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Modelling the optimal capacity of an irrigation system using queuing theory

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Abstract: Modelling the optimal capacity of an irrigation system using queuing theory. The size and stability of yield per hectare of agricultural crops are greatly affected by climatic conditions, temperature, solar radiation, but especially the quantity and quality of rainfall, which for most agricultural crops is insufficient. Building large-scale irrigation systems is difficult in terms of investment, as well as operating costs. Claimed agricultural yields often do not emanate from a set of certain claims for each of the crops, but are only an estimate based upon empirical experience. Precise determination of these data is very difficult and without the use of exact mathematical methods and information technology would be virtually impossible. This work is dedicated to the creation of an analytical model, which would allow the determination of the optimal capacity of the irrigation system with respect to the crops and irrigation facilities.

Key words: irrigation system, queuing theory problem, analytical model, optimal capacity of irrigation system.

INTRODUCTION

Building large-scale irrigation systems is difficult in terms of investment, as well as operating costs. If the capacity of an irrigation system is insufficient, investment costs are saved, but the system will not always be able to fulfil the demand on the required probability of resulting requirements for the delivery of supplementary irrigation. This will reduce the yield of agricultural crops or, in the extreme case, may lead to avoidable damage to crops. If the capacity of the irrigation facility has to be resized, this will involve unnecessarily high investment costs and the capacity of the irrigation facilities will not always be sufficiently utilized. These two limit cases give sub-optimal exploitation and construction of irrigation works.

Solution of the mid- and large-scale irrigation is not possible to precisely and efficiently through traditional methods, without using the mathematical apparatus, modelling, simulation methods of resolution, and of course, without the use of modern computer technology.

If we look at the process of irrigation from the system’s standpoint, the entire irrigation system can be divided into two parts:
• crops that receive irrigation,
• the system that supplies irrigation.

The irrigation system and the irrigated crops are in the process of artificial humidification being the supplier and the customer. The humidity necessity for the plants is acting as the requirement for
a particular type of operator – the supply of the necessary supplementary irrigation amounts. The irrigation system is service station, which meets the requirement – irrigation delivers, or fails, if the capacity is not high enough. In this respect, the problem of determining the irrigation system capacity can be viewed as the problem of queuing theory – the entity from the resources entering into the system at fixed or random intervals. In our case, the entry requirements of plants are at random intervals. On entering the system operator the unit is operated on immediately if it is at least one free channel. Otherwise, the request may be lost.

Queuing theory deals with a large number of modifications to the process of queuing. According to the occurrence of crops that are watered in rotation, the following cases can be distinguished:

a) crops with the same economic efficiency occur in the rotation, this means that none of them is given priority for irrigation over other;

b) some crops have higher economic efficiencies, respectively failure of an irrigation dose can cause indelible damage to them, which means that the irrigation should be given priority.

Another division is imaginable – according to the number of crops in rotation, the possible length of waiting for the start of the delivery of irrigation benefits, and the number of service stations, sprinklers etc.

The queuing network consists of one or more service channels (station operator), which serve the requirements of flow entering the system. In most cases, the situation occurs in which the channels are not able to immediately meet the requirements, and so must either immediately leave the system unattended, or wait in the queue to release the channel.

Most of the queuing system has a stochastic character. A deterministic situation is in practice found only quite exceptionally. Therefore, the queuing theory is based on the theory of probability. The stochastic elements of the queuing model represent:

• input stream,
• time operator.

INPUT STREAM

The input stream of requirements is a random process in continuous time, but with discontinuous requirements. The main majority of queuing models describe the input stream by a Poisson distribution. The probability that the providing system access $k$ requirements for to the time interval $t$ is in the Poisson distribution given by:

$$P_k(t) = \frac{(\lambda \cdot t)^k}{k!} e^{-\lambda t}$$  \hspace{1cm} (1)

where $\lambda$ represents the inputs, the number of inputs per unit of time.

In terms of applications in queuing theory, it is essential that the intervals between inputs are exponentially distri-
buted. In terms of the model, practical application are important characteristics of independence, stationary and ordinary, which determine the conditions under which one is able to use the model with the Poisson distribution.

TIME OPERATOR
Time operator is the second important parameter in queuing system, which determines their capacity. There are several factors influencing the service time and therefore we need to consider it as the exponentially divided variant with distribution function:

\[ F(t) = 1 - e^{-\mu t} \]  \hspace{1cm} (2)

where \( \mu \) is the operator intensity, the number of processed events per unit time.

Exponential distribution of the time operator assumes that the majority of operator is realized for a short time.

Analytical solution of queuing models is difficult without certain simplifications. One of them is the assumption that the input is monitoring the Poisson distribution of the random variable. In irrigation, however, this is not always a satisfied condition of the input stream, which is fulfilled, e.g. irrigation in monocultures. In rotation with several types of irrigated crops there are some crops on the irrigated area for which the need for delivery of irrigation benefits in about the same time. There is therefore very likely a change the number of requirements, and vice versa. The change in one requirement is unlikely.

To determine optimal capacities in irrigation systems using analytical models, it is necessary to arrange such models, so that they answer the following questions:

- average length of queue?
- the expected average number of simultaneously irrigated acres?
- the expected average number of acres that do not require irrigation?
- the expected unused capacity of the irrigation systems?
- the average waiting time in the queue?
- the average number of requirements contained in the system?

In queuing theory, it is possible to define various models that define the irrigation system [Okenka, Palková 2004]. For example:

- An irrigation system with a limited number of requirements and without priorities for service and unlimited waiting time in a queue,
- An irrigation system with a limited number of requirements, without priority in the operation and reduced waiting times in a queue,
- An irrigation system with priority in the operation.

All mentioned models assume that input stream requests have a Poisson distribution. The process of artificial irrigation in the agricultural practice is most closely approximated to a queuing network model which represents a system with a prio-
rity in the operation in service. Because plants cannot wait for an unlimited period for the irrigation delivery their "request" can be satisfied also in the form of natural precipitation (thus the claim to a service station becomes extinct), in practice the model where waiting time for service is restricted fares far better. This requirement can be taken into account in the model by limiting the length of the queue. The service station refuses to abide to a request if there is already a request in the system \( l = N + m \). Among them there is \( N \) number being served and \( m \) is waiting in the queue for service. Whilst examining the service process in this model apart other variables, such as average length of waiting queue, the average number together with irrigated acres, the expected average number of acres which do not require irrigation and the expected unused capacity of irrigation system we are interested in variables, what is the probability of rejection requirements, i.e. the probability that in the system is \( l = N + m \) requires.

The model expects that part of the entering request in the system is preference in service. This priority is necessary in the case that water demand is emerging for those crops, which have great importance in economic terms, or irrigation failure causes major damage.

If the water demand occurs in alternative crops preferred for irrigation at the time when none of the operating stations is free, irrigation will not commence until after the completion of handling the crop without a priority in service. Marks parameter of input current as \( \lambda \) and parameter of the requests with the priority in the operation as \( \alpha \cdot \lambda \), the others marks as \( (1 - \alpha \cdot \lambda) \).

For the differentiation of the individual requirements in the mathematical model put in place the following marking \( P_{x,y,z} \):

- a) the index \( x \) indicates the nature of service requirements:
  - 0 – free system,
  - 1 – a request with the priority,
  - 2 – a request without priority,

- b) index \( y \) indicates the number of requests with priority in the operation, which are located in the system,

- c) the index \( z \) indicates the number of requirements without priorities contained in the system.

For example: \( P_{1,m,n} \) indicate that in the system is a request with priority and in the system there are \( m \) requests with the priority and \( n \) without a priority.

The differential equations describing this system are as follows:

\[
P_{110} + P_{201} = \left( \frac{\lambda}{\mu} \right) \cdot P_{0} \quad (3)
\]

\[
\alpha \left( \frac{\lambda}{\mu} \right) \cdot P_{0} + P_{120} + P_{211} = \left( 1 + \frac{\lambda}{\mu} \right) \cdot P_{110}
\]

\[
(1 - \alpha) \left( \frac{\lambda}{\mu} \right) \cdot P_{0} + P_{111} + P_{202} = \left( 1 + \frac{\lambda}{\mu} \right) \cdot P_{201}
\]
For the probability $P_1$, $m$, $n$ the value $m$ can vary in the range from $1, \infty$, $n$ in the range from $1, \infty$, for the probability $P_2$, $m$, $n$ value $m$ changes in the range $0, \infty$, $n$ from $1, \infty$.

Based on the system of differential equations we get the following attributes:

**a) The average length of waiting queue:**

- $M_{N_1}$ – for acres with the crops with priority in the operation,
- $M_{N_2}$ – for acres with the crops without priorities in the operation.

$$M_{N_1} = \frac{\alpha \cdot \rho^2}{1 - \alpha \cdot \rho} \quad (6)$$

$$M_{N_2} = \frac{(1 - \alpha) \cdot \rho^2}{(1 - \rho) \cdot (1 - \alpha \cdot \rho)} \quad (7)$$

**b) The average waiting time in queue:**

- $T_{N_1}$ – for acres with the crops with priority in the operation,
- $T_{N_2}$ – for acres with the crops without priorities in the operation.

$$T_{N_1} = \frac{\lambda}{(\mu - \alpha \cdot \lambda) \cdot \mu} \quad (8)$$

$$T_{N_2} = \frac{\lambda}{(\mu - \alpha \cdot \lambda) \cdot (\mu - \lambda)} \quad (9)$$
c) The average number of requirements contained in the system:

Acres with the crops with priority in the operation:

\[ (\overline{v} + \overline{k})_1 = \alpha \cdot \rho \frac{1 + \rho - \alpha \cdot \rho}{1 - \alpha \cdot \rho} \]  \hspace{1cm} (10)

Acres with crops without priorities in servicing:

\[ (\overline{v} + \overline{k})_2 = (1 - \alpha) \cdot \rho \frac{1 - \alpha \cdot \rho + \alpha \cdot \rho^2}{(1 - \rho) \cdot (1 - \alpha \cdot \rho)} \]  \hspace{1cm} (11)

where \( \rho = \frac{\lambda}{\mu} \)

\( P_k \) – the probability of the system appearance in the \( k \) state,
\( k \) – number of the state system,
\( m \) – the number of operated machines,
\( N \) – number of operating machines,
\( \lambda \) – the frequency of servicing requirements occurrence,
\( \mu \) – the frequency of processed requests.

CONCLUSION

The propagatory process in agriculture is determined by a large number of factors. Their influences are relatively difficult to quantify due to the fact that, in the majority of cases, they are largely random – stochastic, not deterministic and have dynamic characters. The modelling of this process by means of an economic-mathematical simulation on the basis of analytical methods requires a large amount of computational work even with certain assumptions. These relate mainly to the input stream of requirements and time operator. Our solution assumes that the input stream follows a Poisson and the time operator exponential distribution of a random variable.

To obtain the exact and in practice the useful results from solved models it would be necessary to determine exactly the input stream requirements for the delivery of irrigation amounts and the timescale delivery of required quantities by irrigation technology. From the point of view of practical coincidence with reality that means analytical solution does give us any answer. The significance of this solution, in terms of the optimal capacity planning of irrigation equipment, is evident. It is necessary to possess practical experience as in any other case of the application of a mathematical solution, whilst achieving the optimal capacity of the proposed system. These are so called “post-optimal” methods. The solving of simulation models also gives an adequate response to the project manager. Besides already mentioned questions it also answers the question of the size of the irrigation system downtime and this is in fact in the analytical solution classed as “the expected unused capacity of the equipment”.

REFERENCES


Streszczenie: Modelowanie optymalnej wydajności systemu nawadniającego przy użyciu teorii kolejek. Wielkość i stabilność plonu upraw rolniczych zależy w znacznym stopniu od warunków klimatycznych, temperatury, promieniowania słonecznego, a szczególnie od ilości i jakości opadów, które są niewystarczające dla większości upraw. Budowanie wielkich systemów nawadniania jest trudne ze względu na koszty inwestycyjne i eksploatacyjne. Podawane plony często nie dotyczą poszczególnych roślin, ale są szacowane na podstawie doświadczeń empirycznych. Dokładne określenie tych danych jest bardzo trudne i niemożliwe bez zastosowania metod matematycznych i technologii informatycznych. Celem niniejszej pracy jest opracowanie modelu analitycznego pozwalającego na określenie optymalnej wydajności systemu nawadniającego, z uwzględnieniem uprawianych roślin i wyposażenia do nawadniania.

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Effect of design and exploitation parameters of spreader on the quality of distributed nitro-chalk

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Abstract: Effect of design and exploitation parameters of spreader on the quality of distributed nitro-chalk. The paper presents statistical analysis of the results of measurements on the effect of spreading disk rotational speed, setting angle of disk vanes, number of vanes and their kind on size reduction of nitro-chalk expressed by the share of granules bigger than 1 mm.

Key words: disk spreader, nitro-chalk, disk rotational speed, setting angle of vanes, number of vanes, kind of vanes, size distribution.

INTRODUCTION
The yield of cultivated crops and its quality depend on agro-technical operations, which should be performed in proper time, sequence and with required precision. One of the basic agro-technical operations is mineral fertilizing, essential for proper development and growth of cultivated crops. It also affects decisively the size and quality of yield of the harvested crops (Czuba, Mazur 1988; Stępień 2001).

The disk spreaders are mainly used in mineral fertilizing. The hitherto investigations on the disk spreaders dealt mainly with: metering accuracy, regularity of distribution (Kamionka 1985; Winiarski 1979; Marshall 1989), working width (Kamiński J. 1996), the effect of granule size on regularity of distributed fertilizer (Kamiński E., Witek 1996), the effect of machine preparation by the operator, field contour, wind velocity and spreader’s design on regularity of distribution (Kamiński J. 1999), as well as physical properties of fertilizer granules (Kram 1990; Laskowski 1977).

The equally important problem is quality of distributed fertilizer (size distribution of granules during spreading), affected by design and exploitation parameters of the spreader.

MATERIAL AND METHODS
The granulated nitro-chalk was investigated according to PN-91/R55029 and PN-85/C87010 Standards. The test included filling of the spreader’s hopper with nitro-chalk and its spreading with the mounted disk, e.g. with the vanes of square cross-section. Then, there were changed operational parameters of the spreader: disk’s rotational speed (540, 610, 680, 750, 840 rpm), angle of vanes’ setting on the disk (L, S, P), number of vanes on the disk (2, 3, 4, 6). Each setting was repeated three times. The distributed fertilizer was subjected to sieve analysis on the grain size analyzer AWK.

The weight fraction in the analyzed sample was recalculated to the percent
The arithmetic mean was calculated of three subsequent repetitions.

The factory size distribution of nitro-chalk was taken as the basic sample.

The size distribution characteristic of granules bigger than 1 mm was taken as a criterion for evaluation of the effect of design and exploitation parameters on the quality of distributed nitro-chalk.

ANALYSIS OF INVESTIGATION RESULTS

To check significance of the effect of particular factors on fertilizer’s size distribution expressed by the share of granules above 1 mm, there was carried out the single-factor analysis of variance at significance level $\alpha = 0.05$. The following measuring variants were considered: speed – P (54, 61, 68, 75, 84), angle of vane setting – K (L – left, S – middle, P – right), number of vanes – L (2, 3, 4, 6), kind of vanes R (K – square, C – cylindrical) and their combinations.

The differences between particular levels of factors were determined with the use of Tuckey-Kramer procedure for multiple comparisons for non-orthogonal data (of unequal number of observations within the factor’s levels).

The analysis of particular main factors in combinations (Tab. 1) proved that all the main factors significantly influenced the degree of granule size distribution of the nitro-chalk. There were also found significant interactions between particular main factors, with the exception of combinations P × L and K × R.

Basing on carried out statistical analysis of measurements on the disk rotational speed, one can distinguish four homogeneous groups (Tab. 2). No statistically significant difference was found for speeds 540 and 610 rpm. Every subsequent increase in the disk rotational speed (680, 750 and 840 rpm) caused statistically significant decrease in the share of granules above 1 mm. Basing on the carried out investigations one can find that this decrease starts from 680 rpm.

Considering the effect of angle of vane setting on the mean share of nitro-chalk granules above 1 mm one can find occurrence of the three homogeneous groups (Tab. 3). The biggest share of granules above 1 mm was found for the left side setting of spreading vanes, while considerably lower shares were fund for the middle and right side settings.

The three homogeneous groups were also found for various number of vanes (Tab. 4). No distinct difference in granule size distribution was found for 4 and 6 vanes, while the significant difference was found for 2 and 3 vanes, as well as between 2 and 4 and 6 vanes.

Considering the effect of kind of vanes on the mean share of nitro-chalk granules above 1 mm one can find occurrence of the two homogeneous groups. The results of investigations showed considerable differences in the nitro-chalk granule size distribution for application of square and cylindrical vanes. The better breaking-up of granules was found for the square vanes (Tab. 5).

Among significant differences between the basic sample and the setting variants of investigated factors (combinations) at significant level $\alpha = 0.05$, ...
TABLE 1. Results of variance analysis on the effect of main factors and their combinations on nitro-chalk granule size

<table>
<thead>
<tr>
<th></th>
<th>Degrees of freedom</th>
<th>Sum of squares</th>
<th>Mean square</th>
<th>$F_{emp}$</th>
<th>Significance level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combinations</td>
<td>108</td>
<td>85163.78709</td>
<td>788.55358</td>
<td>20.13*</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Error</td>
<td>208</td>
<td>8146.83467</td>
<td>39.16747</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R – square</td>
<td>0.912691</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Main factors**

<table>
<thead>
<tr>
<th>Factor</th>
<th>Level</th>
<th>Sum of squares</th>
<th>Mean square</th>
<th>F emp</th>
<th>Significance level</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>4</td>
<td>14357.01972</td>
<td>3589.2549</td>
<td>91.64*</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>K</td>
<td>2</td>
<td>8077.80895</td>
<td>4038.90448</td>
<td>103.12*</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>L</td>
<td>3</td>
<td>12241.31601</td>
<td>4080.43867</td>
<td>104.18*</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>R</td>
<td>1</td>
<td>6050.08403</td>
<td>6050.08403</td>
<td>154.47*</td>
<td>&lt; 0.0001</td>
</tr>
</tbody>
</table>

**Interactions**

<table>
<thead>
<tr>
<th>Interaction</th>
<th>Degree of freedom</th>
<th>Sum of squares</th>
<th>Mean square</th>
<th>$F_{emp}$</th>
<th>Significance level</th>
</tr>
</thead>
<tbody>
<tr>
<td>P × K</td>
<td>8</td>
<td>1169.93100</td>
<td>146.24138</td>
<td>3.73*</td>
<td>0.0004</td>
</tr>
<tr>
<td>P × L</td>
<td>12</td>
<td>517.86306</td>
<td>43.15526</td>
<td>1.01</td>
<td>0.3601</td>
</tr>
<tr>
<td>K × L</td>
<td>6</td>
<td>5947.08597</td>
<td>991.18099</td>
<td>25.31*</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>P × K × L</td>
<td>24</td>
<td>3289.46450</td>
<td>137.06102</td>
<td>3.50*</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>P × R</td>
<td>4</td>
<td>1305.36555</td>
<td>326.34139</td>
<td>8.33*</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>K × R</td>
<td>2</td>
<td>139.14150</td>
<td>69.57075</td>
<td>1.78</td>
<td>0.1718</td>
</tr>
<tr>
<td>P × K × R</td>
<td>8</td>
<td>878.01105</td>
<td>109.75138</td>
<td>2.80*</td>
<td>0.0057</td>
</tr>
<tr>
<td>L × R</td>
<td>3</td>
<td>9077.89007</td>
<td>3025.96336</td>
<td>77.26*</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>P × L × R</td>
<td>12</td>
<td>2418.20174</td>
<td>201.51681</td>
<td>5.15*</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>K × L × R</td>
<td>4</td>
<td>1495.93251</td>
<td>373.98313</td>
<td>9.55*</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>P × K × L × R</td>
<td>13</td>
<td>2119.93260</td>
<td>163.07174</td>
<td>4.16*</td>
<td>&lt; 0.0001</td>
</tr>
</tbody>
</table>

* – statistically significant at $\alpha = 0.05$

TABLE 2. Division of mean share of nitro-chalk granules above 1 mm into homogeneous groups according to disk rotational speed

<table>
<thead>
<tr>
<th>Factor</th>
<th>Level of factor</th>
<th>Homogeneous groups</th>
<th>Mean ratio of granules &gt; 1 mm [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotational speed</td>
<td>540</td>
<td>×</td>
<td>47.82</td>
</tr>
<tr>
<td></td>
<td>610</td>
<td>×</td>
<td>45.48</td>
</tr>
<tr>
<td></td>
<td>680</td>
<td>×</td>
<td>36.38</td>
</tr>
<tr>
<td></td>
<td>750</td>
<td>×</td>
<td>30.35</td>
</tr>
<tr>
<td></td>
<td>840</td>
<td>×</td>
<td>22.95</td>
</tr>
</tbody>
</table>
the biggest differences were found for combinations: 84P3K, 84P6K, 75P3K, 75S3K, 75P6K, 61P6K (Tab. 6). Considering the upper limit of confidence, the possible (with 95% probability) difference in the share of granules above 1 mm between the basic sample and mentioned combinations can reach above 72%. Basing on most significant differences between mean values of size from 39.233 to 40.448 there was found that the real differences ranged from 7.295 to 72.386.

\[\text{TABLE 3. Division of mean share of nitro-chalk granules above 1 mm into homogeneous groups according to angle of vane setting}\]

<table>
<thead>
<tr>
<th>Factor</th>
<th>Level of factor</th>
<th>Homogeneous groups</th>
<th>Mean ratio of granules &gt; 1 mm [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angle of vane setting</td>
<td>L</td>
<td>×</td>
<td>46.86</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>×</td>
<td>32.69</td>
</tr>
<tr>
<td></td>
<td>P</td>
<td>×</td>
<td>28.79</td>
</tr>
</tbody>
</table>

\[\text{TABLE 4. Division of mean share of nitro-chalk granules above 1 mm into homogeneous groups according to number of vanes}\]

<table>
<thead>
<tr>
<th>Factor</th>
<th>Level of factor</th>
<th>Homogeneous groups</th>
<th>Mean ratio of granules &gt; 1 mm [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of vanes</td>
<td>2</td>
<td>×</td>
<td>46.63</td>
</tr>
<tr>
<td>Number of vanes</td>
<td>3</td>
<td>×</td>
<td>42.47</td>
</tr>
<tr>
<td>Number of vanes</td>
<td>4</td>
<td>×</td>
<td>39.05</td>
</tr>
<tr>
<td>Number of vanes</td>
<td>6</td>
<td>×</td>
<td>35.79</td>
</tr>
</tbody>
</table>

\[\text{TABLE 5. Division of mean share of nitro-chalk granules above 1 mm into homogeneous groups according to kind of vanes}\]

<table>
<thead>
<tr>
<th>Factor</th>
<th>Level of factor</th>
<th>Homogeneous groups</th>
<th>Mean ratio of granules &gt; 1 mm [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kind of vanes</td>
<td>K</td>
<td>×</td>
<td>31.63</td>
</tr>
<tr>
<td>Kind of vanes</td>
<td>C</td>
<td>×</td>
<td>41.31</td>
</tr>
</tbody>
</table>
TABLE 6. Combinations of biggest significant differences in the share of granules above 1 mm for basic sample and investigated variants of factors with application of Tukey–Kramer procedure

<table>
<thead>
<tr>
<th>Comparison between combinations</th>
<th>Difference between mean values</th>
<th>Limits of confidence interval for difference between mean values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic sample - 84P3K</td>
<td>39.233</td>
<td>7.295</td>
</tr>
<tr>
<td>Basic sample - 84P6K</td>
<td>39.377</td>
<td>7.440</td>
</tr>
<tr>
<td>Basic sample - 75P3K</td>
<td>39.416</td>
<td>7.478</td>
</tr>
<tr>
<td>Basic sample - 75S3K</td>
<td>39.758</td>
<td>7.821</td>
</tr>
<tr>
<td>Basic sample - 75P6K</td>
<td>40.421</td>
<td>8.483</td>
</tr>
<tr>
<td>Basic sample - 61P6K</td>
<td>40.448</td>
<td>8.511</td>
</tr>
</tbody>
</table>

Considering the effect of disk rotational speed and the angle of vane setting on the share of granules above 1 mm (Fig. 1), the biggest effect of middle vane setting and the best breaking-up of nitro-chalk were found over the entire range of the disk speed, when compared to other vane settings. An increase in disk rotational speed caused a decrease in the share of granules above 1 mm at the left-side and right-side settings of vanes.

Analyzing the effect of angle of vane setting and the kind of vanes (Fig. 2) one can find better breaking-up of granules for the square vanes, and no distinct difference in damage of granules at the right-side and middle vane settings. When the vanes were set oppositely to direction of the disk rotation (L), the difference caused by different shape of vanes amounted to 2.03%, while at the angle consistent to disk rotation (P) it was equal to 12.64%.

FIGURE 1. Changes in the share of nitro-chalk granules above 1 mm for various angles of vane setting and disk rotational speed
SUMMARY
The carried out statistical analysis of investigation results proved that all the main factors significantly influenced the quality of nitro-chalk spreading.

The difference in the share of granules above 1 mm between the research sample and particular combinations can exceed 72%.

REFERENCES


Streszczenie: Wpływ parametrów konstrukcyjno-eksploatacyjnych rozsiewaczy na jakość wysiewanego saletrzaku. Przedstawiono wyniki badań wpływu parametrów konstrukcyjno-eksploatacyjnych (prędkości obrotowej tarczy rozsiewającej, kąta ustawienia łopatek na tarczy, liczby łopatek na tarczy i rodzaju łopatek) na jakość wysiewanego saletrzaku. Jako kryterium oceny wpływu badanych parametrów rozsiewacza na jakość wysiewanego saletrzaku przyjęto charakterystykę granulometryczną o wielkości granu powyżej jednego milimetra. Analiza statystyczna wyników badań wykazała, że wszystkie czynniki główne w istotny sposób wpływają na jakość wysiewanego saletrzaku, a różnice w udziale granul

FIGURE 2. Changes in the share of nitro-chalk granules above 1 mm for various angles and kinds of vanes
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o wielkości powyżej jednego milimetrę pomiędzy próbą bazową a poszczególnymi kombinacjami może sięgać powyżej 72%.
Investigations on rehydration process of dried prunes, apples and strawberries obtained under industrial conditions

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Abstract: Investigations on rehydration process of dried prunes, apples and strawberries obtained under industrial conditions. The work aimed at investigating the course of rehydration process of dried prunes, apples and strawberries. The dried material was produced in a chamber drier under industrial conditions. Drying process consisted of three cycles: drying a bit, two-stage drying and two-stage secondary drying. Dried material was rehydrated in distilled water of temperature 20°C during 6 hours and in distilled water of 100°C during 2 hours. It is evident from obtained results that the applied drying conditions are more suitable for apples in respect of their quality.

Key words: drying, rehydration, prunes, apples, strawberries.

INTRODUCTION

Rehydration is a complicated process aimed at restoring dried material’s properties that were characteristic for a raw material prior to its initial processing and drying; it is achieved by the contact of dried material with water. During rehydration the following three processes occur simultaneously: absorbing of water by dried material tissues that results in an increase of its mass and volume, and rinsing out of water-soluble substances from material being rehydrated. The course of these processes depends on raw material properties and conditions of storage, preparation and the range of structural and chemical damage caused by drying [Krokida and Maroulis 2001; Lewicki 1998a]. Thus, the course of rehydration process reflects changes that occurred in the structure and composition of raw material plant tissues as a result of drying and preceded processing as well as a result of rehydration [Lewicki 1998b; Witrowa-Rajchert 1999]. These changes cause that product being dried does not achieve the raw material properties as a result of rehydration; it proves that drying process is irreversible [Krokida and Marinos-Kouris 2003]. Therefore, rehydration ability is one of the most important quality indices of dried food products.

This work aimed at investigating the course of rehydration process of dried prunes, apples and strawberries. The dried material was produced in a chamber drier under industrial conditions. In references one can find investigations on rehydration process of dried apples [Krokida and Marinos-Kouris 2003; Lee et al. 2006; Witrowa-Rajchert and Dworski 2006] and of strawberries [Woźnica
and Lenart 2005a, b]. However, the dried material was obtained under conditions different from that of this work. No works on prunes’ dried material rehydration were found in references.

MATERIAL AND METHODS

Prunes, apples and strawberries were dried in a chamber drier under industrial conditions. The drier cubic capacity amounted to 2 m³ and drier was equipped with a membrane heater; a single charge of raw material amounted to about 110 kg. The drying process consisted of three cycles and occurred as follows:

- I cycle lasted 4 hours and involved drying a bit at temperature 30ºC. Drying air recirculation amounted to 10% and its volume flow was equal to 1800 m³/h.

- II cycle lasted 8 hours and involved two-stage drying. The first stage lasted 4 hours and was performed at temperature 60ºC. Drying air recirculation amounted to 50% and its volume flow was equal to 1200 m³/h. The second stage of drying lasted 4 hours also, but was performed at 55ºC. Drying air recirculation amounted to 50% and its volume flow was equal to 1400 m³/h.

- III cycle lasted 6 hours and involved two-stage secondary drying. The first 3-hour stage was performed at 45ºC. Drying air recirculation amounted to 60% and its volume flow was equal to 1900 m³/h. At the second 3-hour stage drying air temperature was equal to 35ºC; air recirculation amounted to 60% and its volume flow was equal to 2000 m³/h.

Whole strawberries were dried, prunes with removed stones were divided into halves, while apples were cut into slices of thickness 12 mm.

Obtained in this way dried prunes, apples and strawberries were subjected to rehydration process in distilled water of temperature 20ºC. Dried material of prunes and apples was additionally subjected to rehydration in distilled water of temperature 100ºC. A kinetics of rehydration process at 20ºC was investigated for 6 hours. At intervals of 0.5, 1, 1.5, 2, 3, 4, 5, and 6 hours the rehydrated sample was separated from water, dried with an absorbent paper and weighed with accuracy 0.01 g. For each time there was determined a relative mass increment of rehydrated dried material, as a ratio of current sample mass to initial mass of dried material used subjected to rehydration. Determination of relative mass increment was repeated three times. The kinetics of rehydration process in distilled water of temperature 100ºC was investigated for 2 hours and the measurements were carried out after 10, 20, 40, 60 and 120 minutes.

Approximation of experimental data (in three repetitions) was performed with the use of following equations [Kaleta et al. 2008]:

\[
\frac{m_t}{m_0} = a + b \left[ \frac{1}{1 + b \cdot c \cdot \tau} \right] \quad (1)
\]

\[
\frac{m_t}{m_0} = A \left[ B - \exp(-C \cdot \tau) \right] \quad (2)
\]
where:
\( m_\tau \) – dried material mass being rehydrated at moment \( \tau \), kg,
\( m_0 \) – initial mass of dried material, kg,
\( \tau \) – time, h.

Empirical constants \( a, b, c, A, B, C \) were matched with the use of Statistica program.

Basing on the obtained equations there were calculated the balanced values of relative mass increments of dried material, that would have been achieved if rehydration process had lasted infinitely long. These values amounted to \( (m_\tau / m_0)_r = a + b \), \( (m_\tau / m_0)_r = A \cdot B \) respectively.

RESULTS OF INVESTIGATIONS AND THEIR ANALYSIS

Figure 1 presents diagram of changes in relative mass increment of strawber ries dried material during rehydration in distilled water of temperature 20°C. It is evident from the diagram that both empirical formulae (1) and (2) used for approximation of the obtained results of relative mass increment of strawberries dried material give good results, since determination coefficient for both equations amounted to 0.993. Both equations also approximated the remaining results with good accuracy and determination coefficient values ranged: for (1) formula 0.989–0.997, for (2) formula 0.989–0.998.

Figure 2 presents the course of changes in relative mass increment of dried material during rehydration. All investigated samples show the highest relative mass increment at the initial rehydration stage, then at further stage a water absorption by dried material slows down gradually due to approaching of hydrated samples to a state of equilibrium. The initial fast increment of absorption can be found especially during rehydration.
in water of temperature 100ºC, while rehydration at temperature 20ºC is more uniform and slower over the entire process than at 100ºC. This effect of water temperature during rehydration can be caused by an increase in water diffusion rate with temperature rise and, probably, by affected by temperature changes in the structure and chemical composition of dried material during rehydration. Connections between rehydration rate and water temperature call for additional explanations and will be further investigated. It is also evident from carried out investigations that among three investigated materials dried apples are characterized by a highest relative mass increment during rehydration at a given temperature, while prunes by a lowest one. It can suggest that the applied drying conditions were more favourable for apples in respect of their quality.

Figure 3 presents the measured values of relative mass increment of dried material after 6-hour rehydration in water of temperature 20ºC and after 2-hour rehydration at temperature 100ºC, and also the values of balanced relative mass increment of dried material assessed on the basis of equations (1) and (2) (different due to application of extrapolation). It is evident from the diagram that none of investigated samples reached an equilibrium state. Dried material of prunes and apples rehydrated for 6 hours in water at temperature 20ºC was the most remote from that state. It is also evident from the diagram that apples dried material is characterized by the highest values of balanced relative mass increment; this corresponds to the suggestion of Figure 2 – the applied drying conditions are more suitable for apples.
CONCLUSIONS

1. Approximation with formulae (1) and (2) of experimental data of relative mass increment of dried material of prunes, apples and strawberries during rehydration gives good results: determination coefficient ranged from 0.989 to 0.998.

2. Water temperature used for rehydration influence the course of that process – at higher temperature the dried material is moistened very quickly, especially at initial stage, while at lower temperature the process is uniform and slower.

3. Dried apples are characterized by highest relative mass increment during rehydration at a given temperature, while prunes by the least. It can suggest that the applied drying conditions are more suitable for apples in respect of their quality.

REFERENCES


Streszczenie: Badanie przebiegu procesu rehydratacji suszu ze śliwek, jablek i truskawek otrzymanego w warunkach przemysłowych. Celem pracy było badanie przebiegu procesu rehydratacji suszonych śliwek, jablek i truskawek. Susz został wyprodukowany w suszarce komorowej w warunkach przemysłowych. Proces suszenia składał się z trzech cykli: obsuszania w temperaturze 30°C, dwuetapowego suszenia w temperaturze kolejno 60 i 55°C i dwuetapowego dosuszania (45 i 35°C). Susz rehydratowano w wodzie destylowanej o temperaturze 20°C przez 6 godzin i w wodzie destylowanej o temperaturze 100°C przez 2 godziny. Aproksymacja danych doświadczalnych względnego przyrostu masy suszu podczas rehydratacji formułami empirycznymi dała dobre wyniki. Z uzyskanych rezultatów wynika, że stosowane warunki suszenia są bardziej sprzyjające dla jablek ze względu na ich jakość.

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Abstract: Effect of convectional drying parameters on rehydration kinetics of parsley dried slices. Effect of particle thickness, convectional drying temperature and rehydration temperature on rehydration kinetics of dried parsley root slices was investigated. The slice thickness amounted to 3, 6, and 9 mm, while drying temperature was equal to 50, 60 and 70ºC. Process kinetics was investigated for 6 hours during rehydration in water of temperature 20ºC and for 2 hours during rehydration in water of temperature 100ºC; a relative mass increment of dried material during rehydration was determined in both cases. Approximation of experimental data with the use of proposed kinetic equation gave good results. Analysis of rehydration process course showed that thickness of slices and rehydration temperature influenced the rehydration kinetics of parsley root dried slices. No unequivocal or substantial effect of drying temperature on rehydration kinetics was found.

Key words: slice thickness, temperature, drying, rehydration, parsley.

INTRODUCTION

In respect to changes in way of life in the developed countries’ community, the so called convenient food becomes more and more appreciated and wanted. This food may include the dinner dish concentrates, where basic components are dried vegetable, including parsley.

A most common method for drying the food products is convectional drying. However, removing water is connected with many disadvantageous changes in the properties of material subjected to this process, as shrinkage, changes in texture or colour [Lewicki 1998]. Therefore, to obtain proper product quality during drying to enable its long storing without losses in quantity and quality, one should consider both the drying conditions and the process of raw material preparation to drying.

One of most important indices of dried material quality is rehydration ability. The knowledge of rehydration properties of food products being dried is also important, since many dried products are consumed or processed industrially after earlier rehydration. Therefore, dried material preparation for drying, drying itself and rehydration should be carried out under conditions that allow for restoration of material properties characteristic for raw material prior to rehydration. Many works are devoted to this problem, however, results obtained for a given material can not be transferred to other one. This is caused by differences
in material structure and properties that are specific for every vegetable and decide on the size of changes in the material during its preparation to drying and drying itself, and finally on dried material properties during rehydration.

Problems of parsley root rehydration were discussed, among other, by Kaleta et al. [2004, 2005, 2006], Kramkowski et al. [2001], Surma et al. [2006] Witrowa-Rajchert [1999].

This work aimed at analysis of the effect of particle breaking-up, conventional drying temperature and rehydration temperature on rehydration kinetics of dried parsley root slices. There is no wider investigations on that subject in references.

MATERIAL AND METHODS

The cleaned parsley roots of Berlińska species were used in investigations. The root was cut into slices of thickness 3, 6 and 9 mm. Drying air temperature in a drier amounted to 50, 60 and 70°C. Dried parsley root slices were subjected to rehydration process in distilled water of temperature 20°C for 6 hours and in distilled water of temperature 100°C for 2 hours. At intervals of 0.5, 1, 1.5, 2, 3, 4, 5 and 6 hours (for temperature 20°C) or after 10, 20, 40 and 120 minutes (for temperature 100°C) the rehydrated sample was separated from water, dried with an absorbent paper and weighed. For each time there was determined a relative mass increment of rehydrated dried material, as a ratio of current sample mass to initial mass of dried material used subjected to rehydration. Maximal relative error for calculation of relative mass increment amounted to 0.14%, and determination of mass increment was repeated three times.

With the use of Statistica program there were made diagrams on relative mass increment of dried material during rehydration and approximation of experimental data (in three repetitions) was performed with the use of following equation:

\[ \frac{m_\tau}{m_0} = a + b \exp \left(1 - c \tau \right) \]  

where:
- \( m_\tau \) – dried material mass being rehydrated at moment \( \tau \), kg,
- \( m_0 \) – initial mass of dried material, kg,
- \( \tau \) – time, min,
- \( a, b, c \) – constants.

Basing on the obtained equations there were calculated the balanced values of relative mass increments \( \left( \frac{m_\tau}{m_0} \right)_r = a \) of dried material, that would have been achieved if rehydration process had lasted infinitely long. The obtained equations were differentiated to analyze the rate of relative mass increment.

RESULTS AND DISCUSSION

Approximation of experimental data of relative mass increment of parsley root dried material with the use of proposed kinetic equation gave good results, since determination coefficient ranged from 0.944 to 0.999. Figure 1 presents...
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an exemplary diagram of changes in relative mass increment.

Effect of slice thickness and rehydration temperature on relative mass increment and its rate for dried parsley root (drying temperature 60°C) during rehydration are presented in Figure 2. Analogical dependences were obtained for the material dried at 50 and 70°C. Figure 3 presents the effect of drying temperature and rehydration temperature on relative mass increment and its rate for dried parsley root (slice thickness 9 mm) during rehydration.

FIGURE 1. Relative mass increment of dried material (parsley root slices of 3 mm dried at temperature 50°C) during rehydration at temperature 100°C: Δ – experiment, (——) approximation with equation (1)

FIGURE 2. Effect of slice thickness and rehydration temperature on relative mass increment and its rate of parsley root dried material (drying temperature 60°C) during rehydration: broken line – 20°C, solid line – 100°C, thin line – 3 mm, thicker line – 6 mm, thickest line – 9 mm
Analogical dependences were obtained for dried material of slice thickness 3 and 6 mm. It can be found that all investigated samples are characterized initially by a highest relative mass increment, while at further stage the water absorption by slices becomes gradually slower due to approaching of the hydrated samples to the state of equilibrium. An initial fast increase in water absorption can be found especially during rehydration in water of temperature 100°C, while at temperature 20°C it is more uniform during entire process and at slower rate than at temperature 100°C. An increase in rehydration rate with increased temperature may be caused by the increased rate of water diffusion. The investigations proved also the effect of slice thickness on kinetics of their rehydration. For both rehydration temperatures the rate of relative sample mass increment increased along with an increase in breaking-up degree, thus, along with a decrease in slice thickness. This is caused by the increased chip surface at higher breaking-up degree, but probably it is not the only cause. The assumed values of relative mass increment of rehydrated dried material increased with a decrease in slice thickness. However, no unequivocal or high effect of drying temperature on rehydration kinetics was found. Rehydration process in water of both temperatures 20°C and 100°C proceeded at a highest rate in the slices dried at temperature 50°C, and at a slowest rate at temperature 60°C. Therefore, it can be assumed that drying at temperature 50°C causes the least unfavourable changes in parsley slices subjected to this process.

The highest value of relative mass increment (Fig. 3) of 3.7 was achieved along with an increase in breaking-up degree, thus, along with a decrease in slice thickness. This is caused by the increased chip surface at higher breaking-up degree, but probably it is not the only cause. The assumed values of relative mass increment of rehydrated dried material increased with a decrease in slice thickness. However, no unequivocal or high effect of drying temperature on rehydration kinetics was found. Rehydration process in water of both temperatures 20°C and 100°C proceeded at a highest rate in the slices dried at temperature 50°C, and at a slowest rate at temperature 60°C. Therefore, it can be assumed that drying at temperature 50°C causes the least unfavourable changes in parsley slices subjected to this process.

The highest value of relative mass increment (Fig. 3) of 3.7 was achieved

FIGURE 3. Effect of drying temperature and rehydration temperature on relative mass increment and its rate of parsley root dried material (slice thickness 9 mm) during rehydration: broken line – rehydration temperature 20°C, solid line – rehydration temperature 100°C, thin line – drying temperature 50°C, thicker line – drying temperature 60°C, thickest line – drying temperature 70°C
in slices of 3 mm dried at temperature 70°C and rehydrated in water of temperature 20°C, while the least value of 2 was achieved in slices of 9 mm dried at temperature 60°C and rehydrated in water of temperature 20°C. After 6-hour rehydration in water of temperature 20°C the value of relative mass increment is practically independent of drying temperature and amounts to: for 3 mm slices from 3.63 to 3.7 (for drying temperature 50–70°C), for 6 mm slices from 2.58 to 2.75, for 9 mm slices from 2 to 2.15. Comparing the rehydration results at temperature 20°C after 6 hours and at temperature 100°C after 2 hours one can find that only 3 mm slices showed a bigger relative mass increment at temperature 20°C, while in slices of 6 and 9 mm a bigger relative mass increment occurred at rehydration temperature 100°C. After 2-hour rehydration at temperature 100°C a relative increment of dried mass obtained at drying temperature 50–70°C ranged to: for 3 mm slices from 3.05 to 3.35, for 6 mm slices from 2.95 to 3.3 and for 9 mm slices from 2.45 to 2.75.

The highest value of balanced relative mass increment (4.55) was found for 6 mm slices dried at temperature 50°C and rehydrated in water of temperature 20°C, while the least value (2.21) was found for 9 mm slices dried at temperature 70°C and rehydrated in water of temperature 20°C. Only for 9 mm slices
the balanced relative mass increment obtained during rehydration at temperature 100°C was higher than that obtained at 20°C (difference ranged from 0.33 to 0.58). The biggest difference occurred for 6 mm slices; between temperatures 20°C and 100°C ranged from 1.22 to 1.50. One can assume that during rehydration at temperature 100°C all the samples reach an equilibrium state after 2 hours, since the ratio between relative mass increment to the balanced relative mass increment ranges from 97% to 100%, and all the 3 mm samples achieve the equilibrium state. In the slices of this thickness the 6-hour rehydration at temperature 20°C gives a product hydrated in 95–97%, while 6 mm slices after at least 6 hours reached only 58–61% of equilibrium state.

CONCLUSIONS

- Approximation of experimental data of relative mass increment in parsley root dried material during rehydration with the use of proposed kinetic equation give good results, with determination coefficient values from 0.944 to 0.999.
- Rehydration rate increases along with an increase in breaking-up degree (with a decrease in slice thickness) and an increase in rehydration temperature. The rehydration rate was highest in slices dried at temperature 50°C, and lowest in slices dried at temperature 60°C.
- Relative mass increment of parsley root dried material after 6-hour rehydration at temperature 20°C and after 2-hour rehydration at temperature 100°C depends on slice thickness and rehydration temperature, while is independent of drying temperature. The highest value of relative mass increment (3.7) was reached in 3 mm slices dried at temperature 70°C and rehydrated at 20°C, while the least value (2) in 9 mm slices dried at temperature 60°C and rehydrated at 20°C. Only 3 mm slices reached bigger relative mass increment during rehydration at temperature 20°C (when compared to rehydration temperature 100°C).
- One can assume that all the investigated samples reached an equilibrium state after 2-hour rehydration at temperature 100°C. The 6 mm slices were most remote from this state after 6-hour rehydration at temperature 20°C (58–61% of equilibrium state).

REFERENCES


Streszczenie: Wpływ parametrów konwekcyjnego suszenia na kinetykę rehydratacji suszonych plasterków z korzenia piętruszki. Badano wpływ grubości cząstek, temperatury ich konwekcyjnego suszenia oraz temperatury rehydratacji na kinetykę rehydratacji suszonych plasterków korzenia piętruszki. Grubość plasterków wynosiła 3, 6 i 9 mm, a temperatura suszenia 50, 60 i 70°C. Kinetykę procesu badano w czasie 6 godzin podczas rehydratacji w wodzie o temperaturze 20°C i w czasie 2 godzin podczas rehydratacji w wodzie o temperaturze 100°C, wyznaczając w obu przypadkach względny przyrost masy rehydratowanego suszu. Aproksymacja danych doświadczalnych zaproponowanym równaniem kinetycznym dała dobre wyniki. Analiza przebiegu procesu rehydratacji wykazała, że grubość plasterków i temperatura rehydratacji wpływają na kinetykę rehydratacji suszonych plasterków z korzenia piętruszki. Badania nie wykazały natomiast jednoznacznego i dużego wpływu temperatury suszenia na kinetykę rehydratacji.

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Abstract: Drying shrinkage of red currants. The paper presents results of investigations on shrinkage of red currants dried under the natural convection conditions at temperature 60ºC. The volume of dried fruits was measured in a vegetable oil. The drying shrinkage was determined basing on measurements of 12 selected samples of similar initial mass and volume. The shrinkage process was described with a linear function. The maximal shrinkage of 96% was found.

Key words: drying shrinkage, red currant, drying, natural convection.

AIM OF WORK
The work aimed at preliminary evaluation of volumetric changes in red currant fruits under conditions of natural convection. Determination of maximal drying shrinkage parameter has been widely used in modeling of drying kinetics in the first period of fruit drying. Substantial changes in linear dimensions can be found during drying of fruits and vegetables under convection conditions; it is proved by the drying shrinkage, which can amount to even 90% [Szarycz et al. 2003].

MATERIAL AND METHODS
The red currant fruits were put in a laboratory drier and were dried under natural convection conditions. Changes in the mass of standard sample were recorded during entire drying process. These measurements were taken as a basis for determination of changes in water content. The drying kinetics was measured according to the method developed by Stanislaw Pabis [Pabis 1994].

In the drying chamber there were placed 12 selected samples on additional sieves. The fruit selection involved preparation of similar (almost identical) samples with respect of initial mass and volume (Tab. 1) [Kukielko, Jaros 1999]. The subsequent samples 1,…, 12 were taken out at regular intervals (Fig. 1) during drying process.

<table>
<thead>
<tr>
<th>No of sample</th>
<th>Initial mass of sample [g]</th>
<th>Initial volume of sample [ml]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>51.14</td>
<td>48</td>
</tr>
<tr>
<td>2</td>
<td>51.14</td>
<td>48</td>
</tr>
<tr>
<td>3</td>
<td>51.11</td>
<td>48</td>
</tr>
<tr>
<td>4</td>
<td>51.10</td>
<td>48</td>
</tr>
<tr>
<td>5</td>
<td>51.10</td>
<td>48</td>
</tr>
<tr>
<td>6</td>
<td>51.07</td>
<td>48</td>
</tr>
<tr>
<td>7</td>
<td>51.07</td>
<td>48</td>
</tr>
<tr>
<td>8</td>
<td>51.08</td>
<td>48</td>
</tr>
<tr>
<td>9</td>
<td>51.04</td>
<td>48</td>
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<tr>
<td>10</td>
<td>51.01</td>
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</tr>
<tr>
<td>11</td>
<td>50.89</td>
<td>48</td>
</tr>
<tr>
<td>12</td>
<td>51.14</td>
<td>48</td>
</tr>
</tbody>
</table>
Then, the volume was measured by immersing the dried fruits in a vegetable oil of known volume [Zawiślak et al. 2002]. The measurements were executed several minutes after taking out of sample from the drier, when fruits were cooled down. The vegetable oil (due to its consistence) did not penetrate the fruits, thus, did not disturb the volume measurement. The volume of dried fruits was determined basing on difference in the final $V_k$ and initial $V_p$ oil volume:

$$V = V_k - V_p \quad (1)$$

The graduated cylinders for oil and dried fruits were selected to minimize absolute errors of volume measurements (Tab. 2). The determined volume of sample No 1 was burdened with absolute error of 2 ml, the samples 2, ..., 12 with error of 1 ml.

The dry mass was determined by drier method [CEN/TS 14774-3:2004(E), [PN-EN ISO 1666:200]. Additional fruit sample of the same initial mass was dried at temperature 105°C during 24 hours. The measurement was executed in the same time in a smaller drying chamber.

**TABLE 2. Systematic errors of measurements on drying kinetics and shrinkage of red currants dried at temperature 60°C**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Denotation</th>
<th>Absolute error</th>
<th>Relative error</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water content in sample</td>
<td>u</td>
<td></td>
<td>max 0.02%</td>
<td>Beginning of drying</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>max 0.13%</td>
<td>End of drying</td>
</tr>
<tr>
<td>Mass of sample 1,..., 12</td>
<td>M</td>
<td>0.01 g</td>
<td>0.02%</td>
<td>Beginning of drying</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.07%</td>
<td>End of drying</td>
</tr>
<tr>
<td>Drier air temperature</td>
<td>t</td>
<td>0.1°C</td>
<td>0.17%</td>
<td></td>
</tr>
<tr>
<td>Volume of sample</td>
<td>V</td>
<td>2 ml</td>
<td>max 4.17%</td>
<td>Sample 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 ml</td>
<td>max 11.76%</td>
<td>Sample 2, ..., 12</td>
</tr>
</tbody>
</table>

**FIGURE 1. Layout of measurements on shrinkage during red currant drying process at temperature 60°C**
Drying shrinkage of red currants is necessary for determination of water content in the dried fruits (Fig. 1).

The measurements on drying shrinkage by the presented method are very time-consuming and call for selection of fruits of similar initial parameters, so that subsequent samples 2–12 can be regarded as a copy of sample No 1. The shrinkage measurements at drying agent temperature of 60°C were executed in 2008 season in drying laboratory of Faculty of Production Engineering WULS.

RESULTS OF INVESTIGATIONS

The results of measurements on red currant drying kinetics are presented in Figure 1. The initial water content for this measurement series amounted to 6.6 kg/kg.

Figure 2 presents results of measurements on drying shrinkage determined as a dependence between the volume measured and the initial volume as a function of changes in the measured water content and the initial water content. The results of measurements were approximated by a linear method with correlation coefficient $R^2 = 0.960$.

$$\frac{V}{V_0} = 0.87 \cdot \frac{u}{u_0} + 0.04$$  \hspace{1cm} (2)

where:

$V_0$ – initial volume of dried fruits,
$u_0$ – initial water content.

The determined value of maximal shrinkage amounts to 96%. The description of shrinkage with a linear model was verified many times for fruits and vegetables [Pabis 1999] and was consistent with the theory of convectional drying of these agricultural products.

The shape of fresh red currant is close to a sphere. After drying, the shape was evidently deformed, proved by the range of determined shrinkage coefficient.

CONCLUSIONS

- During drying of red currants under natural convection conditions there were found the substantial changes in linear dimensions.
• The drying shrinkage process at temperature 60°C was described with a linear function with correlation coefficient $R^2 = 0.96$.
• Basing on the equation (2), there was found the maximal drying shrinkage of 96%.
• Determination of the red currant drying shrinkage dried at other temperatures is recommended.

REFERENCES


Streszczenie: Skurcz suszarniczzy porzeczki czerwonej. Praca przedstawia wyniki serii badań pomiaru skurczu owoców porzeczki czerwonej suszonych w warunkach konwekcji naturalnej, w temperaturze 60°C. Pomiary objętości suszonych owoców wykonano w oleju roślinnym. Skurcz suszarniczzy określono na podstawie 12 wyselekcjowanych próbek o zbliżonych parametrach masy początkowej i objętości początkowej. Proces skurczu opisano funkcją liniową. Wyznaczono maksymalny skurcz na poziomie 96%.

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Modeling of wood biomass drying process with the use of neural nets

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Abstract: Modeling of wood biomass drying process with the use of neural nets. The problem of modeling of wood biomass drying process obtained from energetic plants is discussed. The model accuracy is a significant problem from the viewpoint of drying process productivity. Within the carried out works there was analyzed a theoretical equation describing the wood biomass drying process and two models of this process based on artificial neural nets were proposed. In investigations there were used data obtained in a series of experiments on drying of several types of biomass under various conditions. The experimental data were used for comparison between results obtained from the investigated models. The models that used the neural nets proposed in the work, yielded better results than those from theoretical equation. In addition, the results obtained from theoretical equation suggest occurrence of some limitations in fitting of this equation parameters to experimental data.

Key words: biomass, drying, modeling.

INTRODUCTION

Biomass has been the oldest energy source utilized by human beings. The solar energy stored in plant tissues during photosynthesis is given back during wood combustion. Large quantity of wastes created in industrial and agricultural production is a potential energy source. The biomass designed for combustion is obtained also from energetic plant plantations. It can be used in the unprocessed state or can be improved in the process of processing into a solid fuel in the form of pellets and briquettes. Both the processes call for appropriate material drying to increase the calorific value of fuel.

The process of wood biomass drying can be described with the use of the following theoretical model:

\[ u(t) = u_r + (u_0 - u_r) \exp^{-Kt} \]  \hspace{1cm} (1)

where:
- \( t \) – time [min],
- \( u_r \) – equilibrium water content,
- \( u_0 \) – initial water content,
- \( K \) – drying coefficient,
- \( u(t) \) – water content level after time \( t \) (Pablos 1982).

The above equation can be used for various types and wood breaking up levels, various drying temperatures and convection types.

Necessity for determination of \( K \) parameter value determines a specific task for regression, where \( u(t) \) is an explained variable and the remaining vari-
able are explanatory variables, while the only unknown parameter is $K$. Fitting of theoretical equation to empirical data involves determination of this parameter. Calculations carried out in this paper suggest that determination of $K$ parameter to obtain ideal fitting is not possible. These problems are well illustrated by Figure 1, which presents dependence between moisture content logarithm and time during the willow convectional drying at temperature 80ºC.

Since application of Equation (1) to description of wood biomass drying process was not satisfactory under these circumstances, it was decided to use the artificial neural nets as a model of “black box” type.

MATERIAL AND METHODS

Artificial neural nets (SN) are a mathematical nonlinear modeling method (Haykin 1999). They are based on biological inspirations for human brain operation, hence there are derived both the name and some ideas used in de-

FIGURE 1. Comparison between experimental data and model results for willow drying process (logarithmic scale)

The artificial neural net consists of neurons; between them there are connections of certain importance. SN receives the input signals, and converts them into the output signals. The conversion is realized due to operation of connections between neurons and the neurons themselves. Depending on importance, the connections cause amplification or weakening of signals, while action of each neuron involves summing up of input signals, conversion of their weighted sum with the use of activation function and generation of the output signal. The net parameters which should be determined on the basis of specific data are the mentioned weights of connections. Process of their determination is known as teaching of neural net; an algorithm used most often is so called method of backward error propagation, involving gradient minimization of the net error function.

The multilayer perceptrons are the specific type of neural nets, where the neurons are grouped into numbered layers with admissible neuron outputs connections from a layer $i$ to neuron inputs of layer $i + 1$.

In further part of this paper there were used perceptrons described with the following equation:

$$y(x) = \sum w_i \tanh(\sum x_j w_{j,i}^0 + b_i^0) + b$$

(2)

where:

- $x$ – $k$-dimension vector of input signals,
- $n$ – number of neurons,
- $w_{j,i}^0$ – weight of connection between $i$-input signal and $j$-neuron,
- $b_i^0$ – characteristic constant of $i$-neuron,
- $w_i$ – weight of input signal of $i$-neuron,
- $b$ – constant added to input signal of entire net.

The carried out experiments were focused on determination of operational accuracy of a theoretical model for wood biomass drying (1) and on investigating possible improvement of the results. The following approaches were tested for this purpose:

1. Linear combination of theoretical models prepared for temperatures $T_1$, $T_2$, ..., $T_N$

$$M_0 = \sum_{i=1,...,n} a_i(T) u_{k_i}(t)$$

(3)

where for $j$ of $T_j \leq T_{j+1}$ $a_i(T) =$

$$\begin{cases} \frac{(T - T_j)}{(T_{j+1} - T_j)} & i = j \\ 0 & i \neq j \land i \neq j + 1 \\ \frac{(T_{j+1} - T)}{(T_{j+1} - T_j)} & i = j + 1 \end{cases}$$
2. Model based on neural nets only

\[ M_1 = \text{NN} \]  \hspace{1cm} (4)

3. Model \( M_0 \) with correction of neural nets

\[ M_2 = M_0 + \text{NN} \]  \hspace{1cm} (5)

Determination of parameters of the model based on Equation (1) involved solving of regression tasks with regard to \( K \) coefficient for each temperature \( T_1, T_2, \ldots, T_N \). A least square method was used.

Preparation of \( M_2 \) model was a two-stage process. At a first stage \( M_0 \) model was prepared, while at a second stage SNs were created with input signals for correction the error of \( M_0 \). The output signal \( M_2 \) was the sum of output signals \( M_0 \) and SN.

Determination (teaching) of neural net parameters was performed with the use of backward propagation algorithm and with application of Levenberg-Marquardt optimization (Hagan and Menhaj 1994). The teaching coefficient was equal to 0.01, while teaching function used the moment of coefficient 0.1. Neural nets used in \( M_1 \) model had \( n = 4 \) neurons in nonlinear layer, while in \( M_2 \) model a size of this layer was equal to \( n = 5 \). The hyperbolic tangent was used as a transition function. The models \( M_1 \) and \( M_2 \) were realized not by single neural nets, but by sets of such nets and their results were averaged. This aggregation approach enable to improve the quality of net’s operation and is known in references as bagging (Breiman 1996). All calculations were performed with the use of Matlab environment with a packet for creation of neural nets.

In calculations there were used data of a series of experiments. Within each experiment some quantity of certain plant material was subjected to drying process; the sample weight was determined in defined time intervals. Basing on measurements a moisture content was determined depending on time. The experiments were carried out for various types of plants, breaking up degrees and convection and temperatures of drying air.

In comparisons between investigated models there were used data of drying shoots of acacia, poplar and willow at temperature equal to 40, 50, 60, 70 and 80ºC with application of natural convection. In calculations there was used a cross validation procedure (Koronacki and Cwik 2005), consisting in dividing data for specific temperature \( T_j \) into the teaching sets (without measurements for \( T_j \) temperature) and the test ones (of measurement for \( T_j \) temperature only). Teaching sets were used for determination of investigated models’ parameters, while the test sets were used for evaluation of models’ operational accuracy. The pairs of sets for \( T = 50, 60 \) and 70ºC were prepared. Temperatures of 40 and 80ºC were not used in testing since they would evaluate a model extrapolation outside the range of temperature of their teaching; this could disturb significantly the results.
RESULTS AND DISCUSSION
Upon preparation of all models their absolute errors were calculated in percent for the test and teaching sets. Table 1 presents results of calculations for the test and teaching set, including quantile values of rows 0.05, 0.50 (median) and 0.95.

The teaching set values can be interpreted as a model ability of fitting to data, while the results for test sets as ability to generalization describing reliability of modeling results.

The obtained results are not homogeneous for all the three tested types

<table>
<thead>
<tr>
<th>Plant</th>
<th>Quant</th>
<th>$M_2$</th>
<th>$M_1$</th>
<th>$M_0$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>U</td>
<td>T</td>
<td>U</td>
</tr>
<tr>
<td>Acacia</td>
<td>$q_{0.05}$</td>
<td>0.00</td>
<td>0.01</td>
<td>0.23</td>
</tr>
<tr>
<td></td>
<td>$q_{0.50}$</td>
<td>2.71</td>
<td>7.54</td>
<td>3.38</td>
</tr>
<tr>
<td></td>
<td>$q_{0.95}$</td>
<td>15.95</td>
<td>34.29</td>
<td>12.40</td>
</tr>
<tr>
<td>Poplar</td>
<td>$q_{0.05}$</td>
<td>0.00</td>
<td>0.01</td>
<td>0.36</td>
</tr>
<tr>
<td></td>
<td>$q_{0.50}$</td>
<td>10.39</td>
<td>13.81</td>
<td>3.61</td>
</tr>
<tr>
<td></td>
<td>$q_{0.95}$</td>
<td>47.75</td>
<td>55.95</td>
<td>21.30</td>
</tr>
<tr>
<td>Willow</td>
<td>$q_{0.05}$</td>
<td>0.00</td>
<td>0.18</td>
<td>0.34</td>
</tr>
<tr>
<td></td>
<td>$q_{0.50}$</td>
<td>8.80</td>
<td>15.30</td>
<td>4.41</td>
</tr>
<tr>
<td></td>
<td>$q_{0.95}$</td>
<td>28.64</td>
<td>127.04</td>
<td>18.68</td>
</tr>
</tbody>
</table>

TABLE 1. Quantiles (0.05, median and 0.95) of absolute errors in percent for teaching (U) and test (T) sets of particular data sets

FIGURE 2. Comparison between results of particular models for test data of poplar drying process at temperature 60°C
of plants. Best fitting of models was obtained for acacia data, however, poplar data seem to be most difficult, since teaching set accuracy is definitely lower than that for the two remaining plants. However, deterioration of teaching set results is relatively small, that proves a good model generalization. Generalization of willow data is most difficult; there is a biggest difference between the teaching set error and the test set error.

Model $M_1$ consisted of neural nets only seems to be the best among all tested models. It can be found on Figure 2, where results of the three models were compared to original data of poplar drying process at temperature 60ºC as well as on Figure 3, where errors of these results are presented. The models $M_1$ and $M_2$ better represent results of wood biomass drying process when compared to an original model, but they are not ideal; therefore, it is possible to obtain further improvement of results. In particular, asymmetry of error distribution observed during error quantile analysis is curious.

SUMMARY

It was proved that wood biomass drying process can be successfully modeled with the use of “black box” type methods such as neural sets. It was proved also that the presented theoretical model does not take into consideration all necessary parameters. It is testified by departure from the experimental results presented on Figure 1. The obtained results point out at possible improvement of modeling
results of wood biomass drying process, with Equation (1) as a reference model.

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Streszczenie: Modelowanie procesu suszenia biomasy drzewnej przy pomocy sieci neuronowych. W niniejszym artykule poruszany jest problem modelowania procesu suszenia biomasy drzewnej pochodzącej z roślin energetycznych. Dokładność modelu jest istotnym problemem z punktu widzenia przeprowadzania procesu suszenia w sposób jak najbardziej wydajny. W ramach wykonanych prac analizowany był teoretyczny wzór opisujący proces suszenia biomasy drzewnej oraz zaproponowane zostały dwa modele tego procesu bazujące na sztucznych sieciach neuronowych. W badaniach wykorzystane zostały dane pochodzące z serii eksperymentów, w ramach których kilka rodzajów biomasy było poddawanych procesowi suszenia w różnych warunkach. Dane eksperymentalne zostały wykorzystane do porównania wyników uzyskiwanych przez badane modele. Wyniki zaproponowanych w pracy modeli wykorzystujących sieci neuronowe są lepsze od wyników wzoru teoretycznego. Ponadto, wyniki przeprowadzonych obliczeń sugerują pewne ograniczenia, którym podlega wzór teoretyczny.

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Greenhouse heating systems in the economic approach

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Abstract: Greenhouse heating systems in the economic approach. Greenhouse production enables to get agricultural crop outside the normal vegetation period with higher yield in comparison to open field production, by controlling environmental factors such as temperature, light and relative moisture. Among these factors, temperature has very important effects on plant growth. Temperature controls many physiological activities in plant life as well as affects the soil as plant life environment. Maintaining temperature at desired level in greenhouse by using suitable systems is needed for modern production. But the share of heating in total greenhouse production cost is very high and it can go up to 60 percent. Due to that, it is very important to reduce heating cost for a profitable greenhouse production by using renewable energy resources and providing energy conservation. In this study, factors affecting greenhouse heating cost and the ways of decreasing cost were examined.

Key words: greenhouse heating systems, cost of heating systems, economic efficiency.

INTRODUCTION

Greenhouse production is a very important agricultural activity in social and economic terms, and because of the opportunity of getting crop outside the normal vegetation period it is generally profitable growing method. The basic reasons for increase in greenhouse areas in the world are generally high demand for early vegetables, dominion of family managership, attractive product prices and government supports. Greenhouses meet an important part of world food demand and the distribution of greenhouse areas can be seen in Figure 1.

Getting agricultural products in adequate quantity and quality can be possible by using convenient heating systems especially in countries having cold climate. It is known that when other factors composing greenhouse climate are suitable, the increase of 10°C in greenhouse temperature rises plant growth two fold with the condition of not exceeding maximum temperature allowed (Yağcıoğlu 2005). Heating greenhouses with optimum plant demands also enables production without hormone because of ideal internal temperature and prevents the diseases depending on high humidity. The im-
important thing in this point is being able to realize an economical application by reducing energy costs (Harzadin 1994). There are many different factors affecting the profitability in greenhouse production. Heating greenhouses is one of the major cost elements and reducing heating cost means transforming the greenhouses into more profitable production structures. Energy used to heat a greenhouse is usually provided by the combustion of some fuel on site, but energy can be provided also by electricity or in many cases alternative energy sources such as solar or geothermal can be used. Utilisation of renewable energy resources like geothermal, sun and wind energy and energy conservation applications should be thought for reducing heating cost. Coal, oil and gas are the most common forms of energy used for greenhouse heating. The choice of which of these to use is based primarily on economics. The delivered cost of fuels is shown below in Table 1.

The amount of energy used to heat a greenhouse depends on the desired inside temperature, the surface area of the building, the thermal resistance of the material covering the building and the outside weather conditions and depend on delivered cost of fuels and energy demand. Energy demand will rapidly increase in the nearest years in all category of fuels (Borowski 2008).

GREENHOUSE HEATING METHODS

The main two systems of heating practical for greenhouses are hot water and steam. Heating systems may utilize hot water or hot air to increase air temperature during the cool season. Hot water systems are generally used in smaller greenhouses. In larger greenhouses hot steam systems should be used. There are numerous systems to generate the heat, such as with direct-fired unit heaters within each greenhouse bay, or centralized hot water boilers that pump hot water to multiple greenhouse units. There are also various heat distribution systems that heat the greenhouse air (air-to-air, and water-to-air heat exchangers), the soil and plant root zone (bench and flo-

<table>
<thead>
<tr>
<th>Type of fuel</th>
<th>Total all sectors</th>
<th>Electric power sector</th>
<th>Commercial sector</th>
<th>Industrial sector</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Electric utilities</td>
<td>Independent power producers</td>
<td></td>
</tr>
<tr>
<td>Total coal (cents per MMBtu)</td>
<td>177</td>
<td>178</td>
<td>171</td>
<td>267</td>
</tr>
<tr>
<td>Total petroleum (cents per MMBtu)</td>
<td>717</td>
<td>712</td>
<td>754</td>
<td>1 404</td>
</tr>
<tr>
<td>Total natural gas (cents per MMBtu)</td>
<td>711</td>
<td>747</td>
<td>692</td>
<td>799</td>
</tr>
</tbody>
</table>

Source: www.eia.doe.gov
Greenhouse heating systems in the economic approach

or heating), and the leaf surface (radiant heating) (Giacomelli 2002).

Heating systems basically can be classified as given below:
- Heating by stove
- Central heating
- Heating by hot air
- Heating by sun energy
- Heating by geothermal energy

The cost of heating system: natural gas, electricity and other greenhouse supplies became major concerns during last years, so the reduction in heating cost should be made in the greenhouse production. Which fuel is the best to heat greenhouses? The right answer depends on price, convenience and availability. Some fuels have a higher heat value than other and some heating units have a greater efficiency. A detailed economic study should be done before purchasing a system.

Greenhouse heating systems should have some specifications technically and temperatures should be uniform as far as possible and the automatic control of the system should be easy. In point of plant photosynthesis activity, leaf temperature is not only parameter and also air flow velocity and direction is important.

In all greenhouse heating systems, it is important that the exhaust should not contact the crop. When the fuel source is of high purity and is thoroughly combusted, only carbon dioxide and water vapour are produced but it is rare that fuels are completely combusted. Products of incomplete combustion, including ethylene gas are injurious to plants (Nelson 1998).

In greenhouse heating systems, heat can be distributed to greenhouse air directly or by pipes. In both methods, heat should be spread homogenously inside greenhouse. In tubular heating, one way of facilitating climate control is placing pipes close to plants. Placing heating pipes below plant level stimulates

![Different tubular heating systems](image)

FIGURE 2. Different tubular heating systems

in point of plant growing. All systems given above should be able to provide the temperature needed for the whole climate conditions. Air, plant and soil the air movement in plant cover. Hot air ascending removes the moisture from plant cover and composes a uniform microclimate around plants (Başçetinçelik
Different pipe arrangements for heating greenhouses can be seen in Figure 2 (Dickson and Fanelli 2004).

In central greenhouse heating systems, there are two different applications depending on fluid temperature in heating pipes as hot water and steam. Steam central heating systems have more complicated structure than hot water systems and due to high installation cost they can’t generally be used economically except big greenhouse operations. Central heating systems are suitable for greenhouse operations bigger than 2–2.5 da area (Yağcıoğlu 2005).

Especially in recent years, renewable energy resources such as sun, wind and geothermal energy can be used in greenhouse heating. Researches focused on sun and geothermal energy utilization among these resources. Sun energy can be used in two types as active and passive for greenhouse heating. In active systems a fluid is heated by means of solar radiation and used for increasing greenhouse temperature. In passive heating, polyethylene tubes filled with water are generally placed on soil between plant rows. In these systems water capacity is 60–100 m$^3$ per 1000 m$^2$ greenhouse area (Başçetinçelik ve Öztürk 1996).

Another way of passive solar greenhouse heating is putting barrels painted in black in greenhouse and filling them with water. Heat energy stored by barrels during day is given to greenhouse environment by natural convection and thermal radiation during night (Fig. 3).

**FIGURE 3. Heating application by water barrels**

Geothermal energy which is another alternative energy resource can be used in greenhouse heating directly or indirectly using a heat exchanger. Heating greenhouses by geothermal energy may include some technical and economical difficulties. One of these difficulties is preliminary survey and drilling work for reaching resource. Geothermal fluid should be reinjected to deep layers after using in greenhouse heating due to their harms to environment and feeding resource. Heat pumps work like a refrigerator in reverse taking the heat from the ground source and transferring it to the greenhouse. Earth tubes capture the heat in ventilation air that is then blown into the greenhouse. The cost of most geothermal systems is fairly high and many things need to be considered before installing such a system (Bartok 2005).

**FACTORS AFFECTING SELECTION OF GREENHOUSE HEATING SYSTEMS AND ECONOMICAL ASPECTS**

There are many types of greenhouse designs, materials, construction and production methods. There are two basic types of greenhouses: attached and free-
Greenhouse heating systems in the economic approach

An attached structure may be even-span, lean-to, or window-mounted. A free-standing type is usually even-span (symmetrical roof). Greenhouses have supporting framework made of wood, aluminium, iron, or galvanized pipe. Some have curved eaves; others have flat eaves. Some are glass or plastic from the ground up. Each type of construction has advantages and disadvantages. A greenhouse structure is advantageous when low initial cost is required or when it is planned for a building to be in use for only a year or two. A wood or metal frame building has advantages when a permanent building is planned and operating costs are most important. The main difference in operating costs is caused by the energy used to heat the structure and water during cold weather. The energy lost through the walls of a structure during cold weather must be replaced by the heating system in order to maintain a stable temperature inside a structure. The amount of energy that must be supplied is related to the difference between inside and outside temperatures and the thermal resistance or "R" value of the building’s roof and walls (Fowler 1997).

The selection process of a particular heating system should not only depend on cost, but also on its effective integration within the crop production system and management procedure. However, the first requirement in the design of a heating system is to determine the size needed, in terms of energy requirement or heat load of the greenhouse (Giacomelli 2002), in order to describe the economic performance of the greenhouse production, including total annual production costs. Fixed and variable expenses should be also calculated. The capacity of the system depends on the size of greenhouse, whether it is covered with a single layer or a double layer of plastic or glass, and the maximum difference between inside and outside temperatures.

There is a wide variety of greenhouse supplies, equipment and accessories to help operate, maintain and improve greenhouse. The biggest factor affecting the cost of greenhouse heating is type of energy resource used for producing heat needed. A lot of various low-temperature water sources are available for greenhouse heating and they are generally cheaper than heat from conventional fossil energy sources, but their disposability and continuity are not always warranted. Among these heat sources the most frequently cited are geothermal energy, industrial heat effluents or waste heat from thermal power plant, water from solar collectors and low-temperature heat generators such as heat pumps, condensation boilers (Baille 1988).

In this point, technical, regional and economical factors should be considered altogether. Especially regional advantages should be benefited in terms of renewable energy resources. For example, in the regions having important geothermal energy potential, total costs can decrease in comparison to fossil fuelled systems. In regions having much solar radiation, solar systems could be used as the main or auxiliary heating systems.
with economical advantages. But studies mostly show that meeting all of heat requirements with sun energy is not economical.

The application of geothermal energy of low temperature has excellent economical prospects as a heat source for protected cultivation especially in mild weather areas which have the advantage of high temperatures and solar radiation during most part of the year. To utilize usefully geothermal water in commercial greenhouses, it is very important to make the use of low cost technologies suitable for plant growing in greenhouses (Campiotti and Picciurro 1988).

The economy of heating greenhouses by geothermal energy depends on availability ratio and heat requirements per unit area in addition to geothermal fluid temperature, depth and flow rate of geothermal resource and transmission distance of geothermal fluid. Installation cost of geothermal heating systems is high and it should be recovered in short term by distributing geothermal fluid to wide greenhouse areas (Başçetinçelik et al. 1994).

Karacabey (2008) made a research on comparison of utilization of geothermal and solid fuel heating systems in a sample greenhouse operation which has 12 da total area and glass cover material and the results are in Table 2.

As it can be understood from Table 2, geothermal heating systems have important advantages especially in terms of variable operating costs. Installation costs in fossil fuel heating systems are 27% bigger than geothermal heating

<table>
<thead>
<tr>
<th>Heating system</th>
<th>Installation costs (USD)</th>
<th>Operating costs (USD/year)</th>
<th>Fixed operating costs</th>
<th>Variable operating costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geothermal heating system</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heat exchanger</td>
<td>10 000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heating pipes</td>
<td>14 749</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Circulation pumps</td>
<td>1 942</td>
<td>Amortization + Interest</td>
<td>4 464</td>
<td>Hot water cost</td>
</tr>
<tr>
<td>Other system elements</td>
<td>6 652</td>
<td></td>
<td></td>
<td>Cost of electricity consumption</td>
</tr>
<tr>
<td>TOTAL</td>
<td>33 343</td>
<td></td>
<td></td>
<td>Total</td>
</tr>
<tr>
<td>Fossil fuel heating system</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heating boiler</td>
<td>23 846</td>
<td>Amortization + Interest</td>
<td>6 163</td>
<td>Fuel cost</td>
</tr>
<tr>
<td>Heating pipes</td>
<td>14 749</td>
<td></td>
<td></td>
<td>Cost of electricity consumption</td>
</tr>
<tr>
<td>Circulation pumps</td>
<td>788</td>
<td></td>
<td></td>
<td>Maintenance and repair cost</td>
</tr>
<tr>
<td>Other system elements</td>
<td>6 652</td>
<td></td>
<td></td>
<td>Total</td>
</tr>
<tr>
<td>TOTAL</td>
<td>46 035</td>
<td></td>
<td></td>
<td>68 632</td>
</tr>
</tbody>
</table>
systems. Total operating costs in geothermal heating systems are 86% lower than fossil fuel heating systems although there is no so much difference in fixed operating costs.

Heat conservation in greenhouse is very important for decreasing the heating cost and different techniques such as thermal screen application could be used for that. Thermal screens are generally regarded as being one of the most effective methods of energy conservation. A very wide range of screen material is available, such as polyethylene (PE), polyester, cloth or film. Nowadays, the most modern thermal screens are made of a combination of polyester and aluminium (Öztürk ve Başçetinçelik 2003).

Glass and plastic cover materials in different types are used in greenhouses. One of the ways of providing heat conservation and decreasing cost is using greenhouse cover material which has high insulation value. Insulation value can also be increased via double cover material. Djevic and Dimitrijevic (2004) made a research on heating requirements and fuel oil amount needed for heating in different greenhouse constructions in Serbia and the results obtained are presented in Table 3.

As seen in Table 3, double plastic cover material has air-tight and high insulation feature and it provides energy saving up to 40%.

<table>
<thead>
<tr>
<th>Greenhouse type</th>
<th>Tunnel type (single plastic)</th>
<th>Tunnel type (double plastic)</th>
<th>Arch-roof type (single plastic)</th>
<th>Arch-roof type (double plastic)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat requirement (kW)</td>
<td>103.0</td>
<td>72.0</td>
<td>107.23</td>
<td>75.0</td>
</tr>
<tr>
<td>Fuel oil needed (kg/h)</td>
<td>8.9</td>
<td>6.22</td>
<td>9.26</td>
<td>6.46</td>
</tr>
</tbody>
</table>

Record keeping is an important factor in cost management in greenhouse heating. A grower can prevent repeating the same errors by keeping records in production system. Records and cost accounting is a system for assessing the costs of conducting a business. The costs of each input labour, utilities and materials are determined and compared to a reasonable proposal of costs. The overall profitability of the system is then determined (Nelson 1998).

CONCLUSION

It is obvious that expansion and progress of greenhouse production is mostly dependent on decreasing heating cost and studies focused on energy conservation technologies and utilization of renewable energy sources in greenhouse production. Although there are different ways of reducing heating cost, a certain
system can’t be suggested for a greenhouse operation. As mentioned above, all regional and technical opportunities should be evaluated while choosing and operating heating system. The elements dependent on region and operation like cost difference between conventional fuel and renewable energy utilization, crop grown, market prices of technical components of greenhouse heating systems entails constituting own cost strategy for a greenhouse operation.

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Streszczenie: Ekonomiczne aspekty systemów ogrzewania szklarni. Produkcja szklarniowa pozwala uzyskać produkty roślinne poza normalnym okresem wiosen. Zaznaczając jednocześnie uzyskanie wyższej wydajności w porównaniu z produkcją polową dzięki kontroli takich czynników środowiskowych, jak temperatura, światło i wilgotność. Wśród wymienionych czynników temperatury ma kluczowy wpływ na wzrost roślin. Utrzymanie temperatury na pożądany poziomie w warunkach szklarniowych jest możliwa
poprzez wykorzystanie odpowiednich systemów grzewczych. Udział ogrzewania w całkowitych kosztach produkcji jest bardzo wysoki i może sięgać nawet do 60%. W celu uzyskania rentownej produkcji w systemie ogrzewania można wykorzystywać odnawialne źródła energii. W artykule zaprezentowano wyniki badań z uwzględnieniem czynników wpływających na koszty ogrzewania i zaproponowano sposoby ich obniżenia.

\textit{MS. received May 2010}
Abstract: Analysis of opening cones of selected coniferous trees. There is described the phenomenon of opening cones of common pine, spruce and European larch during process of seed extraction: at the beginning – when the cones are closed, in the middle of the process – when the cones are deflected but the seeds can not be extracted, and after completion of the process – when the seeds fall out. The specification (structure) and dimensions of cone scales for the above species are given. The highest deflection of cone scales in relation the a stem was found for spruce (up to 50º), causing free extraction of the seeds with wings, while the least angle was found for larch (up to 30º), where seeds could not be extracted from the cone; this called for additional operations, e.g. mechanical crushing of scales.

Key words: drying, scale, cone, pine, spruce, larch.

INTRODUCTION

The common pine, spruce and European larch are coniferous, most important forest-creating species in Polish forests. The harvested cones mature every year (spruce, larch) or every two years (pine) and the seeds can be obtained in spring. In a natural environment, the favourable weather conditions should occur to enable the seeds’ coming out: preferably warm and sunny days and cool and moist nights, when the cones alternately open and close the scales. This phenomenon is connected to their structure. The scales contain layers of cells of various dimensions and wall thickness. The cells of thickest walls are situated on external side of the scale, while cells of thinner walls on internal side [3, 5]. The higher shrinkage of thicker cells (reduction of water content) causes deflection of the scale and uncovering of the seed. Under natural and proper conditions, the process of mature cone opening on trees lasts about two weeks. Under artificial conditions in local kilns, the process of scale opening and obtaining seeds can be advanced to several hours by supplying the cones with heated air of reduced water content; this causes opening of the cones.

AIM OF INVESTIGATIONS

The carried out investigations aimed at elaboration of characteristic of cone opening state (changes in the angle of scale deflection from the stem – necessary for seed extraction) of the mentioned species and the detailed description of external parameters of scales. This information would enable to explain the cause for slower opening of the cones, the considerably longer course
of seed extraction from the larch cones and difficulties in obtaining seeds of this species.

MATERIAL AND METHODS

The cones of three species were investigated: spruce, common pine and European larch. The basic parameters were measured for the selected objects: length and thickness with the use of a caliper; the cones were cut by half along the stem with a circular saw. The prepared cones were placed in a laboratory drier and subjected to seed extraction at temperature 50ºC. Changes of cone scales were recorded every two hours with the use of photo camera and video camera.

Upon obtaining of full opening (the state of cone allowing for extracting all seeds) the parameters of particular parts of selected scales at lower, middle and upper part of the cone and the angle of scale deflection of opened cone were measured.

RESULTS

The spruce cones are biggest, while the larch cones are smallest. They are of cylindrical shape, while the pine cones are medium-size and tapered. The cones of mentioned species increase their diameter during opening: three-fold increase was recorded for spruce cones, two-fold for pine, and the least increase for larch cones [4]. It is influenced by the size, shape and number of scales on the cone and also by angle of deflection from the stem. It was found that an average number of scales amounted to: 41–122 (common pine) [2], 35–50 (European larch) and 180 (common spruce) [4]. The size and shape of scale depend on its position on the cone. The scales taken from middle part of larch cone were smallest, the spruce scales were medium size, and the pine scales were biggest. The pine and spruce scales deflect freely during drying, while the larch scales call for additional mechanical crushing [1].

The view of closed cones (cut along the stem) are presented in Figure 1. The spruce stem is cylindrical, the pine stem is tapered, while the larch stem is cylindrical in the middle part and narrows at the cone bottom and top. In the thickest place of cone its stem amounts to 6 mm (spruce), 5.2 mm (pine) and 1.8 mm (larch).

The views of closed cones (before seed extraction) and open (after seed extraction – finally open) of spruce, pine and European larch, respectively, are presented in Figure 2.

It was found that all scales of spruce and larch cones opened, although not all scales had the seeds. In the pine cone only the scales situated in the upper and middle part of cone deflect from the stem. The scales of this species are most diversified with respect to their shape.

Figure 3 presents the shapes of pine and spruce scales of the thickest middle part of cone.

The following parts can be distinguished in the scale: next-to-stem (I) – connected to the stem, middle (II) – the widest part of end determined by
FIGURE 1. View of closed cones of coniferous species (spruce, pine and larch, respectively): a – external side, b – internal side (the cone stem visible)

position of wing, *top* (III) – finishing the scale. Dimensions of particular scale parts in mm are presented in Table 1.

It is evident from investigations that the length of next-to-stem part of pine and spruce cones amounts to 14% and 26% of the entire scale length, respectively, while of the larch cone to over 37%. Its length changes proportionally in the first two species; the scale length increases with an increase in the length of next-to-stem part. In the larch cones the length of this part is similar in all scales on entire cross-section and ranges from 3.2 to 3.7 mm; in the remaining cones this part shows bigger variability.

Analyzing subsequent views of larch scale opening one can find, that change in the scale angle applies only to its middle and top parts, the next-to-stem part does not change its position significantly (Fig. 4). Such range of larch scale part’s deflection and its length cause difficulties in seed extraction.
### TABLE 1. Dimensions of selected cones and their scale parts

<table>
<thead>
<tr>
<th>Closed/open cone</th>
<th>Species</th>
<th>Length [mm]</th>
<th>Thickness [mm]</th>
<th>Parts of scale</th>
<th>Scales of cone part</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Upper</td>
<td>Middle</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Common spruce</td>
<td>108</td>
<td>21/61</td>
<td>next-to-stem</td>
<td>2.8</td>
<td>2.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>middle</td>
<td>10.7</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>top</td>
<td>4.3</td>
<td>5.0</td>
</tr>
<tr>
<td>Common pine</td>
<td>45</td>
<td>20/50</td>
<td>next-to-stem</td>
<td>3.6</td>
<td>3.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>middle</td>
<td>4.7</td>
<td>5.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>top</td>
<td>2.3</td>
<td>2.4</td>
</tr>
<tr>
<td>Polish larch</td>
<td>31</td>
<td>19/26</td>
<td>next-to-stem</td>
<td>3.6</td>
<td>3.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>middle</td>
<td>5.5</td>
<td>5.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>top</td>
<td>0.2</td>
<td>0.3</td>
</tr>
</tbody>
</table>

**FIGURE 4.** Views of changes in the state of European larch cone during opening process – view of deflecting scales: I – closed cone, II – half of process, III – full opening, IV – graph of changes in scale position (broken line – closed scales, full line – half-open scales, “dot-dash” line – open scales)
Figure 4 (IV) presents the pattern of movement of the larch cone scales in subsequent opening phases. The broken line represents the selected scales on the closed cone cross-section, the deflected scales were outlined with full line, while “dot-dash” line represents the maximal scale opening at the end of the process.

In the cones of spruce there occurs also some opening of next-to-stem part scales (Fig. 5), but this part is shorter in relation to larch scales, although it applies to bigger cones (Tab. 1). Besides, the middle and top parts are longer by two or three times. It affects the bigger opening angle of scale (in the case of scales of middle part even up to 50º – Fig. 6) and facilitates seed extraction situated on the scales. Therefore, the opening time of spruce scales and seed extraction is shortest.

![FIGURE 5. Views of changes in spruce cone during opening process – view of deflecting cone scales (I–IV)](image)

![FIGURE 6. Change in opening angle of spruce cone: a – closed, b – open](image)
The scale thickness is similar in both species, while the pine scales are thicker and their next-to-stem part is about 5 mm long, and the middle and top parts (together) about 15 mm (three times longer). This difference allows for bigger scale opening in favourable temperature conditions, although not as good as in spruce, where middle and top parts are almost six times longer the next-to-stem part. The pine scales are also characterized by least distinct opening limit between the next-to-stem part and the remaining ones. The total bending of the scale occurs in this species, visible in three parts (Fig. 7), while the larch next-to-stem part practically does not change its position. It can be assumed that the lack of deflection of this scale part causes slower seed extracting from the larch cones. Therefore, to improve seed extraction one should change the storage conditions of the cones and to force a continuous movement of cones (closing and opening). It can be done by alternate drying and moistening of cones after previous reduction of their water content.

CONCLUSIONS

1. The three parts can be distinguished in the cones of pine, spruce and Polish larch: next-to-stem, middle and top ones. The two last distinctly change their position in relation to the stem during opening process.

2. The next-to-stem part of scale in investigated European larch cones does not change its position during opening and makes over 37% of scale, while in the remaining species it makes 26% (pine) and 14% (spruce).

3. Change in opening angle of the closed and open scales of Polish larch is smallest and amounts to about 30%, while in spruce it can reach up to 50%. Therefore, the seed extraction is easier in spruce than in larch.

FIGURE 7. Views of changes in pine cone during opening process – view of deflecting cone scales (I–IV)
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Abstract: Investigations on logging process of wind damaged trees with the internal combustion chain saw. The work aimed at determination of the time share of particular technological operations in the process of wood logging of various types of damaged trees. The investigations were carried out during redressing of the hurricane effects in Forest Inspectorate Osie RDLP Toruń in June 2007. It was found that number of operations executed on a tree did not directly affect the logging time. The longest logging time was found for standing inclined trees and windfallen trees (on the average 232 sec. and 181 sec., respectively). Branching was most time-consuming operation and averaged to 57.5% of logging time for all investigated types of trees. It was found that technological down times resulting from specific after-calamity conditions could prolong even several times the logging time of a given tree.

Key words: windfall, logging, operational time balance.

INTRODUCTION

Logging on natural calamity sites is regarded as one of most dangerous forest operations. It is mainly connected to variability of situations resulted from a strong wind impact or e.g. fire; this calls for individual approach of the chain saw operator (Suwała 2004; Muszyński 1999). The broken or partly burnt root systems of trees cause their self-acting falling of still standing trees under even weak wind or the part of crown of adjacent tree during its falling. Strong and difficult to determine internal stress of heaped trees, especially on wind-damaged sites, can cause hitting of saw operator with a tree during unskillful felling, branching or cross-cutting; this often results in a serious accident leading to continuous disablement for work or death (Brzózko 2009).

Application of mechanical logging considerably improves the work safety. The operator of logging machine is protected by a cab, and he can reduce an internal stress in wood by its stretching or shifting with the use of machine. He is usually remote from the place of processing, therefore, even throwing away of strained tree can damage e.g. the working head, but the operator is protected from direct contact with the tree being processed.

However, mechanical logging can not be always applied. If there is lack of appropriate machine or tree damages are small, e.g. in the form of small-area pockets, logging of after-calamity wood in Poland is most often executed with the use of internal combustion chain saws.
The work aimed at recognition of the time balance of saw operator’s work during wood logging of damaged trees on after-calamity area. It would allow for further comparison to the effects of saw operators’ work under felling and pre-felling conditions on undamaged sites. It may enable to determine the effect of difficult (after-calamity) conditions on the logging time prolongation when compared to normal conditions.

MATERIAL AND METHODS

The investigations were carried out on the site of Forest Inspectorate Osie RDLP Toruń in the forest district Zajęcza Kąt, where on 11th May 2007 a several-minute hurricane occurred; it resulted in devastation of 100-year old forest stand in 342d compartment. The estimated area for felling amounted to about 1 ha, while the total volume of trees to be removed was equal to about 200 m³.

The investigations consisted in observations and recording of logging process (with no interference in its realization) with the use of a digital camera.

A five-person team of Forest Service Establishment from Forest Inspectorate Osie was involved in raw timber logging. All workers were very experienced professionally (about 15-20 years of forest employment). The wood was harvested in the longest possible segments. The sawman with his assistant were felling, throwing down, branching and cutting off the tree-top and not useful tops. The task of skidding man was skidding of usable segments with the use of tractor with a yarder to the logging road, where segments were processed and piled by the second sawman with his assistant.

The working team was equipped with:

- two internal combustion chain saws Husqvarna 357XP,
- agricultural tractor Ursus C-330 with log stacker, yarder and catching ropes,
- two axes, plastic wedges, lever – cant hook,
- five safety helmets (for each worker); the sawmen were additionally equipped with: trousers with anti-cutting insert, anti-vibration gloves and eye and hearing protectors.

The work of sawman and his assistant was observed on the after-calamity site during logging. The assistant’s task was to remove branches that disturbed in the sawman’s work during branching, and to put in and to strike of wedges during felling and – if necessary – during cross-cutting. Additionally, then sawman often consulted his assistant with respect to making kerfs during felling and cross-cutting.

The damaged trees were differentiated as follows:

- standing trees inclined (designated as type 1),
- high and low standing trees with broken off part of tree stem (type 2),
- fallen trees (type 3),
- gate-type broken trees (type 4),
- lying tops broken off from standing trees that supplemented type 2 (type 5).
The effect of main parameters of the tree and of the chain saw on timber harvesting time is well known and described in references (Kozłowski 2003; Maciak 2006; Wójcik 2007). One of the most important parameters is diameter of harvested trees. Since measuring of damaged trees’ diameters prior to harvesting was impossible with respect to safety, this factor was estimated on the basis of comparison between the length of chain saw guide used by sawman (45 cm), while particular trees were included in the following ranges: 20–30, 30–40, 40–50, 50–60 and 60–70 cm. No trees of bigger or lower diameters were found in the investigated sample.

In the process of timber harvesting executed by the sawman and his assistant the following operation were distinguished:

1. Felling operation consisted of:
   1.1. Preparation of place,
   1.2. Execution of undercutting kerf,
   1.3. Inclining of tree (beating of wedges),
   1.4. Execution of cutting kerf,
   1.5. Additional operations.
2. Branching operation consisted of:
   2.1. Cutting off branches and knots,
   2.2. Pulling off branches,
   2.3. Additional operations.
3. Cross-cutting operation consisted of:
   3.1. Preparation of place (pulling off branches, pulling off tree stem),
   3.2. Cutting off blocks,
   3.3. Additional operations.

Depending on type of tree damage the logging process could consist of additional operations occurring during execution of distinguished operations, including e.g. removing of suspended tree, releasing of jammed guide (beating of wedges) or cutting off the supported top. Of course, some operations presented in points 1–3 might not be included.

RESULTS OF INVESTIGATIONS AND THEIR ANALYSIS

Figure 1 presents the time balance of particular technological operations in timber harvesting as a result of observations of tree damaged by their inclination (type 1) on the investigated wind-fallen site. In this case the preparation of working place was not time-consuming; in three cases it amounted to 10, 11 and 13 seconds, while in the remaining cases it was needless.

This type of damage is characterized by a forced direction of falling tree resulted from its inclination. Its consequences could be observed in branching. Although average branching time for such type of tree amounted to 120 sec., in the case of the last tree it amounted to 412 sec. This increase was caused by the tree placing among thick bushes and previously cut branches, forced by direction of falling, that made branching longer and more difficult. It was not only difficulty connected with tree falling direction, which can be slightly corrected by an experienced sawman, but sometimes suspension of tree can not be avoided. It occurred in three cases, where pulling off the suspended trees amounted to 115, 163 and 170 sec., affecting an average time of timber harvesting of these trees.

Figure 2 presents time balance for particular operations of technological process of timber harvesting for standing
trees with broken off part of tree stem (type 2). A basic difficulty here was determination of direction of falling. In trees without crowns, direction of the tree’s gravity centre leaning is far more difficult to predict. It was proved by results of investigations. The average time of preparation amounted to 15 sec. and was highest among the investigated types of trees, since the sawman deter-
mined direction of falling. Unlike type 1, the preparation took a significant part of total harvesting time. The difficulties in determination of falling direction affect also the method of logging. In felling of trees with this type damage the woodcutter was leaving slightly bigger hinge to enable the tree movement in other direction than assumed. Additionally, all trees (except one) were fallen with the use of wedges (for safety reasons).

Branching was executed in the three cases out of seven, but was the longest operation. The lack of branching in the remaining cases resulted from the lack of branches and knots on sides of tree. It occurred always in low-broken trees and in most cases in medium-broken trees.

Figure 3 presents time balance for particular operations of technological process of timber harvesting for wind-fallen trees (type 3). Timber harvesting from trees of this type seems apparently simple; trees are already blown over so there is no need for cutting kerfs and falling. However, there were observed many specific situations that do not occur under conditions of undamaged stands or occur occasionally; they affected particular operation times of the entire logging process. These factors were found mainly in this group of damaged trees, e.g. technological breaks occurred in six cases out of twenty one and consisted in pulling off trees out of piles and in releasing of jammed guide. One tree was particularly difficult; all specific times were here longer than that for other trees. It was caused by large number of branches and difficult access to the tree stem. To branch this tree fully, a skidding tractor’s yarder had to be used.

![Time balance for particular operations of technological process of timber harvesting for wind-fallen trees (type 3)](image)

**FIGURE 3.** Time balance for particular operations of technological process of timber harvesting for wind-fallen trees (type 3)
to pull off other trees from an after-hurricane pile. It was complicated operation, since trees were additional twisted which called for appropriate operational sequence. In this case the cross-cutting time exceeded 440 sec. (over 7 minutes). The logging process was difficult due to stresses, big stem diameter and the but broken along its fibres. The long time resulted also from necessity to cut off the rootstock and later the broken butt from the stem. In total pulling off the jammed guide lasted over 300 sec (over 5 minutes). For comparison, the average cross-cutting time for trees of this time amounted to 51 seconds.

Figure 4 presents time balance of particular technological operations of timber harvesting from gate-type broken trees (type 4). This type of damage is one of most difficult in logging on wind-damaged site. The sawman had to be extremely careful since a broken top could come off the stem, creating a serious threat to health or even life of him and his assistant. Proper identification of stresses in the ground-supported part and the butt part of stem can be difficult for inexperienced sawmen. The top by its weight inclines the butt part slightly, while big stresses are created inside the tree’s fibres. Another characteristic feature of wind broken trees is a large number of required operations. Although the butt part can be regarded as the entire tree, one should consider also additional operations as e.g. cutting off the supported top or additional places of cross-cutting – in the place of stem breaking.

Preparation for felling of gate-type broken trees did not take much time, although it was executed more carefully than for other trees with respect to hanging top – on the average it lasted 11 sec. In cutting off the supported top the obtained results were more varied: the
shortest time amounted to 9 sec, the longest 35 sec. Times of kerf execution: undercutting, cutting and branching were similar to other types of damaged trees.

Figure 5 presents time for branching and cross-cutting of tops broken off the stem and laid on the ground (type 5). Very short cross-cutting time and significantly longer branching time are characteristic for trees of this type. The loggers do not like this type of damage since it calls for a big sawman’s effort in branching of numerous branches and timber harvesting productivity is small due to usually small diameter of assortments.

Figure 6 presents the specific average time balance of operations depending on type of harvested wood damage.

The least average time of timber harvesting was found for standing trees with broken off crown. It may be strange, but other trees requiring less technological operations were harvested slower. It can be explained with the fact that felling of trees with damage of this type are similar to typical undamaged trees. Therefore, in spite of fairly big number of operations on a single tree, the sawman’s work was efficient and quick. Additionally, a small number of branches significantly shortened the time of branching.

Average time of timber harvesting from gate-type broken trees was by several seconds longer than that for standing trees without tops. It might be caused by small dimensions of gate-type broken trees when compared to other trees as well as big experience and professionalism of the sawman. Another reason could be the usual smaller density of broken trees, enabling much freedom in the chain saw handling.
The laid tops broken off the stem, in spite of appearances, were not in the group of quickest harvesting. They did not require many various operations, but the work was laborious and less effective. Branching itself lasted longer than average time of total harvesting of fallen and gate-type broken trees. The laid tops were often placed in dense bushes of shrub layer or were entangled with other branches.

The windfallen trees were processed on the average by about 200 sec. and so long time could be caused by dimensions of trees. While in previous cases the sawman processed only the part of standing tree (butt or top), he had here to branch the whole length of tree and this time took half of total time. The cross-cutting of such trees was also not easy. Trees laid often in piles, one on another, that caused strong stresses; this always slows down the operations due to necessity of their minimization. Unskillful or careless cutting off rootstock may cause unintentional kickback of stem or crushing with the rootstock returning to ground or laid in direction of the stem. Various wood stresses call for consultations on application and utilization of tractor yarder.

The inclined trees often occur under normal felling conditions, however, inclinations of windfallen trees are bigger. While at small inclination it is possible to correct direction of falling, at strong...
inclination it is limited. Therefore, the feller practically does not affect the direction of falling that is influenced by the wind direction inclining the tree. This complicates branching; in this case it took half of operational time on a tree. Rest of operations did not much differ from average values obtained for other tree damage.

In total about 32 m³ (46 trees) were harvested during investigations. Operational productivity amounted to about 4 m³/h. This value should be regarded as very high. However, it should be noted the work was done by a very experienced team, and in order to increase the maximal productivity not all safety requirements were observed (e.g. the sawman abandoned preparation of working place for felling). Therefore, comparison of the obtained results to that obtained under normal conditions can not be taken as a basis for general conclusions. The investigations should be then continued on the sites of other type.

CONCLUSIONS

1. Number of operations executed on a tree does not influence directly the rate of logging. Timber harvesting from gate-type broken trees lasted on the average about 90 s with five operations executed, harvesting from the laid tops about 110 sec. with two operations.

2. The most time-consuming operation was branching; it took 57.5% of total time on the average for all types of trees. It is consistent with results of Wójcik (2007) for experienced sawmen harvesting timber with clear felling area by long log system, where branching time amounted to 57% of total harvesting time.

3. The investigated team most harvested timber most quickly from broken trees (on the average 83 sec.) and gate type broken trees (93 sec.), then from laid tops (113 sec.), windfallen trees (181 sec.) and inclined trees (232 sec.).

4. In inclined trees and windfallen trees of shortest harvesting time, there occurred technological breaks more often than for other damage types; it was caused by factors characteristic for after-calamity conditions (e.g. for inclined trees the average time of pulling off the suspended tree amounted to 64 sec. while for windfallen trees the average time of releasing the jammed guide amounted to 25.2 sec.).

5. Some operations executed during work on windbreak site are more difficult when compared to undamaged conditions. It influenced the range of time, e.g. branching amounted to 12 to 412 sec.

6. The operational productivity achieved by the team was high as for after-calamity conditions, but with a sacrifice of safety due to excessive hurry.

7. Diameter of trees of the investigated sample did not significantly influenced the harvesting time. This is opposite to results obtained by other
authors for undamaged felling stands (Wójcik 2007). However, one can not conclude that it is caused by aftercalamity nature of site, since it may result from small sample size recorded for particular types of damage. Therefore, it can not be generalized. Further investigations are needed to confirm it.

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Resistance of basket willow stalks \textit{(Salix viminalis L.)} to static bending

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Department of Agricultural and Forest Machinery, Warsaw University of Life Sciences – SGGW

\textbf{Abstract:} Resistance of basket willow stalks \textit{(Salix viminalis L.)} to static bending. Basing on carried out investigations one can find that stalk wood moisture content increases along with the distance from ground by 3\% per every 300 mm. The wood of average moisture content \( W_1 \) (71.55\%) and \( W_2 \) (28.34\%) is so elastic that no distinct point of sample breaking can be found. The wood resistance to bending depends on its moisture content. The average stress values in bending, depending on average wood moisture content, amount to 40 MPa at moisture 71\%, 46 MPa at moisture 28\%, and 144 MPa at moisture 1\%, respectively.

\textit{Key words:} stress, basket willow, moisture content, resistance, static bending.

\textbf{INTRODUCTION}\n
Basket willow has been recently more and more popular as a plant material grown for energetic purposes (Szczechowski et al. 2006; Dubas 2003). It is easy to cultivate, and is characterized by big weight gains and annual yield of dry mass of about 13 t·ha\(^{-1}\) (Jeżowski 2003; Stolarski 2004; Szczechowski and Tworkowski 2004; Borkowska H. 2005). This yield calculated per hectare corresponds to over 7 tons of coal (Dubas et al. 2004). Therefore, a new market is created to meet the growing demand for the willow chips. It is a chance for local communities towards breaking away from traditional fossil fuels and leaving incomes in the willow cultivation regions (Majtkowski 2007). The barrier determining efficient utilization of energetic willow’s wood is a shortage of special machines for its harvesting and processing (Lisowski 2006; Pasyniuk 2007; Nowakowski et al. 2008). Unfortunately, in available references there is a lack of information on mechanical properties of willow wood, needed for designing of such machinery. This work aimed at determination of basket willow stalks’ resistance \textit{(Salix viminalis L.)} to static bending, depending on moisture content and the zone of taking samples for investigations.

\textbf{MATERIAL AND METHODS}\n
The annual shoots of basket willow \textit{(Salix viminalis L.)} were investigated. They were obtained from experimental plantation of energetic plants of Faculty of Agriculture and Biology WULS in Skiermiewice. From the field 160 shoots were randomly taken; their characteristic is presented in Table 1. In further investigations the butt end of each shoot of length 1200 mm (divided into four
parts) was used. The assumed shoot division created four groups of samples of length 300 mm: A (0–300 mm), B (300–600 mm), C (600–900 mm) and D (900–1200 mm). In further investigations there were used 30 samples, randomly selected from each group.

Resistance to static bending was investigated for three moisture content classes of 10 samples in every group, to determine stress occurring in the machines during various willow harvesting and processing methods. Division of samples with respect to moisture content aimed at obtaining the results corresponding with the following properties of: fresh wood (W1) – obtained and processed directly after harvest, the stored wood (W2) – processed after storage period, when air-dry moisture is obtained, and the wood fully dry (W3) – the control samples used for comparison of the results obtained. The moisture content was measured by dryer method according to PN-EN 13183-1 Standard. The sample mass was determined with accuracy 0.01 mm with the use of scale RADWAG WPS 600/C.

The resistance to static bending was determined basing on PN-77/D-04103 Standard. It called for modification of the concerning recommendations with respect to circular cross-sections of samples. The measurement of destructive (bending) force was performed with the use of a testing machine TIRAtest controlled with the software MATEST. During the stalk bending tests the support spacing amounted to 0.20 m, while the head movement speed was equal to 0.01 m·min⁻¹. The investigated samples were loaded at their half-length, perpendicularly to radial cross-section.

Basing on the performed measurements, the resistance to static bending was determined. The following dependence was used in calculations of maxi-

<table>
<thead>
<tr>
<th>Value</th>
<th>Median</th>
<th>Mode</th>
<th>Standard deviation</th>
<th>Variability coefficient [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of stalk</td>
<td>300.16</td>
<td>168.2</td>
<td>568</td>
<td>289.65</td>
</tr>
<tr>
<td>Length of plant</td>
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<td>2600</td>
<td>4300</td>
<td>3400</td>
</tr>
<tr>
<td>Stalk diameter at height</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>18.30</td>
<td>14.5</td>
<td>25</td>
<td>18</td>
</tr>
<tr>
<td>150</td>
<td>16.62</td>
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<td>23</td>
<td>16</td>
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<tr>
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<td>14.96</td>
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<td>20</td>
<td>16</td>
</tr>
<tr>
<td>750</td>
<td>14.10</td>
<td>11.0</td>
<td>19.5</td>
<td>14</td>
</tr>
<tr>
<td>1000</td>
<td>13.29</td>
<td>10.0</td>
<td>17.5</td>
<td>13</td>
</tr>
<tr>
<td>1250</td>
<td>12.47</td>
<td>9.0</td>
<td>17</td>
<td>12</td>
</tr>
<tr>
<td>1500</td>
<td>11.64</td>
<td>8.5</td>
<td>16</td>
<td>11</td>
</tr>
<tr>
<td>2000</td>
<td>9.84</td>
<td>5.0</td>
<td>14</td>
<td>10</td>
</tr>
</tbody>
</table>

TABLE 1. Specification of research material

<table>
<thead>
<tr>
<th>Stalk diameter at height [mm]:</th>
<th>Value</th>
<th>Median</th>
<th>Mode</th>
<th>Standard deviation</th>
<th>Variability coefficient [%]</th>
</tr>
</thead>
<tbody>
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<td>14.5</td>
<td>25</td>
<td>18</td>
<td>11.6</td>
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<tr>
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<td>16.62</td>
<td>13.5</td>
<td>23</td>
<td>16</td>
<td>10.3</td>
</tr>
<tr>
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<td>14.96</td>
<td>12.0</td>
<td>20</td>
<td>16</td>
<td>10.7</td>
</tr>
<tr>
<td>750</td>
<td>14.10</td>
<td>11.0</td>
<td>19.5</td>
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</tr>
<tr>
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<td>13.29</td>
<td>10.0</td>
<td>17.5</td>
<td>13</td>
<td>11.6</td>
</tr>
<tr>
<td>1250</td>
<td>12.47</td>
<td>9.0</td>
<td>17</td>
<td>12</td>
<td>12.3</td>
</tr>
<tr>
<td>1500</td>
<td>11.64</td>
<td>8.5</td>
<td>16</td>
<td>11</td>
<td>12.5</td>
</tr>
<tr>
<td>2000</td>
<td>9.84</td>
<td>5.0</td>
<td>14</td>
<td>10</td>
<td>15.8</td>
</tr>
</tbody>
</table>
Resistance of basket willow stalks...

Normal normal stress in the cross-section of sample:

\[ \sigma_{g \text{ max}} = \frac{8 P_g l}{\pi d^3} \quad (1) \]

Where:
- \( \sigma_{g \text{ max}} \) – resistance to static bending [MPa],
- \( P_g \) – destructive (bending) force [N],
- \( d \) – diameter of sample [mm],
- \( l \) – spacing of testing machine’s supports [mm].

RESULTS AND DISCUSSION

The obtained results of moisture content measurements for particular zones of sampling are presented in Table 2. The average values for fresh wood amounted to W1 – 71.55%, for stored wood W2 – 28.34% and for fully dried wood W3 – 1.03%.

As it is evident, the absolute moisture content of fresh wood (W1) increases by 3% per every 300 mm of the distance between point of sampling and the butt end. The same trend is maintained for partially dried wood (W2). It is probably connected with differentiation of internal structure of wood on a stalk, with the increase in a distance from the ground. The lower moisture content of the butt end parts of stalks is caused by bigger share of ligneous cells.

The samples of fresh and partially dried wood showed a substantial elasticity. They were so flexible that they did not break within their bending range obtained from the testing machine. The bending force increased very quickly after beginning of test, and its course was almost linear. Then, when a certain point (plasticity limit) was reached, the course of change in force became curvilinear and similar to reversed parabola. The force increased as long as the maximal value was obtained, and then decreased slowly. The wood moisture content in groups W1 and W2 was too big to destruct (to break) the sample, while the samples of group W3 was sufficiently dry to find a distinct occurrence of destructive force on the bending force diagram in the moment of sample breaking up.

Figure 1 presents the destructive force values for particular samples and mean values divided into groups.

As it is evident, a proportionally bigger bending force is needed to destruct the sample of bigger diameter. Deviation

| TABLE 2. Average moisture content of basket willow wood divided into groups |
|------------------|------------------|------------------|------------------|------------------|
|                 | Group A | Group B | Group C | Group D | Mean  |
| W1   Average moisture [%] | 66.67  | 70.10  | 73.12  | 76.29  | 71.55 |
|       Standard deviation [%] | 7.99   | 7.82   | 12.07  | 6.44   | 8.58  |
| W2   Average moisture [%] | 24.48  | 28.06  | 25.02  | 35.81  | 28.34 |
|       Standard deviation [%] | 10.07  | 12.17  | 9.77   | 9.83   | 10.46 |
| W3   Average moisture [%] | 1.14   | 1.03   | 1.00   | 0.94   | 1.03  |
|       Standard deviation [%] | 0.30   | 0.19   | 0.15   | 0.16   | 0.22  |
of the points from a linear course within the same moisture content can be caused by the difference in moisture content of particular samples. As these deviations increase with a decrease in moisture one can conclude that it is also due to other reasons, e.g. the difference in internal structure of the material. Another observable trend is a distinct increase in maximal bending force needed to destruct the sample, along a decrease in absolute moisture content. It means that moisture content is one of the main factors influencing resistance to static bending.

Figure 2 presents the results of investigated wood resistance to static bending.

As it was proved by statistical analysis, the stress values at bending of particular samples of the same moisture content did not significantly differ from each other. The average values amounted to: W1 – 40 MPa, W2 – 46 MPa, W3 – 144 MPa, respectively. It means that the point of sampling does not significantly affect the resistance to static bending.

SUMMARY

Basing on analysis of the results obtained in carried out investigations one can find that the absolute moisture content of basket willow fresh wood increases by 3% per every 300 mm of an increase in
the distance between the point of sampling and the butt end. When the absolute moisture content is decreased, the internal bending stress of the wood fibres increases. It means that the resistance to static bending depends greatly on absolute moisture content of the sample. During drying of samples, their resistance to static bending increased. The maximal bending force needed to destruct the sample increased along with a decrease in absolute moisture content. The sample breaking up did not occur at moisture contents W1 and W2. The wood of such absolute moisture maintains big elasticity. The values of stalk resistance to static bending were similar for all sample groups at each investigated moisture content. As the sample diameter increases, the bending force needed for destruction of the sample increases proportionally. The values of internal bending stress were similar for all the sample of the same moisture content. Therefore, the sampling point on a stalk does not influence significantly the sample’s resistance to static bending. At moisture content W3, the measurements on destructive force variability depending on sample diameter distinctly differed from a linear course, thus, the absolute moisture content is not the only factor affecting resistance to static bending.

FIGURE 2. Resistance of samples to static bending
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PN-77/D-04103 Drewno. Oznaczenie wytrzymałości na zginanie statyczne.

Streszczenie: Wytrzymałość łodyg wierzby wiciowej (Salix viminalis L.) na zginanie statyczne. Drewno wierzby energetycznej jest coraz popularniejszym materiałem stosowanym jako materiał przeznaczony na cele energetyczne. Wierzba charakteryzuje się łatwością uprawy oraz dużymi plonami z jednego ha, odpowiadającymi 7 tonom węgla kamiennego. Barierą decydującą o wydajnym wykorzystaniu drewna wierzby energetycznej jest niedobór specjalistycznych maszyn do jej zbioru i obróbki. Brak informacji na temat mechanicznych właściwości drewna wierzby, potrzebnym do konstruowania takich maszyn wymusiło przeprowadzenie pomiarów i określenie wytrzymałości drewna na zginanie statyczne w zależności od wilgotności i strefy pobrania próbki. Ze względu na kształt próbek i odniesienie wyników do warunków rzeczywistych, oznaczenia wytrzymałości dokonano na podstawie zmodyfikowanych zaleceń zawartych w normie PN-77/D-04103.

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Abstract: Analysis of machinery fleet modernization effects in the farm with an example of strawberry production. Selected strawberry production technologies and their mechanization possibilities were compared in the context of labour inputs, application of special technical equipment and the obtained economic production indices. Basing on carried out analysis there were proved that turning from a traditional row cultivation system to strawberry cultivation in beds enables to increase production profitability and to decrease labour inputs, while the purchase costs of essential equipment will be refunded in a three-season period of strawberry production.

Key words: cost, mechanization, modernization, technology, strawberries.

INTRODUCTION

Strawberry production In Poland takes about 5% of total fruit production, while an average cultivation area in the last decade amounted to about 53.3 thousand ha. At present Poland is the biggest producer and exporter of chilled strawberries in European Union, and the second producer of fresh strawberries (next to Spain). In spite of this fact, enormous percentage of strawberry-producing farms use the old and labour consuming methods [Masny and Żurawicz 2005].

The labour costs constitute a great share in total production costs of strawberries and other fruits and vegetables. Therefore, to increase the horticulture production profit one should apply technologies that enable to reduce the cost inputs and to make production independent of such atmospheric phenomena as drought; it can be achieved, among other things, by mechanization of production system. However, it is not always profitable, and one should analyze in advance the effects of planned modernization in respect of increasing the production profit and the time needed for refunding the investment costs [Pierzga and Szczygiel 2004].

To reduce the strawberry production costs connected to workers’ employment one should apply new technologies and use possibilities of technological progress, that is new machines allowing for mechanization of these fruits’ production, starting from field preparation and planting till harvesting, which is still most difficult to mechanize. A wide market offer of technical equipment for mechanization of fruit production facilitates undertaking the modernization decision concerning production technologies of particular fruit groups in the farms [Gaworski 2008].
Against a background of the above discussion a question of technological improvement profitability is particularly interesting with consideration to increasing share of technical means for mechanization of strawberry production. Therefore, this work aimed at comparison between the selected technologies of strawberry production and mechanization possibilities in the respect of labour inputs, application of special technical equipment and the obtained economic production indices.

ASSUMPTIONS OF COMPARATIVE ANALYSIS

Strawberry production technologies including a traditional row cultivation system and a modern cultivation in beds were selected for detailed comparative analysis.

Taking example of a real farm object situated in the Mazovian region and specialized in strawberry production there were considered the utilization costs of technical means and manual labour inputs in production technologies compared. A direct surplus per 1 ha of grown fruits was calculated in three subsequent years after planting with consideration to variable costs of consumed production means, service costs and the value of strawberry merchandise production.

The farm modernization in respect to strawberry production improvement assumes changes in the selected cultivation stages both through mechanization and turning to more efficient technologies.

A key modernization premise is turning form the row-strap cultivation system to cultivation in beds. It is connected to an increase in plant density per hectare from 50 000 to 64 000 and with installing of a system for plant irrigation and fertigation, consisted of T-tape dripping lines connected to own water intake. It makes the crop independent of drought and allows for additional plant feeding in the fluid form. To control weed development the beds are covered with a black-and-white foil, while the straps between rows are mulched with the cut straw. Due to mulching, irrigation and fertigation it is possible to increase the total yield and average price for fruits, since more fruits are of extra class.

An important action that calls for the highest inputs is purchase of machines needed for strawberry cultivation in beds and for an improvement of operations on the plantation, such as a stake planter and straw spreading machine; their overall cost in 2009 was estimated as about 54 500 PLN. Besides, the tractor should be adapted to new cultivation system including narrow tyres for interrow operation (the second hand tyres cost about 1500 PLN) and a special spraying boom of Fragaria type should be designed to improve effectiveness of chemical applications against pests and diseases.

RESULTS OF ANALYSIS

Results of calculations involving time and tractor operation cost on strawberry plantation during entire production cycle of traditional row cultivation are presented in Table 1.
TABLE 1. Tractor time and operational cost on strawberry plantation during entire production cycle in traditional row cultivation

<table>
<thead>
<tr>
<th>Item</th>
<th>Machine</th>
<th>Time of operation [h]</th>
<th>Cost [PLN]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fertilizer application</td>
<td>fertilizer spreader</td>
<td>0.5</td>
<td>10.99</td>
</tr>
<tr>
<td>Tillage</td>
<td>tillage set</td>
<td>1</td>
<td>30.85</td>
</tr>
<tr>
<td>Lifting of seedlings from nursery</td>
<td>digger</td>
<td>0.5</td>
<td>10.99</td>
</tr>
<tr>
<td>Planting of plants</td>
<td>planter</td>
<td>16</td>
<td>351.68</td>
</tr>
</tbody>
</table>

  **First year after planting**

<table>
<thead>
<tr>
<th>Item</th>
<th>Machine</th>
<th>Time of operation [h]</th>
<th>Cost [PLN]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fertilizer application (2×)</td>
<td>fertilizer spreader</td>
<td>1</td>
<td>21.98</td>
</tr>
<tr>
<td>Mechanical weeding</td>
<td>weeder</td>
<td>7</td>
<td>153.86</td>
</tr>
<tr>
<td>Spraying (10×)</td>
<td>field sprayer</td>
<td>5</td>
<td>109.90</td>
</tr>
<tr>
<td>Transport of fruits to farm</td>
<td>trailer</td>
<td>3</td>
<td>65.94</td>
</tr>
<tr>
<td>Mechanical removing of runners</td>
<td>multi-sectional rotary tiller</td>
<td>5</td>
<td>154.25</td>
</tr>
</tbody>
</table>

  **Second year after planting**

<table>
<thead>
<tr>
<th>Item</th>
<th>Machine</th>
<th>Time of operation [h]</th>
<th>Cost [PLN]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fertilizer application</td>
<td>fertilizer spreader</td>
<td>1</td>
<td>21.98</td>
</tr>
<tr>
<td>Mechanical weeding</td>
<td>weeder</td>
<td>9</td>
<td>197.82</td>
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<tr>
<td>Spraying (14×)</td>
<td>field sprayer</td>
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<td>153.86</td>
</tr>
<tr>
<td>Transport of fruits to farm</td>
<td>trailer</td>
<td>7.5</td>
<td>164.85</td>
</tr>
<tr>
<td>Cutting of leaves</td>
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<td>61.70</td>
</tr>
<tr>
<td>Mechanical weeding</td>
<td>multi-sectional rotary tiller</td>
<td>5</td>
<td>109.90</td>
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</tbody>
</table>

  **Third year after planting**

<table>
<thead>
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<th>Cost [PLN]</th>
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</thead>
<tbody>
<tr>
<td>Fertilizer application</td>
<td>fertilizer spreader</td>
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<td>10.99</td>
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</tr>
<tr>
<td>Transport of fruits to farm</td>
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<td>7</td>
<td>153.86</td>
</tr>
<tr>
<td>Total tractor operation</td>
<td></td>
<td>89.5</td>
<td>2038.17</td>
</tr>
</tbody>
</table>

Source: author’s own elaboration.

The calculated values of direct surplus in strawberry traditional row cultivation system are presented in Table 2.
The time and cost of tractor operation during strawberry cultivation in beds are presented in Table 3.

Table 4 presents the calculated direct surplus values for strawberries cultivated in beds.

Comparing the data of Tables 1 and 3 one can find that the tractor time and cost of its operation are higher for modernized plantation of strawberries cultivated in beds than in traditional cultivation system. The modernization increases the share of machine operations, and decreases the share of manual operations. Besides, the fruit yield and price are also higher, since on traditional plantation 50% of fruits are of extra class designed for direct sale, and 50% are fruits for industrial processing. On the plantation where strawberries are cultivated in beds these figures amount to 80% and 20%, respectively (the price given in Tables is a weighed mean of GUS prices for the last four years).

After modernization, apart from direct surplus the production costs of fruits are also higher twice when compared to previous technology. It results, among other things, from higher input for the workers casually employed during fruit harvest, higher prices for fertilizers used in fertigation in relation to granular mineral fertilizers and the costs of irrigation installation, mulching materials and the production of seedlings in pots.

The reduced quantities of applied plant protection products (herbicides) should also be noted.

---

**TABLE 2. Profit of strawberry production in traditional row cultivation system**

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>Specific price</th>
<th>Value [PLN]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Merchandise production: strawberries</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>First year after planting</td>
<td>2 500 [kg]</td>
<td>1.88 [zł/kg]</td>
<td>4 700.00</td>
</tr>
<tr>
<td>Second year after planting</td>
<td>17 000 [kg]</td>
<td>1.88 [zł/kg]</td>
<td>31 960.00</td>
</tr>
<tr>
<td>Third year after planting</td>
<td>15 000 [kg]</td>
<td>1.88 [zł/kg]</td>
<td>28 200.00</td>
</tr>
<tr>
<td>Services:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Casual employment of workers - cultivation</td>
<td>602 [h]</td>
<td>8.00 [zł/h]</td>
<td>4 816.00</td>
</tr>
<tr>
<td>Casual employment of workers - harvest</td>
<td>34 500 [kg]</td>
<td>0.50 [zł/kg]</td>
<td>17 250.00</td>
</tr>
<tr>
<td>Costs of tractor operation</td>
<td>89.5 [man-hour]</td>
<td></td>
<td>2 038.17</td>
</tr>
<tr>
<td>Variable costs of consumed production means</td>
<td></td>
<td></td>
<td>37 721.89</td>
</tr>
<tr>
<td>Profit per 1 ha</td>
<td></td>
<td></td>
<td>27 138.11</td>
</tr>
</tbody>
</table>

Source: author’s own elaboration.
TABLE 3. Time and cost of tractor operation during strawberry cultivation in beds

<table>
<thead>
<tr>
<th>Item</th>
<th>Machine</th>
<th>Time of operation [h]</th>
<th>Cost [PLN]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tillage</td>
<td>tillage set</td>
<td>1</td>
<td>30.85</td>
</tr>
<tr>
<td>Fertilizer application</td>
<td>fertilizer spreader</td>
<td>0.5</td>
<td>10.99</td>
</tr>
<tr>
<td>Tillage</td>
<td>rotary tiller</td>
<td>5</td>
<td>154.25</td>
</tr>
<tr>
<td>Shaping of beds and planting</td>
<td>stake planter</td>
<td>16</td>
<td>493.60</td>
</tr>
<tr>
<td>Mechanical weeding</td>
<td>weeder</td>
<td>2.5</td>
<td>54.95</td>
</tr>
<tr>
<td>First year after planting</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mechanical weeding</td>
<td>weeder</td>
<td>2.5</td>
<td>54.95</td>
</tr>
<tr>
<td>Chemical plant protection</td>
<td>sprayer + herbicide boom</td>
<td>1.5</td>
<td>32.97</td>
</tr>
<tr>
<td>Spraying (8×)</td>
<td>field sprayer + Fragaria boom</td>
<td>4</td>
<td>87.92</td>
</tr>
<tr>
<td>Mulching</td>
<td>straw spreading machine</td>
<td>8</td>
<td>246.80</td>
</tr>
<tr>
<td>Transport of fruits to farm</td>
<td>trailer</td>
<td>6</td>
<td>131.88</td>
</tr>
<tr>
<td>Inter-row cultivation</td>
<td>multi-sectional rotary tiller</td>
<td>3</td>
<td>65.94</td>
</tr>
<tr>
<td>Second year after planting</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chemical plant protection</td>
<td>sprayer + herbicide boom</td>
<td>1.5</td>
<td>32.97</td>
</tr>
<tr>
<td>Mulching</td>
<td>straw spreading machine</td>
<td>8</td>
<td>246.80</td>
</tr>
<tr>
<td>Spraying (9×)</td>
<td>field sprayer + Fragaria boom</td>
<td>4.5</td>
<td>98.91</td>
</tr>
<tr>
<td>Transport of fruits to farm</td>
<td>trailer</td>
<td>8</td>
<td>175.84</td>
</tr>
<tr>
<td>Cutting of leaves</td>
<td>mower</td>
<td>2</td>
<td>61.70</td>
</tr>
<tr>
<td>Inter-row cultivation</td>
<td>multi-sectional rotary tiller</td>
<td>3</td>
<td>65.94</td>
</tr>
<tr>
<td>Third year after planting</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chemical weeding</td>
<td>sprayer + herbicide boom</td>
<td>1.5</td>
<td>32.97</td>
</tr>
<tr>
<td>Mulching</td>
<td>straw spreading machine</td>
<td>8</td>
<td>246.80</td>
</tr>
<tr>
<td>Spraying (8×)</td>
<td>field sprayer + Fragaria boom</td>
<td>4</td>
<td>87.92</td>
</tr>
<tr>
<td>Transport of fruits to farm</td>
<td>trailer</td>
<td>7.5</td>
<td>164.85</td>
</tr>
<tr>
<td>Total tractor operation</td>
<td></td>
<td>98</td>
<td>2579.80</td>
</tr>
</tbody>
</table>

Source: author’s own elaboration.
As a results of carried out calculations one can find that modernization will enhance a substantial reduction of labour inputs during cultivation operations on strawberry plantation. It is about 600 hours in traditional cultivation system, while in in-beds cultivation system it amounts to almost 400 hours per 1 hectare during entire cultivation cycle. It results from reduced weed development due to mulching of beds with a foil and mulching of inter-row straps with cut straw. Thus, the most time-consuming operation i.e. manual removal of weeds from the plant row is greatly eliminated. A big part of 397 hours spent on in-beds

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>Specific price</th>
<th>Value [PLN]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Merchandise production: strawberries</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>First year after planting</td>
<td>12 500 [kg]</td>
<td>2.11 [PLN/kg]</td>
<td>26 375.00</td>
</tr>
<tr>
<td>Second year after planting</td>
<td>23 500 [kg]</td>
<td>2.11 [PLN/kg]</td>
<td>49 585.00</td>
</tr>
<tr>
<td>Third year after planting</td>
<td>21 500 [kg]</td>
<td>2.11 [PLN/kg]</td>
<td>45 365.00</td>
</tr>
<tr>
<td>Services:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Casual employment of workers - cultivation</td>
<td>397 [h]</td>
<td>8.00 [PLN/h]</td>
<td>3 176.00</td>
</tr>
<tr>
<td>Casual employment of workers - harvest</td>
<td>57 500 [kg]</td>
<td>0.50 [PLN/kg]</td>
<td>28 750.00</td>
</tr>
<tr>
<td>Other costs:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost of water supply</td>
<td></td>
<td></td>
<td>2 940.00</td>
</tr>
<tr>
<td>Peat substrate</td>
<td>35 [l]</td>
<td>9.50 [PLN/l]</td>
<td>332.50</td>
</tr>
<tr>
<td>Multi-pot trays*</td>
<td>400 [pcs.]</td>
<td>0.60 [PLN/pcs.]</td>
<td>240.00</td>
</tr>
<tr>
<td>Mulching black-and white foil 1.4 m × 0.025 um</td>
<td>8020 [mb]</td>
<td>0.85 [PLN/m]</td>
<td>6 817.00</td>
</tr>
<tr>
<td>T-tape dripping line</td>
<td>8010 [m]</td>
<td>0.30 [PLN/m]</td>
<td>2 403.00</td>
</tr>
<tr>
<td>Connecting hose PE 40 mm</td>
<td>100 [m]</td>
<td>3.00 [PLN/m]</td>
<td>300.00</td>
</tr>
<tr>
<td>Couplings</td>
<td>40 [pcs.]</td>
<td>1.50 [PLN/pcs.]</td>
<td>60.00</td>
</tr>
<tr>
<td>Straw</td>
<td>4 [t]</td>
<td>120.00 [PLN/t]</td>
<td>480.00</td>
</tr>
<tr>
<td>Costs of tractor operation</td>
<td>98 [man-hour]</td>
<td></td>
<td>2 579.80</td>
</tr>
<tr>
<td>Variable costs of consumed production means</td>
<td></td>
<td></td>
<td>71 788.63</td>
</tr>
<tr>
<td>Profit per 1 ha</td>
<td></td>
<td></td>
<td>49 536.37</td>
</tr>
</tbody>
</table>

Source: author’s own elaboration.
plantation are taken by operations connected to preparation of seedlings and machine maintenance.

Unfortunately, modernization will not reduce the inputs for fruit harvesting that could even increase in respect to higher yield. The possible purchase of harvesting machines is not fully justified due to their high prices; besides, the employees are generally interested in fruit harvesting by traditional method [Malinowski 2009].

**SUMMARY**

Modernization of production technology can significantly influence an increase in profitability of strawberry production in the farm even by 80%. This increase can result from an increase in general yield of fruits to 23.5 t/ha in the period of full yielding and from the increased share of fruits in extra class to 80% of the total yield. This results from possibility of making production independent of adverse atmospheric conditions as drought, due to installation of drip irrigation system, additional feeding of plants by fertigation, covering beds with foil and interrow straps with straw, and the increased effectiveness of chemical operations due to application of sprayers’ boom of Fragaria type.

Change in production technology will limit the problem of casual employment of workers, since labour inputs for cultivation strawberries in beds will be reduced by about 1/3 when compared to traditional cultivation system.

However, modernization induces high costs, not only single costs of purchasing new machines and adaptation of the existing ones, but also higher costs of running plantation throughout entire cultivation cycle. They are connected, among other things, with the cost of foil to cover the plant rows, installation of irrigation system and more expensive fertilizers for fertigation than granular fertilizers distributed on the field surface.

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Streszczenie: Analiza efektów modernizacji parku maszynowego gospodarstwa na przykładzie technologii produkcji truskawek. Celem pracy było porównanie wybranych technologii produkcji truskawek i możliwości ich mechanizacji w aspekcie ponoszonych nakładów pracy, wyposażenia w specjalistyczny sprzęt techniczny i osiąganych wskaźników ekonomicznych produkcji. Na podstawie przeprowadzonej analizy wskazano, że przejście z tradycyjnego systemu rzędowego na zagonową uprawę truskawek zwiększy dochodowość produkcji, zmniejszy nakłady pracy, a koszty poniesione na zakup niezbędnego sprzętu zwróci się w okresie trzech sezonów produkcji.

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Planning of food production with the use of evolutionary algorithms

RADOSŁAW WINICZENKO
Department of Fundamental Engineering, Warsaw University of Life Sciences – SGGW

Abstract: Planning of food production with the use of evolutionary algorithms. The genetic algorithms have more and more applications in scientific, engineering and management fields. The reason of this popularity is quite obvious: the genetic algorithms are simple, but also powerful tool for searching of better results. Genetic algorithms are biologically inspired search procedures that have been used to solve different problems. They try to extract ideas from a natural system, in particular the natural evolution, in order to develop computational tools for solving engineering problems. The paper presents a general principle of genetic algorithms operation and their application in planning of production.

Key words: genetic algorithms, production planning, optimization.

INTRODUCTION

Present market requirements given to enterprises are high and connected to a substantial risk. An incorrect forecast can result in the stock excess unfavourable for organization, while breach of the set delivery terms can lead to loss of customers. To meet the market requirements the enterprises use new and advanced techniques of production planning and scheduling. Modern planning techniques enable to generate the optimized activity plans in the response to rapid changes in demand and supply.

More and more often the enterprises reach for optimization algorithms, the heuristics-based solutions, where descriptions of production planning and scheduling can be performed manually or by simulation [Cytowski 1996].

So far, the problem of production planning has been most often solved with the use of linear programming methods. Recently, in production planning there are used the genetic algorithms that effectively search for solutions of order establishing problem. Their procedures are often analogical to planning procedures of the user. Optimal solutions are created by evolution. In general, evolutionary algorithms are used in solving problems of detailed scheduling, when majority of problems connected to limitations in the production planning process are solved. The considered limitations concern most often the preparation time, total time of realization or its term.

Production optimization that consists in finding a highest profit will be solved in this paper with the use of genetic algorithms, included in the group of evolutionary algorithms. According to author, the genetic algorithms – in respect to their implementation simpli-
city, high output, versatility, resistance
to local extremes – can be a more effec-
tive tool than other methods (analytical
or enumerative) in finding “better solu-
tions” (in the case of production plan-
ning – finding the maximal production
profits).

MATERIAL AND METHODS

Evolutionary algorithms

Evolutionary algorithms (EA) are algo-
rithms for processing that solve optimi-
ization tasks and searching tasks with the
use of Darwin’s strategy of best adapted
individuals’ survival.

In the group of evolutionary algo-
rithms one should distinguish three ba-
sic optimization methods: genetic algo-
rithms, evolutionary programming and
evolutionary strategies. Each method
emphasizes different attribute of natural
evolution. The genetic algorithms high-
light the role of genetic operators. The
evolutionary programming emphasizes
behavioural changes in at species level.
In evolutionary strategies the behav-
ioural changes at level of individuals are
most important.

Genetic algorithms are the searching
method based on mechanisms of natural
selection and inheritance. They are char-
acterized by high versality and proce-
dures’ simplicity for searching the best
solutions by stochastic method. They
utilize an evolutionary survival principle
for the best adapted individuals [Arabas
2001; Gass 1980].

Genetic algorithms gain more and
more wide application areas in scientific
and engineering community and business
associates. Big interests in this searching
method is caused by its simplicity; it is
also an enormous tool for searching bet-
ter solutions [Ossowski 2006; Cytowski
1980].

The block diagram of a classical ge-
netic algorithm is presented in Figure 1.

Genetic algorithms use in general
the code sequence similarity, therefore,
are mostly free from limitations charac-
teristic for other optimization methods
like continuity, existence of derivatives,
monomodality etc.

Unlike other methods, genetic algo-
rithms determine direction of searching
by application of probabilistic rules of
selection. Genetic algorithms use the
random selection as an instrument indi-
cating direction of further searching in
the areas, where one can expect a sub-
stantial improvement of the results [Vose
1999; Ostantin 2007].

Operational resistance of genetic al-
gorithms consists of four basic features:
coding of parameters, using a minimum
information on the task and random-
ized operations. Conventional searching
techniques are not much resistant, but
their combinations and various variants
are successfully and widely used. How-
ever, as more and more complex prob-
lems occur, there is a need for develop-
ment of new methods, including genetic
algorithms [Zieliński 2000].
Problem of food production planning
The problem of production planning with the use of genetic algorithms is presented giving an example of food production planning described in the Platt’s book (1990).
Numerical example
In a dairy plant 10 000 kg of milk of fat content 3.5% is purchased daily, which gives 350 kg of fat and 9650 of plasma per day. The plant’s daily production capacity amounts to 2000 kg of milk, 400 kg of butter, 800 kg of cheese and 600 kg of sour cream. Plasma consumption per 1 kg of product is equal to: for milk 0.95 kg, for butter 3.44 kg, for cheese 11.08 kg for sour cream 0.75 kg. Fat consumption per 1 kg of product amounts to: for butter 0.85 kg, for cheese 0.78 kg, for milk 0.03 kg, for sour cream 0.22 kg. These number are called technological coefficients.
Particular technological coefficients and profit obtained per product unit are presented in Table 1. Amounts of particular products in kg are designated with symbols $x_1, x_2, x_3, x_4$. 

![FIGURE 1. Block diagram of classical genetic algorithm operation [Rutkowska 1999]](image-url)
Manufacturers are interested in determination of products quantities that provide the highest profit of production.

The task aims at maximization of linear function of profit with satisfying of all limiting conditions.

According to assumed conditions the objective function will be the maximized function in the form:

Max \{ f(x) = 15x_1 + 5x_2 + 0.2x_3 + 4x_4 \}

According to task conditions in development of mathematical model one should assume limitations concerning production of particular products:

\[ 3.44x_1 + 11.08x_2 + 0.98x_3 + 0.78x_4 \leq 9650 \]
\[ 0.85x_1 + 0.27x_2 + 0.03x_3 + 0.22x_4 \leq 350 \]

Besides:
\[ x_1 \geq 400 \] limitations for butter production,
\[ x_2 \geq 800 \] limitations for cheese production,
\[ x_3 \geq 2000 \] limitations for milk production,
\[ x_4 \geq 600 \] limitations for sour cream production,
and decision variables should satisfy additional conditions:
\[ x_1 \geq 0, \ x_2 \geq 0, \ x_3 \geq 0, \ x_4 \geq 0, \]

that limit the range of particular variables variability (quantities of products disposed can not be of negative values).

The task was solved with the use of software package Genetic Algorithm and Direct Search Toolbox of Matlab version R2008a, by introduction of an appropriate function entry in so called m-file of Matlab.

Below there is shown the entry of objective function and limitations in appropriate scripts:

\begin{verbatim}
function y = food_production_planning(x)
    y = 15*x(1) + 5*x(2) + 0.2*x(3) + 4*x(4)
\end{verbatim}

\begin{verbatim}
function [c, ceq] = plan_assumption(x)
    c = [3.44*x(1) + 11.08*x(2) + 0.98*x(3) + 0.78*x(4) - 9650; ...
         0.85*x(1) + 0.27*x(2) + 0.03*x(3) + 0.22*x(4) - 350; ...
         x(1) + 0*x(2) + 0*x(3) + 0*x(4) - 400; ...
         0*x(1) + x(2) + 0*x(3) + 0*x(4) - 800; ...
         ...
    ceq = [ ];
\end{verbatim}

TABLE 1. Values of particular technological coefficients

<table>
<thead>
<tr>
<th>Type of raw material</th>
<th>Products (kg)</th>
<th>Quantity of raw material</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Butter (x_1)</td>
<td>Cheese (x_2)</td>
</tr>
<tr>
<td>Plasma</td>
<td>3.44</td>
<td>11.08</td>
</tr>
<tr>
<td>Fat</td>
<td>0.85</td>
<td>0.27</td>
</tr>
<tr>
<td>Profit (PLN)</td>
<td>15</td>
<td>5</td>
</tr>
</tbody>
</table>

Source: [Platt 1990]
0·x(1) + 0·x(2) + x(3) + 0·x(4) – 2000;
0·x(1) + 0·x(2) + 0·x(3) + x(4) – 600;

where and function \([c, ceq]\) represents the limitation system in the form of non-linear equations and inequalities.

\[LU = [0 0 0 0];\] where \(LU\) is vector of lower limitations for the values of independent variables \(x\).

\[UB = [\text{inf} \ \text{inf} \ \text{inf} \ \text{inf}];\] where \(UB\) is vector of upper limitations for the values of independent variables \(x\). The abbreviation \(\text{inf}\) means infinity.

Selection of chromosomes for a new population was executed with the use of a roulette wheel. This methods consisted in creation of roulette wheel with the fields corresponding to particular chromosomes. Process of chromosome selection was based on rotations of roulette wheel, equal to number of individuals in the population; every time one chromosome was selected for a new population. The size of population amounted to 20 individuals, number of generations was equal to 100, while crossing probability amounted to 0.8.

**RESULTS AND DISCUSSION**

The course of changes in objective function (cost function) in particular generations is presented in Figure 2a. It is evident that objective function achieved the minimal value already in first generations (1–8). The best objective function value amounted to \(f(x) = 6236\) PLN.

Figure 2b presents the best solutions for four assumed decision variables, that amounted respectively to: \(x_1 = 149.68, x_2 = 636.08, x_3 = 339.56, x_4 = 185.62\).

![Figure 2. Course of changes in objective function in particular generations (Fig. 2a) and best solutions for three decision variables (Fig. 2b)](image)
The maximal profit of production will amount to: \( f(x) = 6236 \) PLN for the following production plan:

- Butter production: \( x_1 = 149.68 \) kg
- Cheese production: \( x_2 = 636.08 \) kg
- Milk production: \( x_3 = 339.56 \) kg
- Sour cream production: \( x_4 = 185.62 \) kg

The above problem of milk product production was already solved in the Platt book of 1990. The author with the use of linear programming obtained the maximal production profit that amounted to \( f(x) = 6085.86 \), when the butter production was totally abandoned.

**SUMMARY**

Evolutionary algorithms are an effective tool for searching optimal solutions in many complicated optimization problems. The current range of applications of these algorithms has been continuously widened [Biethahn and Nissan 1995; Knosala 2002; Michalewicz 1999; Vose 1999].

This work aimed at presentation of operational principle of genetic algorithms with an example of determination of maximal plan of food production. With the use of appropriate genetic operators (e.g. selection method, probability, crossing method and mutation) the genetic algorithms quickly found solutions even in first iterations.

Of course, the linear problems with certain limitations used in production planning could be solved with the use of traditional optimization methods, that are based on analysis of derivatives of certain order and are sufficiently quick and accurate for such problem. These methods are fully suitable for continuous and differentiable problems, where determination of searching direction is carried out by analysis of objective function derivative. In the case of discontinuous function tasks, non-differentiable or random ones the traditional methods disappoint and the genetic algorithms are good alternative for the tasks of that type.

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Streszczenie: Planowanie produkcji spożywczej z wykorzystaniem algorytmów ewolucyjnych. Prostota działania algorytmów ewolucyjnych i ich naturalność sprawiły, że stały się one obiecującą metodą rozwiązań wielu problemów technologicznych. Obecnie zastosowanie algorytmów ewolucyjnych jest imponujące, stosowane są one bowiem w podejmowaniu decyzji, minimalizacji kosztów, modelowaniu finansowym, optymalizacji czy planowaniu produkcji. Z reguły algorytmy te mogą być wykorzystane w zadaniach praktycznych dla trudnych zagadnień optymalizacyjnych i poszukiwania, jeśli nie są możliwe rozwiązania numeryczne lub heurystyczne albo zmierzają one do niesatysfakcjonujących rezultatów. W niniejszym artykule przedstawiono ogólną zasadę działania algorytmów genETYcznych i ich zastosowanie w procesie planowania produkcji spożywczej.

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Application of tools for data analysis to customer relationship management in the service enterprise

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Abstract: Application of tools for data analysis to customer relationship management in the service enterprise. There are described results of data analysis carried out with the use of Statistica Data Mining in order to investigate customer relationships in the service enterprise. Data for analysis were collected on the basis of survey carried out among the enterprise customers, data of the enterprise, and interviews with the chairman and staff of the enterprise. The customer satisfaction resulted from service offered by the enterprise was evaluated together with customer behaviour influencing relationships with the enterprise.

Key words: data mining, customer relationship management.

INTRODUCTION

This work aimed at qualitative analysis of customer relationships with the use of selected tools for data analysis on an example of service enterprise. The paper presents a detailed analysis of customer behaviour, with particular consideration to customer satisfaction resulted from services offered by the enterprise; other dependences hidden in the data, which can be used for the improvement of these relationships were also investigated.

The customer relationship management (CRM) is a business strategy designed to optimise enterprise’s profitability, consisting in management of entire customer-enterprise relationships. Various approach to CRM can be found. According to Payne and Frow (2005) one can distinguish a narrow approach as particular technological solution, and wider approach, where CRM is a certain philosophy of controlling the customer relationships.

Undertaken CRM philosophy means the commitment of all employees of the enterprise to satisfy customer target needs effectively and better than competitive enterprises (Little and Marandi 2003). There are various ways for CRM implementation in the enterprise. Winer (2001) in his model recommends 7 basic operations: creating a customer database; analysis of that database; undertaking decisions based on analyses towards selection of customers for the enterprise; selection of tools to win over the customers; creating relationships with the target customers; assuring confidence and data protection; measuring of implemented CRM effectiveness. Pepper and Rogers (2004) recommend the following method for CRM implementation: identification of customers with individual approach; segmentation of customers according to their importance for the enterprise and their own needs; increasing effective-
ness of customer interaction; adaptation to a customer.

Big enterprises use a special CRM-aided software consisted of three subsystems: operational front office for automation of business processes, analytical back office for analysing customer behaviour, and communication office for communication with customers. However, in the carried out investigations there was used one of many universal programs available on the market for data exploration: Statistica Data Mining. The data exploration includes the artificial intelligence methods and statistical methods, which enable to discover the hitherto unknown dependences (regularities, patterns, trends) between values in the large data sets, thus, acquiring knowledge.

MATERIAL AND METHODS

The investigated object was the service enterprise “Building Woodwork Centre Domlux” in Stalowa Wola, dealing with the overhaul, assembling and design services, as well as selling building woodwork. In analyses there were used two groups of data collected due to cooperation with the enterprise. The first data group was taken from the survey carried out among 100 customers selected randomly. The second group of information was obtained on the basis of interviews with the chairman and staff of the enterprise and was also generated from the management-aided programs in the enterprise. It presents the results of goods and services sale in two subsequent years 2006–2007. Names of enterprises and private persons was kept secret, according to the act of 29 August, 1997 on personal details protection (DzU 2002, No 101, p. 926 with later amendments). The patterns of circulated questionnaires are presented in Tables 1 and 2.

<table>
<thead>
<tr>
<th>TABLE 1. Questions included in the 1st questionnaire</th>
</tr>
</thead>
<tbody>
<tr>
<td>Please mark four factors determining selection of “CSB” Domlux” services</td>
</tr>
<tr>
<td>1. Location of enterprise</td>
</tr>
<tr>
<td>2. Kindness of employees</td>
</tr>
<tr>
<td>3. Competence of employees</td>
</tr>
<tr>
<td>4. Variety of goods/services assortments</td>
</tr>
<tr>
<td>5. Quality of goods/services</td>
</tr>
<tr>
<td>6. Price of goods/services</td>
</tr>
<tr>
<td>7. Advertising of enterprise</td>
</tr>
<tr>
<td>8. Time for order realization</td>
</tr>
<tr>
<td>9. Promotions organized by enterprise</td>
</tr>
<tr>
<td>10. Special goods/services</td>
</tr>
<tr>
<td>11. Reputation of enterprise</td>
</tr>
<tr>
<td>12. Other</td>
</tr>
</tbody>
</table>
RESULTS OF INVESTIGATIONS

The first survey aimed at finding out and determining the main factors of the greatest influence on customer selection of enterprise. The survey data served as a source for analysis carried out with the use of Statistica Data Mining.

Among the methods available in Statistica Data Mining program there were chosen those, which allowed for best determination of factors’ significance. Figure 1 presents the factors characterized by biggest importance for customers. Variety of goods and services had highest importance for customers (it was

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TABLE 2. Questions included in the 2nd questionnaire

<table>
<thead>
<tr>
<th>Selected features</th>
<th>Very unsatisfied (1)</th>
<th>Unsatisfied (2)</th>
<th>Neutral (3)</th>
<th>Satisfied (4)</th>
<th>Very satisfied (5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Waiting time for service</td>
<td>□□□□□</td>
<td>□□□□□</td>
<td>□□□□□</td>
<td>□□□□□</td>
<td>□□□□□</td>
</tr>
<tr>
<td>2. Quality of offer</td>
<td>□□□□□</td>
<td>□□□□□</td>
<td>□□□□□</td>
<td>□□□□□</td>
<td>□□□□□</td>
</tr>
<tr>
<td>3. Kindness of employees</td>
<td>□□□□□</td>
<td>□□□□□</td>
<td>□□□□□</td>
<td>□□□□□</td>
<td>□□□□□</td>
</tr>
<tr>
<td>4. Competence of employees</td>
<td>□□□□□</td>
<td>□□□□□</td>
<td>□□□□□</td>
<td>□□□□□</td>
<td>□□□□□</td>
</tr>
<tr>
<td>5. Price</td>
<td>□□□□□</td>
<td>□□□□□</td>
<td>□□□□□</td>
<td>□□□□□</td>
<td>□□□□□</td>
</tr>
<tr>
<td>6. Location</td>
<td>□□□□□</td>
<td>□□□□□</td>
<td>□□□□□</td>
<td>□□□□□</td>
<td>□□□□□</td>
</tr>
<tr>
<td>7. Offer variety</td>
<td>□□□□□</td>
<td>□□□□□</td>
<td>□□□□□</td>
<td>□□□□□</td>
<td>□□□□□</td>
</tr>
<tr>
<td>8. Total quality of services</td>
<td>□□□□□</td>
<td>□□□□□</td>
<td>□□□□□</td>
<td>□□□□□</td>
<td>□□□□□</td>
</tr>
<tr>
<td>9. Total service quality</td>
<td>□□□□□</td>
<td>□□□□□</td>
<td>□□□□□</td>
<td>□□□□□</td>
<td>□□□□□</td>
</tr>
</tbody>
</table>

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FIGURE 1. Factors of biggest importance for customers
chosen by 25% of all respondents). It can be concluded that due to various offer of goods, the enterprise is very competitive on the market and many customers choose its services because of wide possibilities for product selection.

Many customers pointed out at price; about 20% of them select the enterprise with respect to the lowest or at least comparable price of goods and services on the local market. The subsequent important factor was kindness of personnel – 14%. Customer consideration of this factor importance may be advantageous in the contest with competitive firms. The quality of goods and services and enterprise’ reputation were of similar importance. These factors were pointed out by 13% of customers. It can be noted that other subsequent factors took only about 15% of all factors, while the first five factors in total 85%, and the enterprise should concentrate on them in the first place. No indications at advertising or promotions were found in the results of 1st questionnaire.

The 2nd questionnaire aimed at evaluation of present state of satisfaction with services of the enterprise. The randomly chosen customer, who decided to cooperate with the enterprise and responded to survey, evaluated the selected features (Tab. 2) in points from 1 to 5. Using Statistica Data Mining the descriptive statistics were calculated and histograms were created for particular customer-important factors (Tab. 3). As it is evident, the highest marks were given to total quality of services, competence of employees and their kindness as well as offer variety (average mark above 4). Good marks of average slightly above

<table>
<thead>
<tr>
<th>Factor</th>
<th>Valid number</th>
<th>Mean</th>
<th>Sum</th>
<th>Min.</th>
<th>Max.</th>
<th>Standard deviation</th>
<th>Standard error</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Waiting time for service</td>
<td>100</td>
<td>3.45</td>
<td>345.0</td>
<td>1.0</td>
<td>5.0</td>
<td>1.21</td>
<td>0.12</td>
</tr>
<tr>
<td>2. Quality of offer</td>
<td>99</td>
<td>3.88</td>
<td>384.0</td>
<td>1.0</td>
<td>5.0</td>
<td>1.01</td>
<td>0.10</td>
</tr>
<tr>
<td>3. Kindness of employees</td>
<td>98</td>
<td>4.26</td>
<td>417.0</td>
<td>1.0</td>
<td>5.0</td>
<td>0.93</td>
<td>0.09</td>
</tr>
<tr>
<td>4. Competence of employees</td>
<td>99</td>
<td>4.26</td>
<td>422.0</td>
<td>1.0</td>
<td>5.0</td>
<td>0.85</td>
<td>0.08</td>
</tr>
<tr>
<td>5. Price for services and goods</td>
<td>100</td>
<td>3.81</td>
<td>381.0</td>
<td>1.0</td>
<td>5.0</td>
<td>1.11</td>
<td>0.11</td>
</tr>
<tr>
<td>6. Location of enterprise</td>
<td>98</td>
<td>3.99</td>
<td>391.0</td>
<td>1.0</td>
<td>5.0</td>
<td>0.90</td>
<td>0.09</td>
</tr>
<tr>
<td>7. Offer variety</td>
<td>99</td>
<td>4.02</td>
<td>398.0</td>
<td>1.0</td>
<td>5.0</td>
<td>0.94</td>
<td>0.09</td>
</tr>
<tr>
<td>8. Total quality of services</td>
<td>98</td>
<td>3.99</td>
<td>391.0</td>
<td>1.0</td>
<td>5.0</td>
<td>0.96</td>
<td>0.10</td>
</tr>
<tr>
<td>9. Total service quality</td>
<td>99</td>
<td>427</td>
<td>423.0</td>
<td>1.0</td>
<td>5.0</td>
<td>0.81</td>
<td>0.08</td>
</tr>
</tbody>
</table>
4 were obtained for total quality of services and enterprise location.

The lowest mean was found for waiting time for service, but significance of this factor was pointed out by 3% of customers only; therefore, the enterprise does not have to undertake any special actions to shorten it. It is also evident from Table 3 that factors of lowest mean marks, namely: offer variety, price of services and goods, and waiting time for service are characterized by high standard deviation values, which prove a substantial scatter of marks and very subjective customer evaluation of these factors.

At the next stage the data generated from WF-MAG program used by the enterprise were analyzed, with consideration to the following factors: type of service (assembly, sale, other services), price of products or services, date of transaction realized. Analyses were carried out with the use of Statistica Data Mining program. The data set was placed in the working area “data sources”. Then, the data were cleaned by selection of procedure “removing the lack of data”. Thus, incomplete cases were removed and the final data source of 787 transactions for 2006–2007 was created and analyzed. The transaction size in particular months are presented in Table 4. The highest number of transactions was found in July, while the lowest in January.

Figure 2 presents the transaction incomes in particular months. The highest transaction value was found in December. It was influenced by substantial number of transactions and the high mean transaction values (the highest values were obtained in January, March and December). Low transaction values were recorded in March, May and June, due to low number of transactions and the

<table>
<thead>
<tr>
<th>Category</th>
<th>Size</th>
<th>Cumulated size</th>
<th>Percentage</th>
<th>Cumulated percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>15</td>
<td>15</td>
<td>1.91</td>
<td>1.91</td>
</tr>
<tr>
<td>February</td>
<td>24</td>
<td>39</td>
<td>3.05</td>
<td>4.96</td>
</tr>
<tr>
<td>March</td>
<td>24</td>
<td>63</td>
<td>3.05</td>
<td>8.01</td>
</tr>
<tr>
<td>April</td>
<td>36</td>
<td>99</td>
<td>4.57</td>
<td>12.58</td>
</tr>
<tr>
<td>May</td>
<td>64</td>
<td>163</td>
<td>8.13</td>
<td>20.71</td>
</tr>
<tr>
<td>June</td>
<td>67</td>
<td>230</td>
<td>8.51</td>
<td>29.22</td>
</tr>
<tr>
<td>July</td>
<td>115</td>
<td>345</td>
<td>14.61</td>
<td>43.84</td>
</tr>
<tr>
<td>August</td>
<td>74</td>
<td>419</td>
<td>9.40</td>
<td>53.24</td>
</tr>
<tr>
<td>September</td>
<td>95</td>
<td>514</td>
<td>12.07</td>
<td>65.31</td>
</tr>
<tr>
<td>October</td>
<td>98</td>
<td>612</td>
<td>12.45</td>
<td>77.76</td>
</tr>
<tr>
<td>November</td>
<td>85</td>
<td>697</td>
<td>10.80</td>
<td>88.56</td>
</tr>
<tr>
<td>December</td>
<td>90</td>
<td>787</td>
<td>11.44</td>
<td>100.00</td>
</tr>
</tbody>
</table>
low unitary values. The median values of transactions in particular months were less diversified than the mean values and ranged from 744.86 PLN in January to 1898.41 PLN in December.

The subsequent analyses aimed at determination of the share of particular transaction types (sale, assembly, service) in all operations carried out, with consideration to their number and total value. As it is evident from Figure 3, most operations are connected with sale – 656 (83.35%), 70 operations are connected with assembling (8.9%), and 61 transactions are connected with services (7.75%).

The next analysis was carried out for operations of selling value above 7000 PLN. This threshold value was set up above the mean value of all operations (above 6000 PLN) to facilitate determination of most profitable transactions. It was found that services make the biggest share (Fig. 4) (37 items – 58.8%), followed by sale operations (25 – about 40%), and 1 assembly operation (1.5%).

FIGURE 2. Transaction values in particular months (mean and total)

FIGURE 3. Share of particular transaction types in all operations carried out

FIGURE 4. Share of particular transaction types in all operations of value exceeding 7000 PLN
SUMMARY
Application of Statistica Data Mining enabled to find dependences, which have been not noticed up to the present. According to customers, the most important factors determining good cooperation with the enterprise were the following: production offer, price of products and their quality. Kindness of employees is important also. Most transactions took place in July, therefore, during vacation period the enterprise should employ additional assembly staff to satisfy the customer needs. The sale provides a substantial overall income, however, the specific income is small in relation to the number of such transaction types. The share of transactions above 7000 PLN in all transactions is very small. Results of analyses point out that a change in activity profile and concentration on services would be advantageous for the enterprise. They make the highest percentage of income at low specific inputs for services. The carried out analyses can improve the customer relations, since they point out at significant factors influencing customer satisfaction and can increase the enterprise’s profit.

REFERENCES

Streszczenie: Zastosowanie narzędzi analizy danych do zarządzania relacjami z klientami w przedsiębiorstwie usługowym. Przedstawiono wyniki analizy danych przeprowadzonych za pomocą programu Statistica Data Mining w celu zbadania relacji z klientami w przedsiębiorstwie usługowym. Materiał do analizy został zebrany na podstawie ankiet przeprowadzonych wśród klientów firmy, danych firmy, oraz wywiadów z pracownikami i prezesa. Dokonano oceny satysfakcji klientów z usług świadczonych przez firmę oraz zachowań klientów mających wpływ na relacje z przedsiębiorstwem. Analiza transakcji dokonywanych przez klientów pozwoliła na wykrycie pewnych zależności, które mają duży wpływ na dochody firmy.

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Abstract: The mathematical description of technological processes in dynamics. This work presents one of the methods of simulation of the objects of industry. Its chief characteristic is the determination of mathematical dependence between the input and output parameters by using the numbers of Volterra of the second kind. The block diagram of the control object is formed on the basis of the comprised number. The quality of the mathematical description of the system is determined with the help of the integral criterion.

Key words: dynamic technological process, mathematical description, input and output parameters, Volterra numbers.

INTRODUCTION

At the present stage of engineering and technology development, the automation of processes plays a crucial role. This is urgent for all branches of industry, including those of food and processing. The systems of automatization of the processes in food industry must satisfy such requirements as accuracy, constancy, reliability and operational simplicity. Therefore, engineers come across a complex problem, the essence of which consists in the creation of automatization systems, which satisfy the criteria pointed out above. An important stage in this case is the initial simulation of processes.

The aim of this work is to disclose the essence of the mathematical description of technological processes in dynamics, and also to apply the methods of description of the dynamic characteristics. Here, the study will not concern any specific process, but it will be represented in general form.

To achieve the presented goal it is necessary to solve the following tasks:
– to select the most acceptable method of simulation for the process under investigation, with the use of which the basic special features of the object simulated will be considered;
– to conduct the identification of the dynamic characteristics, obtained as a result of the object study;
– to estimate the quality of the obtained model by using the qualitative assessments. The simulation of the dynamics of production units is directly connected with a number of researches on plotting of dynamic curves. In the course of studies of this type the instruments already existing in the production and the systems, which continuously record the basic parameters of the process, are used.
SIMULATION

Before starting the experiment on plotting of dynamic curves of a control object under investigation, it is necessary to develop a procedure on its conducting. There are many procedures; however, the essence of the majority of them consists in the introduction of the disturbing action into the system: single step input, harmonic oscillations, step action and other.

Figure 1 represents the reaction of the system to a single action. It is evident according to the graph that the object is inertia; therefore changes occur not sharply, but with a certain delay.

The description of nonlinear object with the help of the linear on the parameters models seems ideal, since the following properties are inherent in linear objects:
1) the possibility to write down clearly the connection between the entrance and the output;
2) simplicity of the description of the system connections;
3) the possibility of examining random signals.

The properties outlined above must be preserved, also, for the nonlinear objects [1]. For this we will use decomposition by Volterra.

Using the numbers of Volterra, the nuclei of which are the weighting functions of higher orders, it is possible to obtain the description of a nonlinear object, allowing clear physical interpretation. This method has a large advantage, connected with the fact that a nonlinear system is looked at as the direct generalization of a linear case, although the object itself can differ significantly from the linear one. In other words, the method with the use of numbers of Volterra interprets linear objects as the sub-class of nonlinear objects [2].

The essence of the method consists in the fact that with existing input information $x(t)$ and output data $y(t)$ it is necessary to select, using decomposition by Volterra, such a dependence which would be a good approximation $y(t)$.
In the first approximation, let us be limited by $y_{\text{lin}}(t)$, determined from the formula (1)

$$y_{\text{lin}}(t) = h_1 \cdot x_1 \cdot \Delta t + h_2 \cdot x_2 \cdot \Delta t + \ldots = \sum_{i=1}^{N} h_i \cdot x_i \cdot \Delta t$$

where $h_i$ is the amplitude, $\Delta t$ is the pulse width.

With the condition

$$\lim_{\Delta t \to 0, \ N \to \infty} \sum_{i=1}^{N} h_i \cdot x_i \cdot \Delta t = \int_{0}^{t} h_i(\tau) \cdot (t - \tau) d\tau$$

where $\tau$ is time delay, we have the following expression (3):

$$y_{\text{lin}}(t) = \int_{0}^{t} h_i(\tau) \cdot (t - \tau) d\tau$$

When supplying two pulses of input signals $x_i, x_j$ to the object in the form of a linear term of decomposition (in the limit $\Delta t \to 0, \ N \to \infty$) will look as follows:

$$y_{\text{lin}}(t) = \int_{0}^{t} h_i(\tau_1, \tau_2) \cdot (t - \tau_1) \cdot (t - \tau_2) d\tau_1 \cdot d\tau_2$$

Thus, we will obtain that

$$\equiv y(t) = y_{\text{lin}}(t) + y_{\text{qadr}}(t)$$

The expressions for the terms are substituted from formulas (3) and (4) respectively into formula (5).

Consequently, the expansion in the Volterra series is the direct generalization of the model of the linear object in the form of convolution integral. The weighting function $h(t)$ of the linear system is substituted by the weighting functions [3].

Thus, the primary task is the determination of the analytical form of the nuclei $h_i(\tau)$ and $h_2(\tau_1, \tau_2)$, as well as the parameterization $\equiv y(t)$ relating to $y(t)$.

We will use weighting functions of basic dynamic sectional as the kernels of integrals: the integrating, differentiating, periodic component of the second order, as an amplifier.

We will conduct the estimation of the accuracy of the expression selected for the approximation on the basis of the condition:

$$\left(y(t) - \equiv y(t)\right)^2 \rightarrow \min$$

I.e., the square of the difference between the experimentally obtained values of points and the values, obtained analytically, must approach the minimum (let us designate this expression through $\varphi$).

Let us apply this method of the identification of dynamic characteristics to the data, represented in Figure 2.

The work of the aperiodic component of the second order to the integrating component is the nucleus of the number
of Volterra. This form of nucleus is selected because the established accuracy of approximation \( f = 1.144 \) with its use, is the highest.

Taking into account expression (6) and the nuclear structure of the integrals of the first and second orders, the form of the number of Volterra is the following:

\[
y(t) = \int_0^t h_1(t - \tau, x(t - \tau)) \, d\tau + \int_0^t h_2(t - \tau, x(t - \tau)) \, d\tau + \int_0^t h_3(t - \tau_1, \tau_2, x(t - \tau_1), x(t - \tau_2)) \, d\tau_1 \circ d\tau_2 + \int_0^t h_4(t - \tau, x(t - \tau), x(t - \tau)) \, d\tau + \int_0^t h_5(t - \tau, x(t - \tau), x(t - \tau)) \, d\tau + \int_0^t h_6(t - \tau_1, \tau_2, x(t - \tau_1), x(t - \tau_2)) \, d\tau_1 \circ d\tau_2 \quad (8)
\]

where \( h_1(t, \tau, x(t - \tau)) \) are the kernels of the integrals of Volterra (weighting functions).

Figure 3 depicts the block diagram of the control object. This diagram is comprised according to the analytically specific for each of the control channels form of the number of Volterra, described by expression (8). In the case of nonlinear inertial systems with the delay with the composition of the integral number of Volterra as the nucleus of linear component, a simple component of delay is used, which subsequently is summarized with the remaining terms of the series. It is shown on the block diagram, how the description of dynamic characteristics of nonlinear objects with the help of the linear on the parameters models, which was mentioned earlier, is accomplished.
The mathematical description of technological processes...

x₁(t), x₂(t) are the input parameters; y(t) is the output parameter; A(τ), D(τ) are the nuclei of the linear component of the integral number of Volterra; B(τ), C(τ) and E(τ), G(τ) are the nuclei of quadratic component of the integral number of Volterra.

THE SYSTEM QUALITY

The quality of the work of any control system is determined by the value of an error, which is equal to the difference between the required and actual values of the controlled variable.

For evaluating the quality indicators of any system the criteria of quality are used. The integral criterion of quality is one of them. In automatic control the estimation with the infinite upper limit of integration has won acceptance. For such estimations it is necessary that the integrand would disappear by time and would not contain a steady error [4]. The following value can serve as the simplest integral estimation:

\[ I_1 = \int_0^\infty \varepsilon(t) \, dt \]  

where \( \varepsilon(t) \) is the deviation of the controlled variable from the new steady value after transient decay. The more rapidly the transient process attenuates, and the less the deviation of controlled variable from the new steady value of the output variable is, the less will \( I_1 \) be.

For the process being investigated the value of integral estimation (9) will take the following form (10).

\[ I_1 = \int_0^\infty (y_{\text{opt}}(t) - y(t))(x_1(t) - x_{1\text{nom}}(t))(x_2(t) - x_{2\text{nom}}(t)) \, dt \]  

FIGURE 3. The block diagram of the control object
For determining the value of integral (10) it is necessary to compose an algorithm. Thus, the model pointed out above will be realized by a program. The nucleus of the algorithm, represented in Figure 4, will appear to be the determination of values of the output value, according to expression (6), of the integral number of Volterra, and also – the determination of the optimum values of the input parameters. The optimization of the values of the input parameters is accomplished by minimization of the integral criterion. Carrying out the algorithm is possible by using widespread programming languages: Delphi, C+, and also with the help of software MATLAB.

CONCLUSION

The goal, stated in the present work, has been achieved. An example of the construction of a mathematical model with

![Algorithm Flowchart]

FIGURE 4. The algorithm for determination of the optimum value of the parameters
the use of an integral number of Volterra of the second order is given. Thus, it is possible to make the following conclusions:

1) with the help of the integral numbers of Volterra the functional dependence between the input and the output values has been determined with high accuracy;

2) with the use of an integral criterion of quality the optimization is produced immediately from several parameters;

3) the program realization of the mathematical model and its optimization is possible with the help of the comprised algorithm.

REFERENCES


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