding of vegetable varieties bred in Estonia. Applied and basic research on vegetable production, including research on organic farming

Participation in research projects:

2021–2024	„Producing advanced bio-based fertilizers from fisheries wastes“ (9PA1-MU00-SAE2LAND)
2014–2020	„Varieties suitable for use in organic farming in Estonia“ (PA1-RUP-026)
2015–2018	„Improving soil conservation and resource use in organic cropping systems for vegetable production through introduction and management of Agro-ecological Service Crops (ASC)“ (SoilVeg, PA1-RUP-011)
2010–2014	„Improving the growing technology of horticultural crops at the aim of increasing yield quality and competitive strength of the producers“ (8-2/T10039PKAI)
2009–2016	„Breeding of early and medium ripening, disease resistant and high yielding garden pea and tomato varieties“ (PA1-SORT-008)

Inventions:

2020	Tomato, breeding number N1761, owner Estonian Crop Research Institute, author Ingrid Bender. Priority number: 27.11.2020.
2020	Tomato, breeding number N1762, owner Estonian Crop Research Institute, authors Ingrid Bender and Birgit Koll. Priority number: 27.11.2020.
2013	Tomato cultivar 'Evelle', owner Estonian Crop Research Institute, authors Ingrid Bender and Maia Raudseping. Priority number: 8/2013. Priority date: 08.02.2013.
2012	Garden pea, cultivar 'Virges', owner Estonian Crop Research Institute, authors Maia Raudseping and Ingrid Bender. Priority number: 38/2012. Priority date: 08.03.2012.

2005	Tomato, cultivar 'Malle' F1, owner Estonian Crop Research Institute, authors Maia Raudseping and Ingrid Bender. Priority number: 146. Priority date: 09.03.2005.

ELULOOKIRJELDUS

Eeesnimi:	Ingrid
Perekonnanimi:	Bender
Sünniaeg:	24.04.1954
Ametikoht:	teadur
Teaduskraad:	Teadusmagister (MSc), 1992, taimekasvatuse erialal „Lutsernisortide ja aretusnumbrite talvekindlus Jõgeval aastatel 1982–1992“

Haridus:

2003–(katkestatud)	doktoriõpe, Eesti Põllumajandusülikool
1980–1985	Eesti Põllumajanduse Akadeemia, õpetatud agronoom
1972–1975	Räpina Aianduskool, aia- ja maastikukujundamise eriala
1961–1972	Elva Gümnaasium

Teenistuskäik:

2013–...	Eesti Taimekasvatuse Instituut, teadur, köögiviljade aretaja
2008–2013	Jõgeva Sordiaretuse Instituut, köögiviljade osakonna juhataja kt
1992–1013	Jõgeva Sordiaretuse Instituut, teadur
1981–1992	Eesti Maaviljeluse ja Maaparanduse Teadusliku Uurimise Instituut, Jõgeva Sordiaretusjaam, agronoom
1975–1980	Eesti Maaviljeluse ja Maaparanduse Teadusliku Uurimise Instituut, laborant

Teadusorganisatsiooniline tegevus:

1992– ...	Akadeemiline Põllumajanduse Seltsi (APS) liige, eestseisuse liige
2003– ...	Eesti Taimekaitse Seltsi liige
2005−...	Rahvusvahelise Aiandusteaduste Ühingu (ISHS) liige
2005– ...	Põhjamaade Põllumajandusteadlaste Organisatsiooni (NJF) liige

Teadustöö põhisuunad:

Tomati ja aedherne sordiaretus, Eestis aretatud köögiviljasortide säilitusaretus. Köögiviljakasvatuse rakendus- ja alusuuringud, selhulgas maheviljelusealased uuringud

Osalemine uurimisprojektides:

2021–2024	„Täiustatud biopõhiste väetiste tootmine kalandusjäätmetest" (9PA1-MU00-SAE2LAND)
2014–2020	„Mahepõllumajanduses Eestis kasutamiseks sobivad sordid" (PA1-RUP-026)
2015–2018	„Agroökoloogiliste vahekultuuride kasutuselevõtmine tootmise tõhustamiseks ja mullaomaduste parandamiseks maheköögiviljade kasvatamisel" (SoilVeg, PAI-RUP-011)
2010–2014	„Aiakultuuride kasvatus- ning taimekaitsetehnoloogiate täiustamine toodangu kvaliteedi konkurentsivõime suurendamise eesmärgil" (8-2/T10039PKAI)
2009–2016	„Varajaste ja keskvalmivate, haiguskindlate, suuresaagiliste ning heade maitseomadustega aedherne- ja tomatisortide aretus. Köögiviljasortide säilitusaretus" (PA1-SORT-008)

Patentsed leiutised:

2020	Harilik tomat, aretis N1761, omanik Eesti Taimekasvatuse Instituut; autor Ingrid Bender. Prioriteedi kuupäev on 27.11. 2020.
2020	Harilik tomat, aretis N 1762, omanik Eesti Taimekasvatuse Instituut; autorid Ingrid Bender ja Birgit Koll. Prioriteedi kuupäev on 27.11. 2020.
2013	Harilik tomat, sort 'Evelle', omanik Eesti Taimekasvatuse Instituut; autorid Ingrid Bender ja Maia Raudseping. Prioriteedi number: 8/2013. Prioriteedi kuupäev on 08.02. 2013.
2012	Harilik hernes, sort 'Virges', omanik Eesti Taimekasvatuse Instituut; autorid Maia Raudseping ja Ingrid Bender. Prioriteedi number: 38/2012. Prioriteedi kuupäev on 08.03. 2012.

2005	Harilik tomat, sort ’Malle’ F1, omanik Eesti Taimekasvatuse Instituut; autorid Maia Raudseping ja Ingrid Bender. Prioriteedi number: 146. Prioriteedi kuupäev on 09.03. 2005.

LIST OF PUBLICATIONS

1.1 Articles indexed by Thomson Reuters Web of Science

Hefner, M., Canali, S., Willekens, K., Lootens, P., Deltour, P., Beeckman, A., Arlotti, D., Tamm, K., **Bender, I**., Labouriau, R., Kristensen, H.L. (2020). Termination method and time of agro-ecological service crops influence soil mineral nitrogen, cabbage yield and root growth across five locations in Northern and Western Europe. *European Journal of Agronomy*, 120, 126144. DOI: 10.1016/j.eja.2020.126144.

Navarro-Miró, D., Iocola, I., Persiani, A., Blanco-Moreno, J.M., Kristensen, H.L., Hefner, M., Tamm, K., **Bender, I**., Védie, H., Willekens, K., Diacono, M., Montemurro, F., Sans, F.X., Canali, S. (2019). Energy flows in European organic vegetable systems: Effects of the introduction and management of agroecological service crops. *Energy*, 188, 116096.10.1016/j.energy.2019.116096.

Tamm, K., **Bender, I**., Nugis, E., Edesi, L., Võsa, T. (2018). The impact of the termination technology of agro-ecological service crops on soil properties in open field vegetable production. *Agronomy Research*, 16 (4), 1896−1904. DOI: 10.15159/AR.18.152.

Anton, D., **Bender, I**., Kaart, T., Roasto, M., Heinonen, M., Luik, A., Puessa, T. (2017). Changes in polyphenols contents and antioxidant capacities of organically and conventionally cultivated tomato (*Solanum lycopersicum* L.) fruits during ripening. *International Journal of Analytical Chemistry*, ARTN 2367453. DOI: 10.1155/2017/2367453.

Anton, D., Matt, D., Pedastsaar, P., **Bender, I**., Kazimierczak, R., Roasto, M., Kaart, T., Luik, A., Püssa, T. (2014). Three-year comparative study of polyphenol contents and antioxidant capacities in fruits of tomato (*Lycopersicon esculentum* Mill.) cultivars grown under organic and conventional conditions. *Journal of Agricultural and Food Chemistry*, 62 (22), 5173−5180. DOI: 10.1021/jf500792k.

Olle, M., **Bender, I**. (2009). Causes and control of calcium deficiency disorders in vegetables: a review. *The Journal of Horticultural Science and Biotechnology*, 84, 6, 577−584. DOI: 10.1080/14620316.2009.11512568.

1.2. Peer-reviewed articles in other International research journals with an ISSN code and International editorial board

Bender, I., Põldma, P. (2017). Cracking of tomato fruits in organic greenhouse trial. *Acta Horticulturae*, 1164, 527−534.

Bender, I., Ingver, A. (2012). The influence of production methods on yield and quality of carrots and swedes. *Acta Horticulturae,* 960, 293−298.

Bender, I., Ingver, A. (2011). Incidence of fungal diseases on organically grown tomato fruits. *Acta Horticulturae,* 914, 97−100.

Olle, M., **Bender, I**. (2010). The content of oils in umbelliferous crops and its formation. *Agronomy Research*, 8, 687−696.

Olle, M., **Bender, I**. (2010). The effect of non-woven fleece on the yield and production characteristics of vegetables. *Agraarteadus*, 1, 24−29.

Vabrit, S., Leedu, E., **Bender, I**., Suigusaar, K. (2008). Effect of sewage sludge and pig manure compost on the ornamental quality of impatiens 'Candy Coral Bee' container grown plants. *Acta Horticulturae*, 779, 637−642.

Bender, I., Vabrit, S., Raudseping, M. (2008). Effect of organic mulches on the growth of tomato plants and quality of fruits in organic cultivation. *Acta Horticulturae*, 779, 341−346.

Bender, I., Vabrit, S., Raudseping, M. (2005). Development of *Botrytis cinerea* and *Phytophthora infestans* on organically grown tomato fruits. *Acta Horticulturae*, 695, 67−71.

Bender, I., Raudseping, M., Vabrit, S. (2004). Tomato early yield formation dynamics in transition period from traditional to organic agriculture. *Horticulture and Vegetable Growing*, 23, 248−255.

Raudseping, M., **Bender, I**., Sooväli, P. (2002). The New Tomato Varieties of Estonia. *Zemdirbyste=Agriculture*, 78, 264−272.

3.2. Articles published by other publishers

Bender, I. (2020). Köögiviljad. Ants Bender (Toim.). Eesti Taimekasvatuse Instituut 100 (91−97). Jõgeva: AS Rebellis.

Bender, I. (2020). Söödajuurviljad. Ants Bender (Toim.). Eesti Taimekasvatuse Instituut 100 (105−106). Jõgeva: AS Rebellis.

Abubaker, S., **Bender, I**., Cubison, S., Dewitte, J., Dorais, M., Fuchs, J., Gomez, P., Jennings, N., Kempkes, F., Koch, R., Koller, M., Lambion, J., Messelink, G., Mitchell, C., Palme, W., Pinillos, V., Postweiler, K., Richter, E., Rayns, F., Schmutz, U., ... Voogt, W. (2016). 3.1.1 Variety comparison experiments; 4.2.1 Tomatoes. In: Koller, M.; Rayns, F.; Cubison, S.; Schmutz, U. (Eds.). *Guidelines for Experimental Practice in Organic Greenhouse Horticulture* (23–25; 71–75). Wageningen : Wageningen UR.

3.4. Articles published in conference proseedings not listed by Thomson Reuters or Scopus

Bender, I., Moor, U., Luik, A. (2015). The effect of growing systems on quality of carrots. *Research for Rural Development 2015: Annual 21st International Scientific Conference,* Jelgava, Latvia, 12–15 May, 2015. 118−123.

Bender, I., Põldma, P. (2013). Organic tomato yield and quality of fruits depending on year. *Abstract booklet: II International Symposium on Organic Greenhouse Horticulture,* Avignon, France, 28–31 Oct, 2013, 32.

Bender, I., Põldma, P. (2013). Influence of fertilization on the yield and some quality parameters of organically grown greenhouse tomato. *Abstract booklet: II International Symposium on Organic Greenhouse Horticulture,* Avignon, France, 28–31 Oct, 2013, 58.

Bender, I., Ingver, A. (2013). Influence of organic and conventional production on yield and quality of carrots. *NJF Seminar 461: Organic Farming Systems as a Driver for Change,* Bredsten, Denmark, 21–23 Aug, 2013, 179−180.

Bender, I., Ingver, A. (2011). The influence of production methods on yield and quality of carrots and swedes. In: *Book of Abstracts: 5th Balkan Symposium on Vegetables and Potatoes* (162). *5th Balkan Symposium on Vegetables and Potatoes*, Tirana, Albania, 9–12 Oct, 2011, 163.

Bender, I. (2010). Incidence of fungal diseases on organically grown tomato fruits. *Abstract book: 3rd International Symposium on Tomato Diseases;* Ischia, Naples-Italy; 25–30 July, 2010, 100.

Bender, I., Annamaa, K., Raudseping, M. (2007). Genetic resources conservation of tomato in Estonia. *Report of a Working Group on Vegetables of ECPGR: Seventh meeting of the ECPGR vegetables working group.* Olomouc, Czech Republic, 28-30 July, 2007, 142−145.

Bender, I., Raudseping, M. (2005). Yield and disease resistance of the superior last tomato varieties in an organic trial in Estonia. *Proceedings of the Seminar: Envirfood. Enviromental friendly food production system: requirements for plant breeding and seed production*. Stende, Latvia, 31 May–3 June, 2005, 111−113.

Bender, I., Vabrit, S., Raudseping, M. (2004). Development of *Botrytis cinerea* and *Phytophthora infestans* on organically grown tomato fruits. *Program and abstract book of 1st International Symposium on Tomato Diseases and 19th Annual Tomato Diseases Workshop*. Orlando, Florida, USA, 20–24 June, 2004, 37.

Raudseping, M., **Bender, I**., Sooväli, P. (2001). Utilization of different tomato forms in breeding in Estonia. In: *NJF-Utreding/NJF-Rapport* . Tartu University Press, 53−55.

3.5. Articles published in local conference proceedings

Bender, I. (2019). Kapsa vahele külvatud vahekultuuri mõju põhikultuuri saagile ja umbrohtumusele maheviljeluses. Tupits, I., Tamm, S., Tamm, Ü., Toe, A. (Eds). *Aronoomia 2019*. 28.02.2019, Jõgeva. Vali Press, 184−190.

Anton, D., **Bender, I**., Roasto, M., Püssa, T. (2017). Polüfenoolide sisalduse ja antioksüdantsuse muutused mahe- ja tavatomatite küpsemisel. Metspalu, L., Luik, A., Peetsmann, E. (Eds). *Teaduselt Mahepõllumajandusele: Mahepõllumahjandus ja keskkond*. 27.11.2017, Tartu. SA Eesti Maaülikooli Mahekeskus, 15–18.

Anton, D., Pedastsaar, P., **Bender, I**., Püssa, T. (2014). Viljelusviiside mõju tomati maitset kujundavate keemiliste ainete sisaldusele. Metspalu, L., Luik, A. (Eds). *Teaduselt Mahepõllumajandusele: Eesti mahepõllumajandus täna ja tulevikus*. 20.11.2014, Tartu, 9−12.

Bender, I., Põldma, P. (2014). Euroopa Liidu aiandusprojekt mahekasvuhoonetest. Olevsoo, V. (Toim). *Aiandusfoorum 2014*. Aiandusfoorum, 20.03.2014, Räpina, 4.

Bender, I., Põldma, P. (2014). BioGreenhouse: Jätkusuutlik ja produktiivne mahepõllumajanduslik katmikaiandus Euroopa Liidus. Olevsoo, V. (Toim.). *Aiandusfoorum 2014*. Aiandusfoorum, 20.03.2014, Räpina, 24–26.

Bender, I. (2014). Sibula viljelusviiside mõju saagi keemilisele koostisele ja toiteväärtusele. Tupits, I., Tamm, Ü., Tamm, S. (Eds).

Põllumajandusteaduselt tootjale. Aastaseminar, 29.01.2014, Jõgeva, 96–99.

Bender, I. (2014). Porgandi viljelusviiside mõju saagi keemilisele koostisele ja toiteväärtusele. Tupits, I., Tamm, Ü., Tamm, S. (Eds). *Põllumajandusteaduselt tootjale*. Aastaseminar, 29.01.2014, Jõgeva, 92–95.

Bender, I., Keppart, L. (2014). Viljelusviisi mõju kaalika toiteväärtusele. Metspalu, L., Luik, A. (Eds). *Teaduselt Mahepõllumajandusele: Eesti mahepõllumajandus täna ja tulevikus.* 20.11.2014, Tartu. AS Ecoprint, 17−20.

Starast, M., Põldma, P., Veromann, E., Karp, K., Kahu, K., Mänd, M. **Bender, I**. (2013). Keskkonnasäästlikud kasvatustehnoloogiad aianduses. Olevsoo, V. (Ed). *Aiandusfoorum 2013*. Eesti Põllumajandus-Kaubanduskoda, 6–9.

Bender, I. (2012). Porgandi viljelusviiside mõju saagi toitainete sisaldusele. Metspalu, L., Luik, A. (Eds). *Teaduselt mahepõllumajandusele: Mahepõllumajanduse arengusuunad – teadlaselt mahepõllumajandusele.* 08.11.2012, Tartu, AS Ecoprint, 12−14.

Bender, I., Ruumet, M. (2012). Mulla aurutamise mõju üheaastaste umbrohtude levukule. Lindepuu, R., Tamm, S. (Eds). *Põllukultuuride sordid ja nende kasutamine: Aastaseminar 2012*. 25.01.2012, Jõgeva, 76−79.

Bender, I. (2012). Aedherne koristuskonveier kaunakasvatuses. Lindepuu, R., Tamm, S. (Eds). *Põllukultuuride sordid ja nende kasutamine.: Aastaseminar 2012*. 25.01.2012, Jõgeva, 72−75.

Bender, I. (2012). Porgandikatsete tulemusi 2011. aastal. Lindepuu, R., Tamm, S. (Eds). *Põllukultuuride sordid ja nende kasutamine: Aastaseminar 2012*. 25.01.2012, Jõgeva, 80−87.

Bender, I. (2011). Aedherne seemnekasvatus tugikultuuriga. Tamm, S. (Ed). *Efektiivne taimekasvatus: Aastaseminar 2011*. 27.01.2011, Jõgeva, 76−79.

Bender, I. (2011). Köögiviljakatsete tulemusi. Tamm, S. (Ed). *Efektiivne taimekasvatus: Aastaseminar 2011*. 27.01.2011, Jõgeva, 68−75.

Bender, I. (2010). Uus aedoasort 'Lemmik'. Haljak, M., Tupits, I., Tamm, S. (Eds). *Sordiaretus ja Seemnekasvatus. Teaduslikud tööd X*. VALI trükikoda, 106−109.

Bender, I., Annamaa, K. (2010). Jõgeval aretatud tomatisortide kirjeldamine ja võrdlemine. Haljak, M., Tupits, I.; Tamm, S. (Eds). *Sordiaretus ja Seemnekasvatus. Teaduslikud tööd X*. VALI trükikoda, 110−117.

Anton, D., **Bender, I**., Püssa, T. (2010). Lükopeen tomatites ja tomatitoodetes. *Terve loom ja tervislik toit* . Tartu: Eesti Maaülikool, 66−67.

Bender, I. (2009). Tomati haigustest kütteta kasvuhoones. *Põllukultuuride sordid, omadused ja soovitusi kasvatamiseks: Jõgeva Sordiaretuse Instituudi Aastaseminar 2009*. 28.01.2009. Jõgeva, 88−91.

Bender, I. (2008). Köögiviljade sordi- ja säilitusaretus. Sordiagrotehnika ja seemnekasvatusega seonduvad rakendusuuringud. *Aiandusfoorum 2008*. 25.03.2008, Paide, 17−18.

Bender, I. (2008). Võimalusi tomati kasvatamiseks kütteta kasvuhoones. *Põllukultuuride uuemad sordid, nende omadused ja kasvatamise eripära*. Jõgeva. Vali Press, 80−85.

Bender, I. (2007). Tomatisaagi kujunemist mõjutavad tegurid mahetingimustes. Ess, M. (Ed). *Põllukultuuride ja nende sortide sobivus maheviljeluseks*. Jõgeva: Vali Press, 34−39.

Raudseping, M., **Bender, I.** (2006). Köögiviljandusalane teadustöö Jõgeval. *Aiandusfoorum 2006*. 23.03.2006, Paide. Tallinn: Eesti Põllumajandus-Kaubanduskoda, 20−21.

Bender, I. (2005). Tomati maheviljeluskatsed Jõgeval. Annamaa, K. (Ed). *Sordiaretus ja Seemnekasvatus. Teaduslikud tööd IX*. Jõgeva: Jõgeva Sordiaretuse Instituut, 147−152.

Bender, I., Vabrit, S., Raudseping, M. (2005). Tomatisortide lõhenemiskindlus Jõgeva Sordiaretuse Instituudi mahekatses aastatel 2001–2003. *Agronoomia 2005*. Tartu: Estonian Agricultural University, 120–122.

Bender, I., Raudseping, M., Vabrit, S. (2004). Ilmastikutingimuste mõjust hahkhallituse (*Botrytis cinerea* Pers.) esinemisele tomati kasvatamisel kütteta kilekasvuhoones. *Agronoomia 2004*. *Teadustööde kogumik*. Tartu: Estonian Agricultural University, 178–180.

Koppel, M., Tsahkna, A., **Bender, I**. (1998). Nematoodikindlate kartulisortide aretamisest Jõgeval. Annuk, K., Lember, A., Praks, J., Reintam, A., Saveli, O., Tikk, H., Viiralt, R. (Eds). *Akadeemilise Põllumajanduse Seltsi Toimetised 6*. Tartu: Akadeemiline Põllumajanduse Selts, 35−38.

Bender, I., Koppel, M. (1995). Mõnede kõrreliste heintaimede haiguskindlus seenhaiguste suhtes. Bender, A. (Ed). *Sordiaretus ja Seemnekasvatus VII*. Jõgeva: Jõgeva Sordiaretuse Instituut, 170–177.

Bender, A., Jaagus, M., **Bender, I**. (1990). Lutsernisordi 'Jõgeva 118' õite viljastumine. Johandi, E. (Ed). *Sordiaretus ja Seemnekasvatus.*

EMMTUI Teaduslikud Tööd LXIX. Saku: Eesti Maaviljeluse ja Maaparanduse Teadusliku Uurimise Instituut, 151−163.
Bender, A., Jaagus, M., **Bender, I**. (1989). Hariliku lutserni (*Medicago sativa* L.) ja hübriidlutserni (*Medicago varia* Mart.) fertiilsus ja isefertiilsus. Zaletajev, G. (Ed). *EMMTUI Teaduslikud Tööd LXIV*. Saku: Eesti Maaviljeluse ja Maaparanduse Teadusliku Uurimise Instituut, 93−101.

5.2. Conference abstracts not indexed by Thomson Reuters Web of Science

Bender, I., Annamaa, K., Michelson, A., Põldma, P., Rungis, D. (2019). Cultivation of potato onion (*Allium cepa* var. *aggregatum)* in Estonia. *Programme- and Abstract Book: NJF Conference on Horticulture 2019*. 10–12 June, 2019, Tartu, Estonia. Publicon, 22.
Bender, I. (2015). Enamkasvatatud köögiviljasordid, sordiaretus ja seemnekasvatus. Olevsoo, V. (Ed). *Aiandusfoorum 2015*. *Aiandusfoorum*, Randivälja, Tori vald, Pärnumaa, 26.02.2015, 22–25.
Anton, D., Matt, D., **Bender, I**., Kazimierczak, R., Luik, A., Püssa, T. (2013). Three-year comparison of antioxidant compounds in organically and conventionally grown tomato (*Lycopersicon esculentum* Mill.) cultivars. In: Kahl, Johannes; Rembialkowska, Ewa; Zaleka, Aneta; Lesiński, Grzegorz (Eds). *Book of Abstracts. Second International Conference on Organic Food Quality and Health Research,* 5–7 June, 2013, Warsaw, Poland, 75.
Bender, I., Ess, M., Matt, D., Moor, U., Tõnutare, T., Luik, A. (2009). Quality of organic and conventional carrots. *NJF Report: NJF Seminar 422: Fostering healthy food systems through organic agriculture - Focus on Nordic-Baltic Region.* Matt, D.; Peetsmann, E. (Eds). 25–27 Aug, 2009, Tartu, Estonia, 70.
Bender, I., Püssa, T., Anton, D., Luik, A. (2009). Comparison of the chemical composition of conventionally and organically produced tomatoes. *NJF Report, NJF Seminar 422. International Scientific Conference: Fostering healthy food systems through organic agriculture – Focus on Nordic-Baltic Region.* 25–27 Aug, 2009, Tartu, Estonia, 70.
Annamaa, K., **Bender, I.** (2009). Characterisation and evaluation of Estonian tomato (*Lycopersicon esculentum* L.) genetic resources. *Book of Abstracts: 19th EUCARPIA genetic resources section meeting*. 26-29 May, 2009, Ljubljana, Slovenia, 86.

Bender, I. (2007). Influence of organic mulches on tomato fruit weight in organic cultivation. *NJF 23rd Congress: Trends and Perspectives in Agriculture.* 26-29 June 2007, Viborg, Denmark, 338−339.

Bender, I., Vabrit, S., Raudseping, M. (2006). Gray mold occurrence on tomato plants in conventional and organic cultivation. *Programme and Abstracts: Development of Environmentally Friendly Plant Protection.* 5–7 Sept, 2006, Pühajärve, Estonia. Tartu: Estonian Agricultural University, 22.

Vabrit, S., Leedu, E., **Bender, I**., Suigusaar, K. (2005). Effect of sewage sludge and big manure compost on the ornamental qualityof impatiens 'Candy Coral Bee' container grown plants. *Program and Abstracts: International Symposium on Growing Media.* 4–10 Sept, 2005, Angers, France, 114.

Bender, I., Vabrit, S., Raudseping, M. (2005). Effect of organic mulches on the growth of tomato plants and quality of fruits in organic conditions. *Program and Abstracts: International Symposium on Growing Media.* 4–10 Sept, 2005, Angers, France, 69.

Bender, I., Raudseping, M. (2003). Results of the presustainable trials in tomato cultivation. *Proceedings of the NJF's 22nd Congress Nordic Agriculture in Global Perspective.* 1–4 July, 2003, Turku, Finland. Finland: Tampere University Print, 241.

Jaagus, M., **Bender, I**. (1995). White clover varieties bred for grazing at Jõgeva Plant Breeding Institute, Estonia. *Seminar Notes: Recent White Clover Research and Development in Europe. Meeting: Recent White Clover Research and Development in Europe.* 28–31 Aug, 1995. Saku-Jõgeva-Tartu, Estonia, Tartu, 12.

6.3. Popular science articles

Bender, I. (2020). Tomati kasvatamisest ja Jõgeval aretatud sortidest. *Minu Aed*, 1, 68−71.

Bender, I. (2020). Avamaale istutage tomat juuni algul. *Postimees. Maa Elu*, 21, 15.

Bender, I. (2018). Suurepärased Eestis aretatud aedherne ja oasordid. *Maakodu*, august, 70−72.

Bender, I. (2018). Aedherne sortide võrdlus mahe- ja tavaviljeluse katses. *Mahepõllumajanduse leht*, 83, 8−9.

Michelson, A., Banner, A., Annamaa, K., **Bender, I**. (2017). 'Kõpu', 'Viiner'', 'Kihnu kirju' ja teised vanad sordid. *Eesti Loodus*, 4, 46−49.

Bender, I. (2016). Jõgevalt tulevad uued köögiviljasordid. *Maaleht; Messileht,* 14. aprill 2016, 11.
Bender, I. (2016). Uudse köögiviljade kasvatustehnoloogia katsetamine Jõgeval. *Mahepõllumajanduse Leht* ,72, 12.
Bender, I. (2015). Tunne ära: haigused tomatimajas. *Targu Talita. Maalehe nõuandelisa*, 32, 492–493.
Bender, I. (2014). Katmikalade maheviljelus huviorbiidis. *Mahepõllumajanduse leht*. 64, 5−6.
Bender, I. (2014). Pesasibul ja selle kasvatamine. *Maaleht: Messileht,* 17. aprill 2014, 28.
Bender, I. (2013). Tomati ABC kasvuhoones. *Maamajandus*, 5, 10−11.
Bender, I. (2011). Köögiviljakatsed Jõgeval. *Kodukiri*, *Aed*, mai/juuni, 44−46.
Bender, I. (2011). Tuntud ja hinnatud Jõgeva sordid. *Maamajandus*, mai, 16−18.
Bender, I. (2011). Köögiviljade tava- ja mahekasvatuse eripärad. *Maamajandus*, nov, 10−13.
Bender, I. (2009). 7 tõelist tomatisorti. *Kodu ja Aed*, 8, 78−79.
Bender, I. (2009). Maitsvad köögiviljad koduaia peenralt. *Maaleht: Messileht*.
Bender, I. (2008). Isegi kortermajas saab tomatit kasvatada. *Maaleht: Messileht*, 10. aprill, 31.
Bender, I. (2008). Kasvatagem kodumaiseid sibula-, kapsa-, porgandi- ja redisesorte. *Maaleht: Messileht*, 10. aprill, 32. .
Bender, I. (2008). Väikese koduaia köögiviljalapp. *Praktiline aiavihik, 11. Tarbeaed*. *Kodu ja Aed*, 21−26.
Bender, I. (2007). Tomativiljade lõhenemisest. *Mahepõllumajanduse Leht*, 41, 8–9.
Bender, I. (2006). Küüslaugukasvatus Vierala talus. *Mahepõllumajanduse Leht*, 35, 19.
Bender, I. (2006). Bioväetised tomatikasvatuses. *Mahepõllumajanduse Leht*, 37, 8−9.
Bender, I. (2005). Multšid tomati maheviljeluses. *Mahepõllumajanduse Leht*, 33, 6−7.
Bender, I. (2005). Tomati seenhaigused mahe- ja tavaviljeluse katsetes 2004. aastal. *Mahepõllumajanduse Leht*, 30, 4−5.
Bender, I. (2003). Tomati sordivõrdluskatsete tulemusi Jõgevalt. *Mahepõllumajanduse Leht*, 26, 2−3.
Raudseping, M., **Bender, I**. (2003). Aedhernes koduaias. *Aed*, 3, 56−58.

Raudseping, M., **Bender, I.** (2003). Aeduba koduaias. *Aed*, 4, 45−47.
Raudseping, M., **Bender, I**. (2003). Soovitusi sibulakasvatuseks. *SL Õhtuleht*, 19. märts, 16.
Raudseping, M., **Bender, I**. (2002). Soovitusi tomati kasvatamiseks. *SL Õhtuleht*, 20. märts, 17.

6.4. Popular science books

Bender, I. (2018). *Maalehe herne- ja oaraamat*. OÜ Hea Lugu.
Ardel, P., Tamm, I., Aavola, R., **Bender, I**., Ess, M., Narits, L., Tamm, S., Tamm, Ü., Ingver, A., Koppel, R., Tupits, I., Tsahkna, A., Vetemaa, A. (2017). *Mahepõllumajanduslik seemnekasvatus*. Eesti Mahepõllumajanduse Sihtasutus.
Bender, I. (2013). *Maalehe tomatiraamat*. Hea Lugu.
Aavola, R., Ardel, P., **Bender, I**., Ess, M., Narits, L., Tamm, I., Tamm, S., Tamm, Ü., Tupits, I. (2010). Mahepõllumajanduslik seemnekasvtus. Vetemaa, A., Mikk, M. (Toim). *Mahepõllumajanduslik seemnekasvatus*. AS Ecoprint, 1–11.
Tamm, I., **Bender, I.**, Narits, L., Aavola, R., Tamm, S., Tamm, Ü. (2008). *Mahepõllumajanduslik seemnekasvatus*. Tallinn: Põllumajandusministeerium.

VIIS VIIMAST KAITSMIST

HARES KHAN
PELAGIC CALCITE PRECIPITATION IN LAKES: FROM A GLOBAL TO A LOCAL PERSPECTIVE ON ITS DRIVERS AND IMPLICATIONS
KALTSIIDI AVAVEELINE SADENEMINE: PÕHJUSED JA TAGAJÄRJED GLOBAALSES JA KOHALIKUS VAATES
Doktor Biel Obrador (University of Barcelona, Hispaania), **doktor Alo Laas**
16. september 2021

MARGUS ARAK
CULTIVATION TECHNOLOGY FOR LOW-BUSH BLUEBERRY CULTIVATION IN MILLED PEAT FIELD PLANTATIONS
AMMENDATUD FREESTURBAVÄLJADEL KASVATATAVA AHTALEHISE MUSTIKA MASINVILJELUSTEHNOLOOGIA
Professor Jüri Olt
1. november 2021

LIINA JÜRISOO
DISTRIBUTION OF AND DAMAGES CAUSED BY DUTCH ELM DISEASE AGENTS IN NORTHERN EUROPE
JALAKASURMA LEVIK JA KAHJUSTUSED PÕHJAEUROOPAS
Professor Rein Drenkhan
11. november 2021

HEIKI LILL
NOVEL APPLICATION PRINCIPLES FOR ENERGY STORAGE TECHNOLOGIES IN NEARLY ZERO ENERGY BUILDINGS
ERINEVATE ENERGIA SALVESTUSTEHNOLOOGIATE UUDSED RAKENDUSPÕHIMÕTTED LIGINULLENERGIAHOONETES
Teadur Alo Allik, professor Andres Annuk
24. november 2021

PIRET RAUDSEPP
POLYPHENOLIC COMPOSITION OF RHUBARB (*RHEUM RHAPONTICUM L.*) AND BLACKCURRANT (*RIBES NIGRUM L.*), ANTIBACTERIAL AND FREE RADICAL SCAVENGING PROPERTIES OF THESE PLANTS IN COMPARISON WITH SOME OTHER FOOD PLANTS
HARILIKU RABARBERI (*RHEUM RHAPONTICUM L.*) JA MUSTA SÕSTRA (*RIBES NIGRUM L.*) POLÜFENOOLNE KOOSTIS, NENDE TAIMEDE ANTIBAKTERIAALSE TOIME JA VABADE RADIKAALIDE SIDUMISE VÕIME VÕRDLUS MÕNEDE TEISTE TOIDUTAIMEDEGA
Professor Tõnu Püssa, vanemteadur Ave Kikas
10. detsember 2021

ISSN 2382-7076
ISBN 978-9916-669-15-0 (trükis)
ISBN 978-9916-669-16-7 (pdf)