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ADOPTING CROP MODELS FOR GREENHOUSE PRODUCTION OF PEPPERS TOWARD INTEGRATED PEST MANAGEMENT

Nebojsa MOMIROVIC

University of Belgrade, Faculty of Agriculture, Serbia
(Corresponding author: emomirov@agrif.bg.ac.rs)

Abstract

Advanced vegetable production under protected conditions have accomplished by multifunctional integration of several methods and techniques in order to get produce for fresh consumption with an added biological value. This paper deals with recent achievements in the field of integrated, biological and organic vegetable production and possibilities for biological control of common pests and diseases in different crop models. The usage of modern greenhouse covering films and mulch films has afforded several benefits in more precise control of microclimate fluctuations. Photo-selective plastic films could change the character and spectral composition of solar radiation, which leads to less pests and disease infection and better crop performances, such us earliness, fruit size and uniformity and cumulative and total yield.

Induced systemic resistance is one of the modes of action that allows soil born diseases suppression with regular application of organic composted amendments as well application of beneficial microorganisms: *Trichoderma harzianum*, *Bacillus subtilis*, *Bacillus amyloliquefaciens* etc. Besides its mycoparasitism, permanent exudations of enzymes and bioactive ingredients after roots colonization have influenced the decrease of inoculums presence and disease susceptibility of the resistant varieties of peppers. Practical results of application of lactate peroxidase, phosphytes, other simple salts and biopreparation, and bioactive ingredients have showed great possibilities for wide implementation of IPM, especially with advanced application techniques. By pheromone traps and usage of predators *Amblyseius swirskii*, *Orius laevigatus*, *Aphidius colemani*, as well application of oxymatrine extracted from *Sophora lutescens* we could manage good balance in biological protection under especially adopted and designed greenhouse conditions.

Keywords: *peppers, crop models, greenhouse microclimate, beneficial, predators,*

Introduction - Consumers perceptions and preferences to vegetable's origin, quality and cultural practice

Understanding how the environment and production and cultivation practices influencing the composition and quality of food crops being fundamental to the production of high-quality nutritious foods. Consumers demand healthy, bio, or organic products because they believe they are more flavorful and respectful to the environment and human health. High quality and health safety, high nutritive and biological value, high aesthetic values: color intensity, shininess, uniformity in shape and size, preferable aroma and taste, and finally high marketability; storability, transportability, the shelf life, these are the most important issues of vegetables marketing. Many research have been dedicated last decade to investigate the effects of conventional, integrated, and organic farming growing practice on quality of vegetables.

Vegetable nutritional quality is related to concentrations of antioxidants and other minerals. The results of Aghili et al., (2012) indicated that bell pepper is an excellent source of ascorbic acid and potassium for humans. Improved nutritional management in greenhouses could enhance micronutrient concentrations in this vegetable. Field-grown vegetables had lower contents of Cu, Mn, Fe, Zn, and ascorbic acid compared to greenhouse-grown vegetables, In general, the nutritional quality (contents of micronutrients and ascorbic acid) of greenhouse-grown vegetables was better than that of field-grown vegetables, although fruit micronutrient concentrations of field- and greenhouse-grown vegetables were lower than expected levels.

Reporting the effects of conventional, integrated, and organic farming, grown in a controlled greenhouse, on color, minerals, and carotenoids of sweet pepper fruits, Perez-Lopez et al., (2007) have proved that organic farming provided peppers with the highest intensities of red and yellow colors, contents of minerals, and total carotenoids. Integrated fruits presented intermediate values of the quality parameters under study, and conventional fruits were those with the lowest values of minerals, carotenoids, and color intensity. As an example, the concentrations of total carotenoids were 3231, 2493, and 1829 mg kg $^{-1}$ for organic, integrated, and conventional sweet peppers, respectively. Finally, organic red peppers could be considered as those having the highest antioxidant activity.

In 3-year study Chassy et al., (2006), were measured total phenolics, percent soluble solids, ascorbic acid, and the flavonoid aglycones quercetin, kaempferol, and luteolin in two varieties of tomatoes and two varieties of bell peppers grown by certified organic and conventional practices. Significantly higher levels of soluble solids (17%), quercetin (30%), kaempferol (17%), and ascorbic acid (26%) were found in Burbank tomatoes. Bell peppers were influenced less by environment and did not display cropping system differences. Cultivars and growing conditions seems to play an important role in affecting the metabolism of antioxidant components and antioxidant capacity. Deepa et al. (2006) have reported results of ten cultivars of red sweet peppers grown over two consecutive years with regard to ascorbic acid, total reducing content, β-carotene, total antioxidant activity and free radical scavenging activity. All cultivars fulfilled common requirement for vitamin C, but only some of them excelled in terms of β-carotene.

It is obvious that greenhouse production of vegetables should go to a certain level of ecologization, trying to imitate natural ecosystems in their balance and sustainability, where biological plant protection have a crucial importance for successful implementation of modern growing practices.

Modeling greenhouse performance for passive energy efficiency and optimal microclimate control

The development of energy conservative greenhouse systems is the overall result of improvement of greenhouse construction, cladding materials and insulating techniques, innovative climate control equipment and implementation of physical and physiological knowledge in the operational climate control systems (Bakker et al., 1995; Bakker, 2006). The development of these systems represents an optimization problem and the use of both physical as well as physiological information and models have shown to be a most powerful tool in dealing with these issues. A control philosophy is described for maximizing the financial margin between the value of a greenhouse crop and the cost of controlling the greenhouse climate. This uses physical models, which describe how the conditions inside the greenhouse are influenced by external conditions, to determine the inputs necessary to create the internal climate. Biological models are used to predict the influence of the climate on crop production. Economic models provide input costs and crop market value. These models are used in an optimization algorithm to determine the values of specific climate variables which maximize the financial margin. The algorithm will operate in real time in the greenhouse climate controller to reduce the cost of greenhouse heating by optimizing the closing and opening thermal screens, and by controlling heating on the basis of integrated air temperature.

Sweet pepper production is characterized by large fluctuations in fruit yield per week. Buwalda et al., (2006) had described a dynamic, calibrated model which was able to simulate the measured data fairly well, in particular the yield fluctuations, in order to improve chain's supply efficiency that requires farmers to supply production forecasts several weeks in advance. Yield prediction was helpful for efficient labor planning, while the results obtained in research of Van Henten et al., (2006) indicate that fluctuations in sweet pepper production can be reduced using optimized temperature strategies, either by controlling production in one part/block or by controlling production in opposite phase in two different parts.

For the continental climate of Serbia (Momirovic et al., 2010) passive methods (double inflation plastic, IC screens and covers, transparent water tubes, mulching, shading) for optimization energy efficiency of advanced tunnel's production have enormous influence on its sustainability

Baille et al., (2006) have analyzed the night energy balance of an air-heated greenhouse in mild-winter climatic conditions of Almería, south-eastern Spain. In their conclusion the measures to improve the energy efficiency would be: (i) to improve the air tightness of the greenhouse, (ii) to reduce radiation losses by means of thermal screens or IR-opaque plastic covering materials, and (iii) to increase the soil efficiency in storing solar energy and releasing it during the night.

Precise, highly efficient irrigation could also have enormous impact on energy efficiency of peppers production grown as protected crops, both because of cost and yield influence, as well heat transfer to the soil layers. Greenhouse grown white blocky and white conical peppers were used to develop recently introduced Time-Space deficit irrigation (TSDI), irrigation technique based on regulated deficit irrigation (RDI) and partial root zone drying (PRD) trough 3 drip laterals per each two-row beds covered by plastic mulch film.

By measuring plant growth, yield and irrigation water use efficiency Shao Guang-Cheng et al., (2010) was concluded that it is difficult generally to apply TSDI for increasing vegetative biomass but with it is possible to prevent crop yield reduction or to improve crop quality. The ultimate profitability of a given watering regime for plant growth in the greenhouse requires fine-tuning of the pattern and level of water supply to the plant response during different stages.

Management of solar radiation toward better environmental conditions and less pressure of pests and diseases

Because of the inability to cure plant virus diseases and the need to protect the environment from toxic pesticides, alternative indirect strategies of disease control are required. In recent decades, virologists have developed non-pesticide, cultural control practices aimed at reducing the damage caused by these virus diseases by interrupting their epidemiological cycle. Accumulated data on the insects search for the host plants and environment associated with visual communication by insect vectors have facilitated the development of cultural practices that interfere with their search, landing and orientation to the crop (Antignus et al., 1996a).

Modern PE films has afforded several benefits in greenhouse climate control, significant savings of resources, machines and labor cost, as well as efficient control of plant diseases and pests (Momirovic et al., 2011). Photo-selective films could have significant application in Integral Pest Management Systems for vegetables, fruits, flowers and herbs.

Many authors have reported benefits of these materials decreasing incidence of pests and diseases (Antignus et al., 1996b, Antignus, 2000, Elad et al., 1997).

Antivirus (UV blocking) films have decreased application of pesticides for the suppression of aphids, white fly, thripses, leaf miners and other pests and affording efficient pollination and biological protection. Effects of particular films application and methods of its combination in order to achieve better energy efficiency of the protected cultivation of horticultural crops (Momirovic et al., 2010) In addition to conventional polymers used in agriculture for greenhouses and mulches such as PE, PVC, EVA, photo-selective and luminescent polymers have been used, in order to improve the quality of crops. For the same reason plastic nets are used mainly in countries with tropical and Mediterranean climates. For an environmentally friendly agricultural activity, an alternative strategy can be represented by bio-based agricultural raw materials. For low environmental impact applications, biodegradable materials for agricultural films are nowadays produced (Scarascia-Mugnozza, ey al., 2011).

The individual and joint effects of covering the soil with polyethylene mulch before planting and fungicides commonly being used by organic growers on tomato late blight (caused by *Phytophthora infestans*), while in peppers *Botrytis cinerea* is the main problematic disease. According to Shtienberg et al., (2010) application of fungicides resulted in inconsistent and insufficient late blight suppression (control efficacy +/- standard error of 34.5 +/- 14.3%) but the polyethylene mulch resulted in consistent, effective, and highly significant suppression (control efficacy of 83.6 +/- 5.5%) of the disease. It was found also that the type of polyethylene mulch used (Al-Or, clear, or black) did not affect the efficacy of late blight suppression. The disease-suppressing effect of mulch appeared to come from a reduction in leaf wetness duration, because mulching led to reductions in both the frequency of nights when dew formed and the number of dew hours per night when it formed. Mulching also reduced relative humidity in the canopy, which may have reduced sporulation.

Reflected diffused light could have great impact on yield and performance of several vegetable crops, due to a spectral interception (Kasperbauer and Hunt, 1998;. Kasperbauer et al., 2007), as well different soil temperature regime (Momirovic and Savic, 2007).

Soil microbial activity and Induced Systemic Resistance-(ISR)

Enriching soils permanently with composted organic manure characterized by high concentrated microbial activity, except fertility and aggregate stability could participate also with lower soil born disease potential. History of organic amendment use to suppress plant diseases is abundant (Hoitink and Boehm, 1999). In most cases, there is no single mechanism controlling plant diseases in any given plant growing system; rather several mechanisms operate concurrently to suppress plant diseases. A recent literature review on biologically and organic matter mediated disease suppression highlights several predominant mechanisms (Stone et al., 2004): competition for energy and nutrient sources and for organic matter substrate colonization. antagonism, competition for root colonization and induced systemic resistance (ISR) or systemic acquired resistance (SAR).

Warman (2005) by his study have demonstrated that the long-term use of compost can produce similar yields and elemental analysis for most crops in compost- amended and conventionally-fertilized soils. On the other hand, combined application of boat composted manure and beneficial microbial: *Bacillus subtilis, Bacilus amyloliquefaciens, Trichoderma harzianum* etc. especially after few years of permanent application could lead to a certain decrease or total avoidance of chemical pesticides.

The best explanation of several modes of action on roots infected by bacterial have been revived by Compant et al., (2005). *Trichoderma spp.* are free-living fungi that are common in soil and root ecosystems. Recent discoveries show that they are opportunistic, avirulent plant symbionts, as well as being parasites of other fungi. Root colonization by *Trichoderma* spp. also frequently enhances root growth and development, crop productivity, resistance to abiotic stresses and the uptake and use of nutrients (Harman et al., 2004). Ahmed et al., (2000) were studied the effect of pepper seed and root treatments with *Trichoderma harzianum* spores on necrosis caused in stems by *Phytophthora capsici* inoculation and on the course of capsidiol accumulation in the inoculated sites. The results indicate that seed treatments significantly reduced stem necrosis, which fell by nearly a half compared with the values observed in plants grown from non-treated seeds. Necrosis was also reduced in plants whose roots were drenched with various doses of *T. harzianum* spores, although the extent of necrosis was not correlated with the dose used.

Elicitation of induced systemic resistance (ISR) by plant-associated bacteria was initially demonstrated using *Pseudomonas* spp. and other gram-negative bacteria (Kloepper et al., 2004).

Published results are summarized showing that specific strains of the species *B. amyloliquefaciens, B. subtilis, B. pasteurii, B. cereus, B. pumilus, B. mycoides*, and *B. sphaericus* elicit significant reductions in the incidence or severity of various diseases on a diversity of hosts. Protection resulting from ISR elicited by *Bacillus* spp. has been reported against leaf-spotting fungal and bacterial pathogens, systemic viruses, a crown-rotting fungal pathogen, root-knot nematodes, and a stem-blight fungal pathogen as well as damping-off, blue mold, and late blight diseases. ISR elicited by several strains of *Bacillus* spp. is independent of salicylic acid but dependent on jasmonic acid, ethylene, and the regulatory gene. Ramirez and Kloepper, (2010) have studied the effect of soil P-related properties and inoculum concentration on plant growth promotion by the phytase-producing strain *Bacillus amyloliquefaciens* FZB45. Significant interaction between P regime and bacterial inoculation was found. FZB45.

Trichoderma harzianum could be used (Elad et al., 1993) for spaying vegetable crops with concentrations 1g l^{-1} plus surfactant, to achieve up to 90% of control fruit and stem grey mould. Populations of *T. harzianum* were on a level of 3×10^5-8×10^5 c.f.u. per leaf and ten times lower on one fruit. They remained high after the second and third sprays. Conditions favoring the ability of *T. harzianum* to control grey mould were temperatures above 20°C and relative humidity between 80 and 97%. Another treatments with amino-acids, see-weeds extracts, phosphytes, as well lactate-peroxydase, potassium iodide, potassium-thiocyanate, or *Aureobasidum pullulans* yeast strains, could afford very successful protection against diseases.

Predator’s activity and their role to achieve certain threshold level of biological protection

Among several pests attacking greenhouse crop of peppers, by far, thripses could affect severely, both the yield and quality of fruits, as well could transmit several viral diseases. Knowledge of thrips population dynamics in relation to temperature can be used to its successful control. In order to have monitoring, both blue and yellow sticky plates and films being used frequently with pheromone attractant as it is Lurem.

The use of *Amblyseius swirski* (*Neoseiulus swirski*) and *Orius laevigatus* has proved to be successful in the control of thrips and tomato spotted wilt virus (TSWV) incidence. In the Southeast of Spain, about 10 000 ha of sweet pepper are grown in plastic houses, in the provinces of Almeria, Murcia and Alicante as have reported Sanchez et al. (2000). Out of 1300 ha in Israel amost 1000 ha is under IPM control with biological protection against thripses. After introduction of *Amblyseiuss cucumeris* which was successful in reducing the increase of thrips populations in the first few months with lower temperature, we are now in position to use *Amblyseiuss swirski* which is much more sustainable in hot and dry climate conditions. Most of the other pests are controlled by natural enemies too.

Frankliniella occidentalis (Pergande) and *Thrips tabaci* Lindeman (*Thysanoptera: Thr*ipidae) are major pests of sweet pepper for direct damage and tospovirus transmission. To control their infestations, *Orius laevigatus* (Fieber) (*Heteroptera: Anthocoridae*) is produced by many commercial insectaries and widely used on IPM vegetable crops of Europe. This predator is naturally widespread along the Mediterranean and Atlantic coasts, and not in more continental areas, where other *Orius* spp. are more common. Bosco et al., (2008) were conducted research in a continental area of Northwest Italy to access the natural presence of anthocorids on pepper, and to compare their colonization and predatory ability with those of the species artificially introduced. *O. laevigatus* was rarely found and only in the greenhouses in which it had been released. However, its introduction resulted in thrips control before natural colonization by the native species occurred.

Population dynamics of *Frankliniella occidentalis*, *Thrips tabaci*, and *Orius spp*. were studied by Tavela et al., 2008 in sweet pepper crops, northwestern Italy, and best control was achieved by *Orius laevigatus*, which was abundant in greenhouses that practiced integrated pest management (IPM). *O. laevigatus* could overwintered in Mediteranian area on flowering plants (e.g., *Eriobotrya japonica, Rosmarinus officinalis*, and *Vicia faba*), and in the spring, the adults spread to wild and cultivated plants both outside and inside greenhouses. *O. laevigatus* adults appeared naturally inside sweet pepper greenhouses in June and effectively controlled thrips, but it suppose to be late. The minimum night temperature allowing *Orius* introduction is 16-17^{o}C, Thrips populations decreased rapidly and disappeared after 20–30 days. Predator populations increased and reached their maximum in August. *O. laevigatus* remained in the sweet peppers even at very low levels of thrips and fed on pollen. When high thrips infestations occurred, *O. laevigatus* was introduced as a control agent (1-2 adult/m^2). Good results were obtained at 25°C when the sweet pepper plants were in flower and covered with foliage.

As a cultural control strategy for reducing the spread of non-persistently transmitted aphid-borne viruses, barrier crops have been used since the early 1950's in Spain (Fererras , 2000), and since then, this strategy has been investigated by several authors, resulting in a wide range of divergent conclusions on its effectiveness. The barriers acted as natural 'sinks' for non-persistent viruses and did not reduce the number of aphids landing in the protected crop, as suggested by some authors. It is concluded that use of barrier crops can be an effective crop management strategy to protect against virus infection, but only under specific circumstances. Barley crop barrier oftenly being used in sweet pepper crops (Pineda and Marcos-Garcia, 2008).

Aphidius colemani Viereck*, Aphidius matricariae* Haliday (*Hymenoptera: Aphidiidae*) are the main parasitic wasps used for biological control of aphids (Dik et al., 2002). Since some aphid species has a very high rate of development and it is able to increase up to 12 times per week, we need to develop population of parasitic wasps very fast by increasing air temperature up to 25^{o}C for *A. colemani* and up to a 30 ^{o}C, for *A. matricariae*. Several experiments have shown that the aphid parasitoid *A. matricariae* performs better and faster as compared to *A. colemani* on *Myzus* species. The tobacco aphid *Myzus nicotianae*, a major problem in sweet peppers, is easily controlled.. The ratio of female wasp:aphid at the start should be approximatelly 1:20.

Against moths and caterpillars, especially *Ostrinia nubilalis*, very promising results we had achieved with oxymatrine, the natural extracts from *Sophora lutescens*, but we also could use *Bacillus thuringiensis var. kurstaki*. There is also very good effect against mites, so we are not forced to use chemicals as it is Nissorun and Torque.

Possibilities and constraints among crop models intensity toward integrated pest management and full ecologization of greenhouse peppers production

Long term studies and practical achievements with particular pilot projects among main growing regions in Serbia have resulted by significant export increase and price high enough to cover certain improvements in greenhouse practice. Opposite to a standard crop model with soil production of peppers in walking plastic tunnels, advanced systems were good enough to accept integrated pest management or full biological protection, predominantly because of optimized microclimate control.

Table 1. Long-term performance of different crop models of greenhouse peppers in Serbia

Production / Crop model	Total yield (kg/m^2)	Healthy status	Quality range	I class shares (%)	Average bottom price (EUR/kg)
A) Soil production / Simple tunnels	7	+/-	*	50	0,30
B) Soil production / Advanced tunnels / Spanish system	14	+	**	65	0,45
C) Soil production / Double inflated plastic / Trellising / Additional heating	20	++	****	75	0,65
D) Hydroponic on coco-peat / Modern greenhouses / Full heating	25	+++	*****	85	0,85

Testing different crop models on the way to its full sustainability

Following average yield, quality and price dynamics data, then after with appropriate cost calculations and trough few economics issues, we could confirm high profitability, as well low risk of advanced crop models, comparing to a standard crop model of pepper production. It is clear that based on domestic market, crop model B had the lowest risk regarding price and yield break even points, while for export purpose both soil and coco-peat grown peppers with heating are the crop models generating higher profit. Comparing results with sensitivity analysis by Jovicich et al. (2005) for colored blocky peppers hydroponically grown in pots, we could see similar results. Variation of the yield data had shown range between 7 and 15 kg m^{-1}. Based on the yield of 13 kg m^{-1}, breakeven point was 7,8 kg^{-1}, even expected price were bit higher.

Table 2. Break even points for yield and price of peppers among examined crop models

Crop models	Yield of peppers t ha^{-1}	Price EUR t^{-1}	Annual income EUR ha^{-1}	Peppers turnover EUR ha^{-1}	Yield breakeven point t ha^{-1}	Price breakeven point EUR t^{-1}
Model A	70	350,0	37.000,0	24.500,00	69,09	345
Model B	140	650,0	123.000,0	91.000,0	84,54	393
Model C	200	800,0	160.000,0	160.000,0	152,31	609
Model D	250	1.000,0	250.000,0	250.000,0	171,46	686

Conclusions

This article reweaving the modern trends in precise conventional, integrated, and organic greenhouse production of peppers toward full ecologization of cultural practices and growing techniques. The practical achievements in this field have shown great possibilities of vegetables growers in Serbia and in the region to achieve certain level of quality and to respond on high expectations in fresh consumption of vegetables regarding human health implications and benefits. Sustainable crop models of greenhouse production of peppers that could accept integrated pest management methods are based on advanced growing techniques with higher energy efficiency, enabling growers to have longer production cycle and higher yields, as well precise microclimate control to avoid infection and to keep well balanced biological protection against common pests and diseases.

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References

Aghili, F.A., Khoshgoftarmanesh, H., Afyuni, M., Mobli, M. (2012): Mineral and ascorbic acid concentrations of greenhouse and field-grown vegetables: implications for human health. International Journal of Vegetable Science, Vol. 18(1): 64-77

Ahmed, S.A., Sanchez, C.P., Candela, M.E. (2000): Evaluation of induction of systemic resistance in pepper plants (*Capsicum annuum*) to *Phytophthora capsici* using *Trichoderma harzianum* and its relation with capsidiol accumulation. European J. of Plant Pathology, Vol. 106: 817–824.

Antignus, Y., Mor, N., Ben Joseph, R., Lapidot, M., and Cohen, S. (1996). UV absorbing plastic sheets protect crops from insect pests and from virus diseases vectored by insects. Environmental Entomology, Vol. 25: 919-924.

Antignus, Y., Cohen, S., Mor, N., Masika Y., and Lapidot, M. (1996). The effects of UV blocking green house covers on insects and insect borne virus diseases. Plasticulture, Vol. 112: 5-20.

Antignus, Y. (2000). Manipulation of wavelength-dependent behavior of insects: an IPM tool to impede insects and restrict epidemics of insect-borne viruses. Virus Research, Vol. 71(1-2): 213-220.

Bakker, J.C., Bot, G.P.A., Challa, H., Van de Braak, N.J. (1995): Greenhouse climate control: an integrated approach. Wageningen Acad. Publ.: 1-279.

Bakker, J.C. (2006): Model application for energy efficient greenhouses in the Netherlands: greenhouse design, operational control and decision support systems. ISHS III Innt. Symp. on models for plant growth, Acta Horticulturae Vol. 718: 191-202.

Baille J., Lopez, A.C., Bonachela, S., Gonzalez-Real, M.M., Montero, J.I. (2006): Night energy balance in a heated low-cost plastic greenhouse. Agr. and Forest Meteorology, Vol. 137(1-2): 107-118.

Bosco, L., Giacometto, E., Tavella, L. (2008): Colonization and predation of thrips (*Thysanoptera: Thripidae*) by *Orius* spp. (*Heteroptera: Anthocoridae*) in sweet pepper greenhouses in Northwest Italy. Biological Control, Vol. 44(3): 331-340.

Buwalda, F., van Henten, E.J., de Gelder, A., Bontsema, J., Hemming, J. (2006): Toward an optimal control strategy for sweet pepper cultivation -1. Dynamic crop model. ISHS Environmental control and farm management in protected cultivation, Acta Horticulturae, Vol. 718: 367-374

Compant, S., Duffy, B., Nowak, J., Clement, C., Barka, E.A. (2005): Use of plant growth-promoting bacteria for biocontrol of plant diseases: principles, mechanisms of action, and future prospects. Appl. Environ. Microbiol. Vol. 71: 4951–4959.

Chassy, A.W., Bui, L., Renaud, E.N.C., Van Horn, M., Mitchell, A.E. (2006): Three-Year Comparison of the Content of Antioxidant Microconstituents and Several Quality

Characteristics in Organic and Conventionally Managed Tomatoes and Bell Peppers.J. Agric. Food Chem., Vol. 54(21): 8244–8252.

Deepa, N., Kaur, C., Singh, B., Kapoor, H.C. (2006): Antioxidant activity in some red sweet pepper cultivars. Journal of Food Composition and Analysis, Vol. 19(6–7): 572–578.

Dik, A.J.,Ceglarska, E., Ilovasi, Z. (2002): Sweet peppers. IPM in greenhouse Crops, Developments in Plant Pathology, Vol. 14(V): 473-485.

Elad Y. (1997). Effect of solar light on the production of conidia by field isolates of *Botrytis cinerea* and on several diseases of greenhouse grown vegetables. Crop protection, Vol. 1(7): 635-642.

Elad, Y., Zimand, G., Zaqs, Y., Zuriel, S., Chet, I. (1993) Use of *Trichoderma harzianum* in combination or alternation with fungicides to control cucumber grey mould (*Botrytis cinerea*) under commercial greenhouse conditions. Plant Pathol. Vol. 42: 324–332.

Fereres, A. (2000). Barrier crops as a cultural control measure of non-persistently transmitted aphid-borne viruses. Virus Research, Vol. 71(1-2): 221-231.

Harman, G.E., Howell, C.R., Viterbo, A., Chet I., Lorito, M. (2004): *Trichoderma species*-opportunistic, avirulent plant symbionts. Nature Reviews Microbiology, Vol. 2: 43-56

Hoitink, H.A.J., and Boehm, M.J. (1999): Biocontrol within the context of soil microbial communities: A substrate-dependent phenomenon. Annual Review of Phytopathology, Vol. 37: 427-446.

Jovicich, E., VanSickle, Cantliffe1, D.J., Stofella, P.J. (2005): Greenhouse grown colored peppers: a profitable alternative for vegetable production in Florida. Hort. Tech., Vol. 15(2): 388-369.

Kasperbauer, M.J., Hunt, P.G. (1998). Far red lights affects photosithate allocation and yield of tomato over red mulch. Crop Science, Vol. 38: 970-974.

Kasperbauer, M.J., Louhrin, J.H., Wang, S.Y. (2007), Light reflected from re mulch ripening strawberries affects aroma, sugar, and organic acid concentrations. Photochemistry and Photobiology, Vol. 74(1): 103-107.

Kloepper, J.W., Ryu, C.M., Zhang, S. (2004): Induced systemic resistance and promotion of plant growth by *Bacillus* spp. Phytopathology Vol. 94:1259–1266,

Momirović, N., Savić Jasna (2007). Efekat primene različitih malč folija u plasteničkoj proizvodnji paprike. Zbornik radova II Simpozijum Inovacije u ratarstvu i povrtarstvu Zemun, Srbija

Momirović, N., Oljača, M., Dolijanović, Ž., Poštić, D. (2010). Energetska efikasnost proizvodnje paprike u zaštićenom prostoru u funkciji primene različitih tipova polietilenskih (PE) folija. Poljoprivredna tehnika, Vol. 35(3):1-13.

Momirović, N., Oljača, M., Dolijanović, Ž., Poštić, D. (2011): Primena polietilenskih folija u integralnim sistemima hortikulturne proizvodnje. Savetovanje o biotehnologiji sa međunarodnim učešćem, 16, Agronomski fakultet, Čačak: 39-46

Perez-Lopez, A.J., López-Nicolas, J.M., Núñez-Delicado, E., delAmor, F.M., Carbonell-Barrachina, A.A. (2007): Effects of agricultural practices on color, carotenoids composition, and minerals contents of sweet peppers, cv. Almuden. J. Agric. Food Chem., Vol. 55(20): 8158–8164.

Pineda, A., Marcos-Garcia, A. (2008): Introducing barley as aphid reservoir in sweet-pepper greenhouses: Effects on native and released hoverflies (Diptera: Syrphidae). *Eur. J. Entomol. Vol.*105: 531–535.

Ramirez, C.A., Kloepper, J.W. (2010): Plant growth promotion by *Bacillus amyloliquefaciens* FZB45 depends on inoculum rate and P-related soil properties. Biology and Fertility of Soils, Vol. 46(8): 835-844.

Sanchez, J.A., Alcazar, A., Lacasa, A., Llamas, A., Bielza, P. (2000): Integrated pest management strategies in sweet pepper plastic houses in the Southeast of Spain.

Proceedings of the meeting "Integrated Control in Protected Crops, Mediterranean Climate", Antalya, Turkey, Bulletin OILB/SROP 2000 Vol. 23(1): 21-30

Scarascia-Mugnozza, G., Sica, C., Russo, G. (2011): Plastic materials in European agriculture: actual use and perspectives. J. of Ag. Eng. - Riv. di Ing. Agr. Vol. 3: 15-28

Shao Guang-Cheng, Liu Na, Zhang Zhan-Yu, Yu Shuang-En, Chen Chang-ren (2010): Growth, yield and water use efficiency response of greenhouse-grown hot pepper under Time-Space deficit irrigation, Scientia Horticulturae,Vol. 126(2): 172–179

Shtienberg, D., Elad, Y., Bornstein, M., Ziv, G., Grava, A., Cohen, S. (2010): Polyethylene mulch modifies greenhouse microclimate and reduces infection of *Phytophthora infestans* in tomato and *Pseudoperonospora cubensis* in cucumber. Phytopathology, Vol. 100(1): 97-104.

Stone, A.G., Scheurell, S.J., Darby, H.M. (2004): Suppression of soil borne diseases in field agricultural systems: Organic matter management, cover cropping, and other cultural practices: 131-177. *In* Soil Organic matter in Sustainable agriculture. CRC Press. New York: 1-398.

Tavella, L., Alma, A., Conti, A., Arzone, A. (1996): Evaluation of the effectiveness of *Orius spp.* in controlling *Frankliniella occidentalis*. ISHS Tospoviruses and Thrips of Floral and Vegetable Crops, Acta Horticulturae Vol. 431: 499-506.

Van Henten, E.J., Buwalda, F., de Zwart, H.F., de Gelder, A., Hemming, J., Bontsema, J. (2006): Toward an optimal control strategy for sweet pepper cultivation -2. Optimization of the yield pattern and energy efficiency. ISHS Envinromental control and farm management in protected cultivation, Acta Horticulturae, Vol. 718: 391-398.

Warman, P.R. (2005): Soil Fertility, yield and nutrient contents of vegetable crops after 12 years of compost or fertilizer amendments. Biological Agriculture & Horticulture: An International Journal for Sustainable Production Systems, Vol. 23(1): 85-96.