ENERGY EFFICIENCY IMPROVEMENT OF GREENHOUSE TOMATO PRODUCTION BY APPLYING NEW BIOFERTILIZERS

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Abstract


Greenhouse tomato production in Bulgaria is extremely energy intensive; therefore the majority of producers grow tomatoes in greenhouses without heating. The aim of the research was to improve the tomato production energy effectiveness by using new technology conventional fertilization based on soil analysis and novel biofertilizers instead of manure. Two biofertilizers were used bacterial fertilizer BioLife (USA) and mycorrhizal inoculum Media Mix (USA). The application of biofertilizers to improve soil fertility combined with optimized use of synthetic fertilizers can increase the energy output with the yield which leads to an increased energy output-input ratio to 1.19 and 1.11 respectively. The energy output with the yield exceeds the energy inputs and energy gains of 19.45 GJ.ha\(^{-1}\) and 11.40 GJ.ha\(^{-1}\) are achieved. The results show that the total energy output (90.52 GJ.ha\(^{-1}\)) increased by 32.0% when BioLife was used and by 22.9% when Media Mix was used. Bacterial fertilizer, mycorrhizal inoculum and tomato fruits energy equivalents of 0.01 MJ.kg\(^{-1}\), 14.5 MJ.kg\(^{-1}\)and 1.2 MJ.kg\(^{-1}\) respectively have been established to allow an energy assessment of tomato production.

Key words: energy, energy productivity, tomato, greenhouses, mycorrhiza

Introduction

Tomato production in unheated greenhouses requires 157.2 GJ.ha\(^{-1}\) totals energy inputs (Mihov et al., 2008). Synthetic fertilizers and manure shares of the total energy expenses are respectively 21.2% and 15.4%, e.g. fertilization constitutes considerable part of the total energy inputs. The application of synthetic fertilizers in agriculture is associated with lots of disadvantages. Not only is the industrial production of fertilizers costly and depletes non-renewable resources but the over-reliance on synthetic fertilizers also leads to nutrient imbalance in the growth medium and excessive leaching of polluting nutrients into the environment. Application of manure is highly energy consuming procedure, which has a number of weaknesses, mainly because the manure contains weed seeds and soil pathogens.

It is widely recognised that microorganisms are a major component of the natural fertility of soils and they can influence plant growth, development, health, as well as nutrient and water uptake (Kennedy, 1999). The management of soil microbial community is an important aspect of successful and sustainable agriculture especially in cereal and vegetable crops (Artursson et al., 2006; Lucy et al., 2004).
A promising method for soil fertility management is the application of biofertilizers, containing beneficial soil microorganisms, which can increase nutrients availability in soils, especially N, P and micronutrients. In addition, soil microbes produce specific metabolites such as phytohormones, vitamins, enzymes, which stimulate root system development thus improving nutrient uptake by plants (Bi et al., 2003; Gamalero et al., 2004; Wu et al., 2005).

It was found that the increase of total tomato yield after application of biofertilizers comes as a result of the increase of the yield of standard production, therefore it was concluded that biofertilizers improve fruit market quality (Tringovska, 2004; Tringovska and Kanazirska, 2008).

The aim of this research was to improve the energy effectiveness of greenhouse tomato production by applying biofertilizers as ecologically friendly alternative for soil fertility management.

**Material and Methods**

Energy efficiency of the tomato production is the relation of output energy to input energy (Singh et al., 2002):

\[ R = \frac{E_{output}}{E_{input}} \]  

where: \( R \) the energy output-input ratio.

In practice we eliminate the solar energy in calculations and introduce the energy added by people:

\[ E_{input} = E_p + E_f + E_d + E_m + \ldots + E_{hp} \ (MJ\ \text{unit}^{-1}) \]

where: \( E_p \) the energy of plant protection products (MJ),
\( E_f \) the energy of fertilizers (MJ),
\( E_d \) the energy of diesel oil (MJ),
\( E_m \) the energy of machinery (MJ),
\( E_{hp} \) the energy of human power (MJ).

\[ EP = \frac{TY}{E_{input}} \ (kg\cdotMJ^{-1}) \]

where: \( EP \) the energy productivity (kg\cdotMJ^{-1}),
\( TY \) the tomato yield (kg\cdotha^{-1}).

The research was carried out at Maritsa Vegetable Crops Research Institute in the period between 2002 and 2004 in Venlo type unheated greenhouses with 3.2 m width of the spans. The scheme of tomato growing (variety Belle) was 40+90+60+90+40 cm (35.10^3 plants per ha). A new plan for fertilization with optimized use of synthetic fertilizers with the addition of biofertilizers was developed.

Two commercial biofertilizers were used BioLife and Media Mix. BioLife (BioL.I.F.E. Technologies USA) is liquid, concentrated bacterial fertilizer, containing a combination of 13 bacterial strains, while Media Mix (Plant Health Care USA) is mycorrhizal inoculum, containing spores of four species mycorrhizal fungi as well as N2-fixing and P-solubilizing bacteria, rock phosphates and humic acids (Tringovska, 2005).

Three variants were accepted in the investigation:
- **Variant V₀**: Control;
- **Variant V₁**: Application of bacterial fertilizer BioLife in dose 1.0 L.ha^{-1};
- **Variant V₂**: Application of 10.5 kg.ha^{-1} mycorrhizal inoculum Media Mix.

Basis technological schemes (electronic tables) were developed for the three variants to allow results comparison. The consumption of plant protection products, seedlings and all other subsidiary materials in all these technological schemes were the same. The distance from the farm to the glasshouse was 2 km.

All variants covered optimized plan for conventional fertilization where the total amount of the applied mineral fertilizers (in active ingredients) was decreased from 1466.0 kg to 650.5 kg in comparison with the average values applied by farmers, and the total energy equivalent reduced by 55.6% (Mihov et al., 2008).

In this research, the conventional fertilization was applied based on the initial nutrient content and was the same for all the three variants. The following nutrients were applied as fertilizers in a hectare area: 115.5 kg a.i. (active ingredient) nitrogen, 69.0 kg a.i. phosphorus, 366.0 kg a.i. potassium and 100.0 kg a.i. magnesium with total energy equivalent 11.39
GJ.ha\(^{-1}\). Bacterial fertilizer BioLife (Variant V\(_1\)) was applied by the drip irrigation system after transplanting, while mycorrhizal inoculum Media Mix (Variant V\(_2\)) was applied manually during transplanting.

The total energy consumption of plant protection products was 15.85 GJ.ha\(^{-1}\); of seedlings 0.016 GJ.ha\(^{-1}\); of water for irrigation 6.05 GJ.ha\(^{-1}\), of electricity 16.20 GJ.ha\(^{-1}\) and of plastic products 9.00 GJ.ha\(^{-1}\).

The energy inputs and outputs were converted from physical unit measures to forms of energy by using their energy equivalents. The energy equivalents of the biofertilizers and tomato were determined by the authors by using a calorimeter. The energy equivalents are 0.01 MJ.L\(^{-1}\), 14.50 MJ.kg\(^{-1}\) and 1.2 MJ.kg\(^{-1}\) for BioLife, Media Mix and tomato fruits respectively. The equivalents used in the research (Table 1) were accepted by some researchers in the evaluation of the energy inputs for greenhouse tomato production in Turkey (Ozkan et al., 2004, Canakci and Akinci, 2006, Hatirli et al., 2006).

### Results and Discussion

The inputs used in tomato production by applying biofertilizers are illustrated in Tables 2 and 3. The use of biofertilizers in protected tomato production leads to an increase in the material and energy consumption for bioproducts, diesel oil, machinery and human power. At Variant V\(_1\) the increase of diesel oil is 11.76% and the increase of human power is 0.13%, while at Variant V\(_2\) the increase is lower 6.22% and 1.57% respectively, because it is due to the greater machinery volume, load-upload and transport operations as a result of increased yield, especially in Variant V\(_1\).

The biofertilizers have small energy equivalents and their total energy inputs are very low. They are 0.01 MJ.ha\(^{-1}\) for BioLife and 152.25 MJ.ha\(^{-1}\) for Media Mix.

The results reveal that 8464.94-8598.20 h.ha\(^{-1}\) (19.47-19.76 GJ.ha\(^{-1}\)) of human power and 90.10-91.67 h.ha\(^{-1}\) (5.65-5.75 GJ.ha\(^{-1}\)) of machinery power are required to produce greenhouse grown tomatoes. Human power has the highest share of 19.68% average for all the three variants, followed by diesel oil (15.77%) and fertilizers (11.44%).

The parameters shown in Table 4 are interesting for the energy assessment. The total energy inputs needed to produce tomatoes in greenhouses without

<table>
<thead>
<tr>
<th>Consumption</th>
<th>Fertilizers total (a.i.), kg</th>
<th>Bioproducts, L, kg</th>
<th>Diesel, kg</th>
<th>Human power, h</th>
<th>Machinery, h</th>
<th>Seedlings, kg</th>
<th>Water for irrigation, m(^3)</th>
<th>Electricity, kWh</th>
<th>PE products, kg</th>
<th>Tomato fruits, kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fertilizers total (a.i.), kg</td>
<td>650.50</td>
<td>650.50</td>
<td>350.76</td>
<td>90.40</td>
<td>8464.94</td>
<td>8476.20</td>
<td>8598.20</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
heating on a hectare basis when good agricultural practices for plant nutrition are applied increase insignificantly from 98.45 GJ ha\(^{-1}\) to 100.30 GJ ha\(^{-1}\) (1.89%) in the case of BioLife (Variant V\(_1\)) and 99.81 GJ ha\(^{-1}\) (1.38%) in the case of Media Mix (Variant V\(_2\)). These results are demonstrated in a Figure 1, where it is also obvious that the energy inputs needed to produce one ton tomato decrease from 1.30 GJ t\(^{-1}\) to 1.01 GJ t\(^{-1}\) (22.31%) and to 1.08 GJ t\(^{-1}\) (16.92%) for the respective variants.

From another point of view, however, biofertilizers contribute to a considerable increase in the energy output with the yield (Figure 2). The total yield of tomatoes increases by 32.0% and by 22.9% in Variant V\(_1\) and Variant V\(_2\) respectively. The differences in the volumes of the yield are statistically significant at P<0.001.

As the energy output with the yield exceeds the energy inputs, energy gains of 19.45 GJ ha\(^{-1}\) in Variant V\(_1\) and 11.40 GJ ha\(^{-1}\) in Variant V\(_2\) are achieved.

**Table 3**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Variant V(_0)</th>
<th>Variant V(_1)</th>
<th>Variant V(_2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fertilizers total (a.i.)</td>
<td>11385.64</td>
<td>11385.64</td>
<td>11385.64</td>
</tr>
<tr>
<td>Bioproducts</td>
<td>0.01</td>
<td>152.25</td>
<td></td>
</tr>
<tr>
<td>Diesel, kg</td>
<td>14812.59</td>
<td>16555.00</td>
<td>15733.21</td>
</tr>
<tr>
<td>Machinery, h</td>
<td>5668.08</td>
<td>5747.71</td>
<td>5649.27</td>
</tr>
<tr>
<td>Human power, h</td>
<td>19469.36</td>
<td>19495.26</td>
<td>19775.86</td>
</tr>
</tbody>
</table>

**Table 4**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Variant V(_0)</th>
<th>Variant V(_1)</th>
<th>Variant V(_2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total energy inputs, GJ ha(^{-1})</td>
<td>98.45</td>
<td>100.30</td>
<td>99.81</td>
</tr>
<tr>
<td>Tomato yield, kg ha(^{-1})</td>
<td>75431.00</td>
<td>99568.92</td>
<td>92671.00</td>
</tr>
<tr>
<td>Total energy outputs, GJ ha(^{-1})</td>
<td>90.52</td>
<td>119.48</td>
<td>111.21</td>
</tr>
<tr>
<td>Energy intensity, MJ kg(^{-1})</td>
<td>1.31</td>
<td>1.01</td>
<td>1.08</td>
</tr>
<tr>
<td>Energy productivity, kg MJ(^{-1})</td>
<td>0.77</td>
<td>0.99</td>
<td>0.93</td>
</tr>
<tr>
<td>Energy output-input ratio [R]</td>
<td>0.92</td>
<td>1.19</td>
<td>1.11</td>
</tr>
</tbody>
</table>

The higher energy equivalent of tomato fruits found in our country has considerable contribution for this positive result.

Among the variants under investigation, Variant V\(_1\) has the highest energy output-input ratio. The control Variant V\(_0\) has the lowest output-input ratio. The energy output-input ratio, which shows by how much the output, exceeds the energy inputs (energy efficiency), increases by 29.3% to 1.19 in Variant V\(_1\) and by 20.6% to 1.11 in Variant V\(_2\). The results are compared with the results of investigators Ozkan and Hatirli from the countries in the region (Ozkan et al., 2004, Hatirli et al., 2006).

The use of biofertilizers, containing combinations of beneficial soil microorganisms lead to significant increase not only of the total yield, but also of the
early yield with 18.9% and 15.3% respectively for the Variant V₁ and Variant V₂ (Figure 2). The quantity of the early yield is also very important for the producers.

Conclusions

The results from the research show that by applying conventional fertilization based on soil analysis and novel biofertilizers instead of manure, the tomato yield can be increased by 32.0% when using bacterial fertilizer BioLife and by 22.9% when using mycorrhizal inoculum Media Mix.

The total energy input required for the tomato production per hectare in unheated greenhouses increase insignificantly by 1.88% with the application of BioLife and by 1.38% with the application of Media Mix; however they decrease by 22.31% and 16.92% respective per ton of production. The increase of the energy output with the yield leads to an increase of the energy output-input ratio to 1.19 and 1.11 units.

References


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