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EFFECT OF DURATION OF DEVELOPMENT STAGES ON THE QUANTITY OF FIELD CUCUMBER (*CUCUMIS SATIVUS* L.) YIELD IN POLAND

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Key words: pickling cucumber, sowing, harvest, development stage, reduction in yield, Poland.

Abstract

The goal of the present work was to find temporal and spatial distribution of agrotechnical dates and phenological phases and duration of development stages of pickling varieties of cucumber and also to determine influence of duration of development stages on the yield in the whole country and in its various regions.

In Poland, in the years 1966–2005, both agrotechnical and phenological dates and development stages of cucumber were characterised by high temporal and spatial variability; with temporal variability being, on average, twice as high as spatial variability and oscillating between 2–3 and 7 weeks. All considered cucumber dates were characterised, year on year, by acceleration (from -0.07 day per 10 years in the case of sowing up to -6.4 days per 10 years in the case of the end of harvesting), and development stages by shortening (the whole growing season by -7.4 days per 10 years). Regression analysis describing relationship between yield and duration of cucumber development stages confirmed a negative influence of the period from sowing to the beginning of harvesting on the total yield and a positive influence of the period from the beginning of harvesting to the end of harvesting on the total and marketable yield. In Poland, potential reduction in the total yield of cucumber caused by assumed ten-day lengthening of duration of the period from sowing to the beginning of harvesting usually oscillated between 3 and 18% below the multi-annual average and caused by shortening of duration of the period from the beginning of harvesting to the end of harvesting between 9 and 18% in the case of the total yield and between 15 and 24% in the case of the marketable yield; the highest reduction occurred in the Sudetian Foothills, the Carpathian Foothills and in the north-east. Frequency of the occurrence of an excessively long period from sowing to the beginning of cucumber harvesting oscillated in Poland between 10 and 20%, and an excessively short period from the beginning of harvesting to the end of harvesting between 10 and 40%.

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WPŁYW DŁUGOŚCI OKRESÓW ROZWOJOWYCH NA WIELKOŚĆ PLONU OGÓRKA POLOWEGO (*CUCUMIS SATIVUS* L.) W POLSCE

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Słowa kluczowe: ogórek konserwowy, siew, zbiór, okres rozwojowy, zmniejszenie plonu, Polska.

Abstrakt

Celem pracy było rozpoznanie czasowego i przestrzennego rozkładu terminów agrotechnicznych, faz fenologicznych i długości okresów rozwojowych konserwowych odmian ogórka, a także określenie wpływu długości okresów rozwojowych na plon w skali całego kraju i w różnych jego rejonach.

W Polsce w latach 1966–2005 zarówno terminy agrotechniczne, fenologiczne, jak i okresy rozwojowe ogórka charakteryzowały się dużą zmiennością czasową i przestrzenną, przy czym zmienność czasowa była przeciętnie dwukrotnie większa niż przestrzenna i wahała się od 2 do 7 tygodni. Wszystkie rozpatrywane terminy odznaczały się z roku na rok przyśpieszeniem (od -0,07 dnia na 10 lat w przypadku siewu do -6,4 dnia na 10 lat w przypadku końca zbioru), a okresy rozwojowe – skróceniem (cały okres wegetacji o -7,4 dnia na 10 lat). Analiza regresji, opisująca zależność między plonem a długością okresu rozwojowego ogórka, potwierdziła ujemny wpływ okresu siew – początek zbioru na plon ogólny i dodatni – okresu początek zbioru – koniec zbioru na plon ogólny i handlowy. Na terenie kraju potencjalne zmniejszenie plonu ogólnego ogórka powodowane założonym 10-dniowym wydłużeniem długości okresu siew – początek zbioru wahała się najczęściej od 3 do 18% poniżej średniego wieloletniego, a powodowane skróceniem długości okresu początek zbioru – koniec zbioru od 9 do 18% w przypadku plonu ogólnego i od 15 do 24% w przypadku plonu handlowego. Największe zmniejszenie plonu występowało na Przedgórzu Sudeckim, Pogórzu Karpackim i na północnym wschodzie. Częstość występowania zbyt długiego okresu siew – początek zbioru ogórka wynosiła na terenie Polski od 10 do 20%, a zbyt krótkiego okresu początek zbioru – koniec zbioru – od 10 do 40%.

Introduction

Knowledge of temporal and spatial variability of the dates of sowing, harvesting, phenophases and development stages of vegetables and other crop plants, both in a multi-annual perspective and a yearly one, can be utilised, among other things, in computer decision support systems, especially concerning cultivation and protection of plants as an important element of using good production practices (DĄBROWSKI et al. 2003). According to DEPUTAT (1999), thorough knowledge of the course of growth and development of crop plants, especially in multi-annual periods may be of great importance while evaluating effect of climate warming on plant production, and according to KALBARCZYK (2006, 2009b) – in forecasts about duration of development stages, regionalisation of plant cultivation and in creating a schedule of field works. According to SOKOŁOWSKA (1980), phenological observations fulfil a role of a calendar of successive stages of plant growth and development, useful in forecasting the dates of maturation and harvesting. On the other hand, according to AHAS et al. (2000) and CHMIELEWSKI et al. (2004), the course of phenological phases in a growing season is a reflection of habitat conditions of plants and, as a result, in addition to the knowledge of variability distribution of the sowing date, it can be used to forecast the date of harvesting and the quantity of yield of crop plants. For example KOŹMIŃSKI and MICHALSKA (2001) forecast reduction in yield of different crop plants and determine its risk on the basis of retardation of the sowing date. According to these researchers, a ten-day delay of the sowing date in comparison to the optimal one may reduce yield of spring cereals, in most areas of the country, by 5–10%.

However, previous knowledge of agrotechnical dates and especially phenological ones and duration of development stages is not sufficient for the needs of cucumber cultivation. The main reason for this is a fact that results of the majority of works have a local character, more seldom a regional one, and different periods of observations used in them do not usually enable a general synthesis for the whole area of the country (GÓRKA 1987).

The aim of the work was to find temporal and spatial variability of agrotechnical dates, phenological phases and also development stages and to determine effect of duration of development stages on yield of pickling cucumber varieties in the whole country and in its various regions.

Material and Methods

The work used data concerning agrotechnical and phenological dates and duration of cucumber development stages coming from 28 stations of the Research Centre for Cultivar Testing (COBORU) in the 1966–2005 multi--annual period, excluding the years 2003 and 2004, when experiments were not carried out. Starting materials included the following dates: sowing (*Sg*), the end of emergence (*Ee*), the beginning of flowering (*Bf*), the beginning of fruit-setting (*Bfs*), the beginning of harvesting (*Bh*) and the end of harvesting (*Eh*); and the periods: from sowing to the beginning of harvesting, from the beginning of harvesting to the end of harvesting and the whole growing season (sowing – the end of harvesting). The study, apart from the above-mentioned data also used data concerning the quantity of total and marketable cucumber yield. Basic materials (dates, periods and yield) were collected for all the most commonly cultivated varieties of pickling cultivars examined in a given year which after averaging were taken as a collective standard of the analysed plant, considered at a further stage of the research.

A linear trend of dates and period duration in the analysed multi-annual period and relationship between cucumber yield and duration of development stages were calculated on the basis of, respectively, single regression analysis and multiple regression analysis. To evaluate regression equations, apart from determination coefficient (R^2) and a coefficient describing a difference between a standard deviation of a dependent variable and standard error of equation estimation ($S - Sy$), two other indexes were also used – relative forecast error, determined according to the formula:

$$RFE = \frac{y - y_p}{y} \cdot 100\%$$

and average relative forecast error, for all the analysed stations and examined years 1966–2005, which was calculated on the basis of the formula:

$$ARFE = \frac{1}{n} \sum_{i=1}^{n} |RFE|$$

where:
y – actual yield (t ha^{-1}),
y_p – yield calculated on the basis of the equation (t ha^{-1}),
n – number of years in a time series (number of stations × number of years).

On the other hand, a partial correlation coefficient was used to determine contribution which independent variables (duration of cucumber development stage, a linear trend of a dependent variable in the years 1966–2005) have in prediction of the total and marketable yield.

Reduction in field cucumber yield caused by lengthening of duration of the period from sowing to the beginning of harvesting or shortening of the period from the beginning of harvesting to the end of harvesting was calculated on the basis of multiple regression equation, taking into account successive development stages and the linear trend of yield in the years 1966–2005. Lengthened or shortened by 10 days duration of the period in relation to the multi-annual average, successively for each examined station of COBORU was substituted into each of the formed equations describing the effect of duration of a development stage on yield. Next, the yield calculated for a given station was compared with the multi-annual actual yield of field cucumber determined for the whole country and differences were expressed in %.

Risk of the occurrence of an excessively long or excessively short development stage in the 1966–2005 multi-annual period was determined on the basis of the formula:

$$P = \frac{n_1}{N} \cdot 100\%,$$

where:
n_1 – number of excessively long periods (or excessively short),
N – number of all considered periods.

Results and Discussion

Temporal structure of dates and periods

In the years 1966–2005, the average domestic date of cucumber sowing in field conditions fell on 16th May, the earliest average date was 10th May (2002) and the latest date – 20th May (1993) – Figure 1. The end of cucumber emergence was observed averagely on 3rd June, the beginning of flowering on 7th July and the beginning of fruit-setting on 12th July. The average date of the beginning of harvesting fell on 22nd July and the end of harvesting on 3rd September, with the earliest average date falling on 9th July (1979) for the first harvesting and 14th August (1992) for the last harvesting, the latest average date – respectively on 9th August (1974) and on 27th September (1974). Similar temporal distribution for average dates of sowing and harvesting of this plant was obtained by GÓRKA (1987), according to whom cucumber in field cultivation is most often sown at the end of the first ten-day of May or at the beginning of the second decade, and harvesting usually starts in the third ten-day of July and finishes in the first ten-day of September.

A difference between the latest and the earliest dates of successive agrotechnical dates and phenophases oscillated averagely between 10 and even 44 days (Figure 1). The date of sowing was characterised with the lowest variability and the date of the end of harvesting with the highest. Linear trend analysis of agrotechnical dates and phenological phases of cucumber showed a statistically significant negative temporal trend, i.e., acceleration, year on year, of almost all the examined dates, excluding the sowing date for which the trend turned out to be insignificant. Correlation coefficients determined for a trend of particular dates oscillated between -0.34 ($P \leq 0.1$) and -0.69 ($P \leq 0.01$) and the best description was obtained for the end of harvesting and the worst for the end of emergence. Temporal variability of the analysed cucumber dates is determined, like in the case of other crop plants, most of all by meteorological conditions, especially solar and thermal conditions of air, of which an above-average increase accelerates occurrence of successive phenophases in the growing season of the plant (GÓRKA 1987, KUSKOWSKA, WIERZBICKA 2000, GRABOWSKA 2004, KALBARCZYK 2003, KALBARCZYK 2009a, GRABOWSKA et al. 2007).

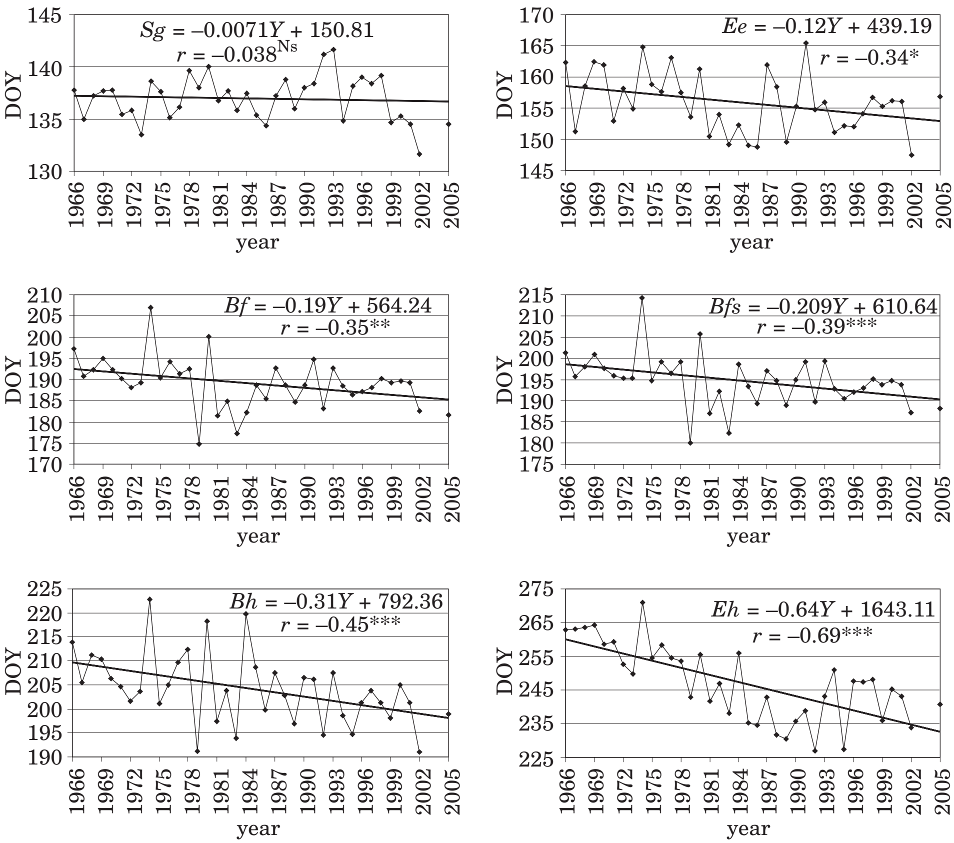

Fig. 1. Course of agrotechnical dates (*Sg, Bh, Eh*) and phenological phases (*Ee, Bf, Bfs*) of cucumber in Poland, 1966–2005. Trends are significant with $^{**}P \leq 0.05$, $^{***}P \leq 0.01$, Ns – non-significant, DOY – day of the year, Y – year, *Sg* – sowing, *Ee* – end of emergence, *Bf* – beginning of flowering, *Bfs* – beginning of fruit-setting, *Bh* – beginning of harvesting, *Eh* – end of harvesting

As illustrated by spectra of agrotechnical dates and development stages in Poland, cucumber was most frequently sown in the period from 13th to 17th May, when as much as 43% of all the dates occurred (Figure 2). On the other hand, the end of emergence occurred most often in the period from 30th May to 3rd June, the beginning of flowering and fruit-setting – respectively in the period from 3rd to 7th July and from 8th to 12th July, and the beginning and the end of harvesting – respectively in the period from 17th to 21st July and from 2nd to 9th September.

In Poland, average duration of the examined cucumber development stages: sowing – the beginning of harvesting, the beginning of harvesting – the end of harvesting and the whole growing season (from sowing to the end

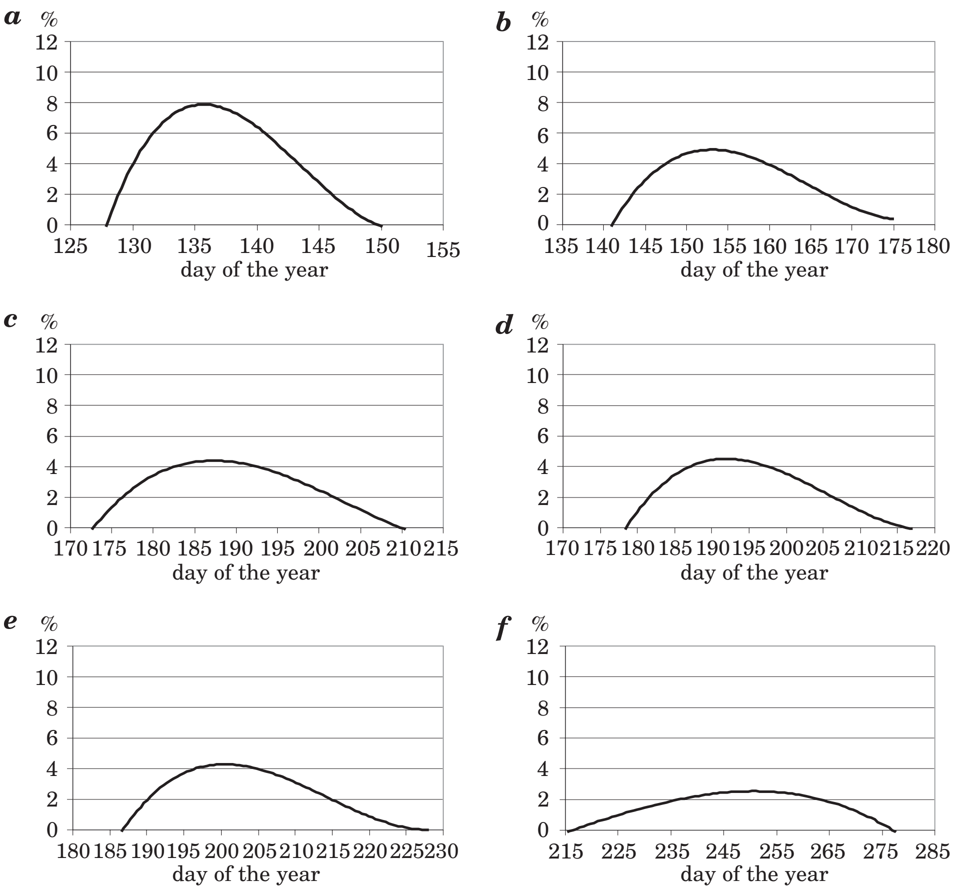

Fig. 2. Spectra of agrotechnical dates (*Sg, Bh, Eh*) and phenological phases (*Ee, Bf, Bfs*): *a – Sg*, *b – Ee*, *c – Bf*, *d – Bfs*, *e – Bh*, *f – Eh* of cucumber in Poland, 1966–2005
Other explanations, see Figure 1

of harvesting) amounted to, respectively, 66, 44 and 110 days (Figure 3). According to KOŹMIŃSKI and RAAB-KRZYSZTOPORSKA (1974) and SOKOŁOWSKA (1980), in Poland the beginning of cucumber harvesting occurs on average 68 days after the date of sowing and the end of harvesting after 112 days, but there are also years when the period from sowing to the beginning of harvesting lasts even 95 days, and the period from sowing to the end of harvesting – 150 days. GÓRKA reports (1987) that longer, averagely by 8–10 days, periods of cucumber growing seasons in field cultivation were recorded in the years 1970–1985.

A range between extreme lengths of agrophenological periods in 1966–2005 oscillated in the case of the first half of the growing season (sowing – the

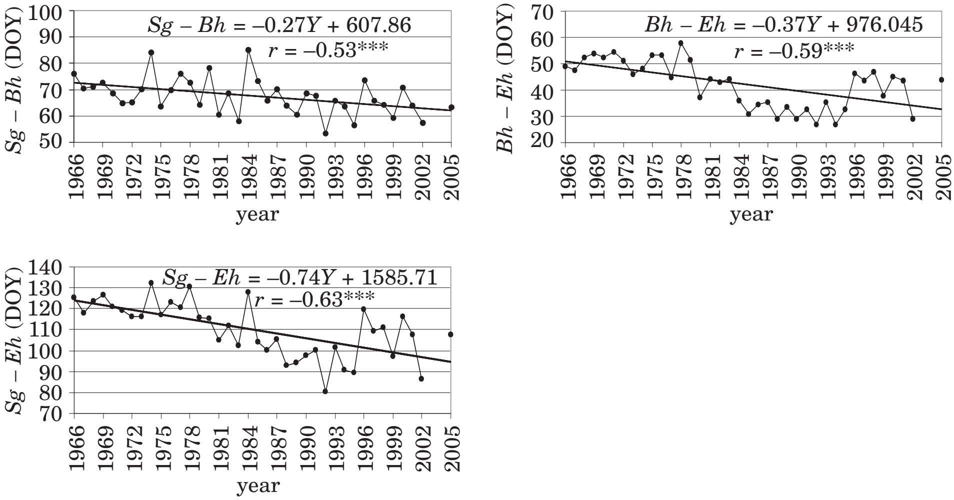

Fig. 3. Course of duration of cucumber development stages in Poland, 1966–2005
Other explanations, see Figure 1

beginning of harvesting) between 53 days in 1992 and 85 days in 1984. In the second half of the growing season (the beginning of harvesting – the end of harvesting) the range amounted to 31 days, and in the period from sowing to the end of emergence – even 52 days. In the years 1966–2005 statistically significant, at the level of $P \leq 0.01$, shortening of the analysed development stages of cucumber was noticeable. Correlation coefficients determined for a significant linear trend oscillated between -0.53 for the period from sowing to the beginning of harvesting and -0.63 for the period from sowing to the end of harvesting. Shortening of agrophenological periods is also observed among other crop plants, not only in Poland but also in other European countries. For example, in Poland in the case of potato of mid-early and late cultivars, in the years 1972–1995, shortening of the emergence – flowering period was proved (KALBARCZYK 2003, KALBARCZYK, KALBARCZYK 2004), and in Germany in the case of rye, in the years 1961–2000, shortening of the periods: sowing – emergence and full flowering – harvesting; and for maize the sowing – emergence period (CHMIELEWSKI et al. 2004).

It results from the diagrams (Figure 4) presenting duration spectra of cucumber agrophenological periods that, most frequently, duration of development stages amounted to: for the period from sowing to the beginning of harvesting – 62–66 days, the beginning of harvesting – the end of harvesting – 45–49 days, and for the whole growing season, lasting from sowing to the end of emergence – 109–113 days.

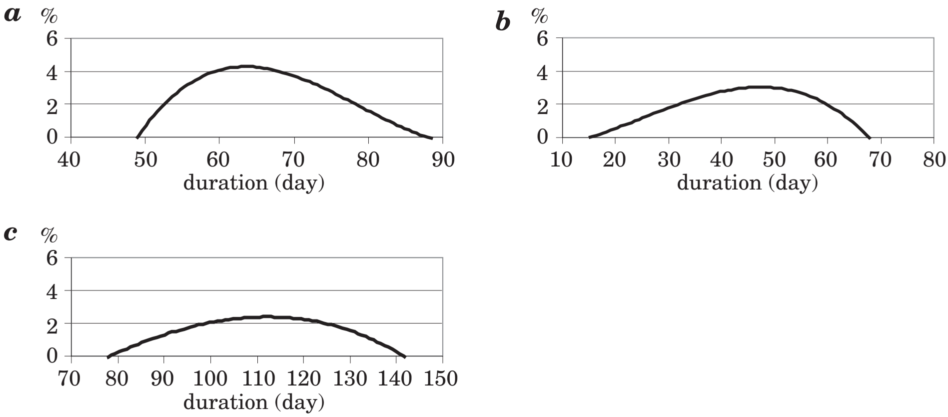

Fig. 4. Spectra of duration of cucumber development stages in Poland, 1966–2005: *a* – *Sg–Bh*, *b* – *Bh–Eh*, *c* – *Sg–Eh*
Other explanations, see Fig. 1.

Spatial structure of dates and periods

Spatial distribution of average agrotechnical dates and the course of successive dates of phenophases of cucumber was shown in Figure 5. In most areas of the country average dates of cucumber sowing occurred in the second decade of May. On average, earliest, before 10th May, cucumber seeds were sown in the Opole Plain and in the Sandomierz Basin. After 20th May cucumber was sown in the northern, south-western and south-eastern parts of the country and in the Suwałki Lakeland, the Pomeranian Lakeland and in submountainous regions even after 25th May. The date of cucumber sowing is to a large extent dependent on thermal conditions of soil and air and on occurrence of ground-frost (KRUG, THIEL 1985, BITTSÁNSZKY et al. 1990, MARCELIS et al. 1993, KALBARCZYK 2006). According to KOŹMIŃSKI and TRZECIAK (1971), in the north of the country, in the Pomeranian Lakeland, the Suwałki Lakeland and Warmia, average dates of occurrence of the latest spring ground-frost are observed in the period from 10th–15th May, and in places even in the period from 15th–20th May, and in the south of the country, in submountainous regions, even after 25th May. According to the same authors, in the north and in the south of the country the latest spring ground-frost may take place after 30th May, and sometimes after 5th June.

In the central strip of Poland – in the Wielkopolska Lakeland, the Wielkopolska Lowland, the Silesian Lowland and the Mazovian Lowland, emergence averagely occurred in the third decade of May and in the north and in the south of Poland as late as after 10th June. Cucumbers started the next

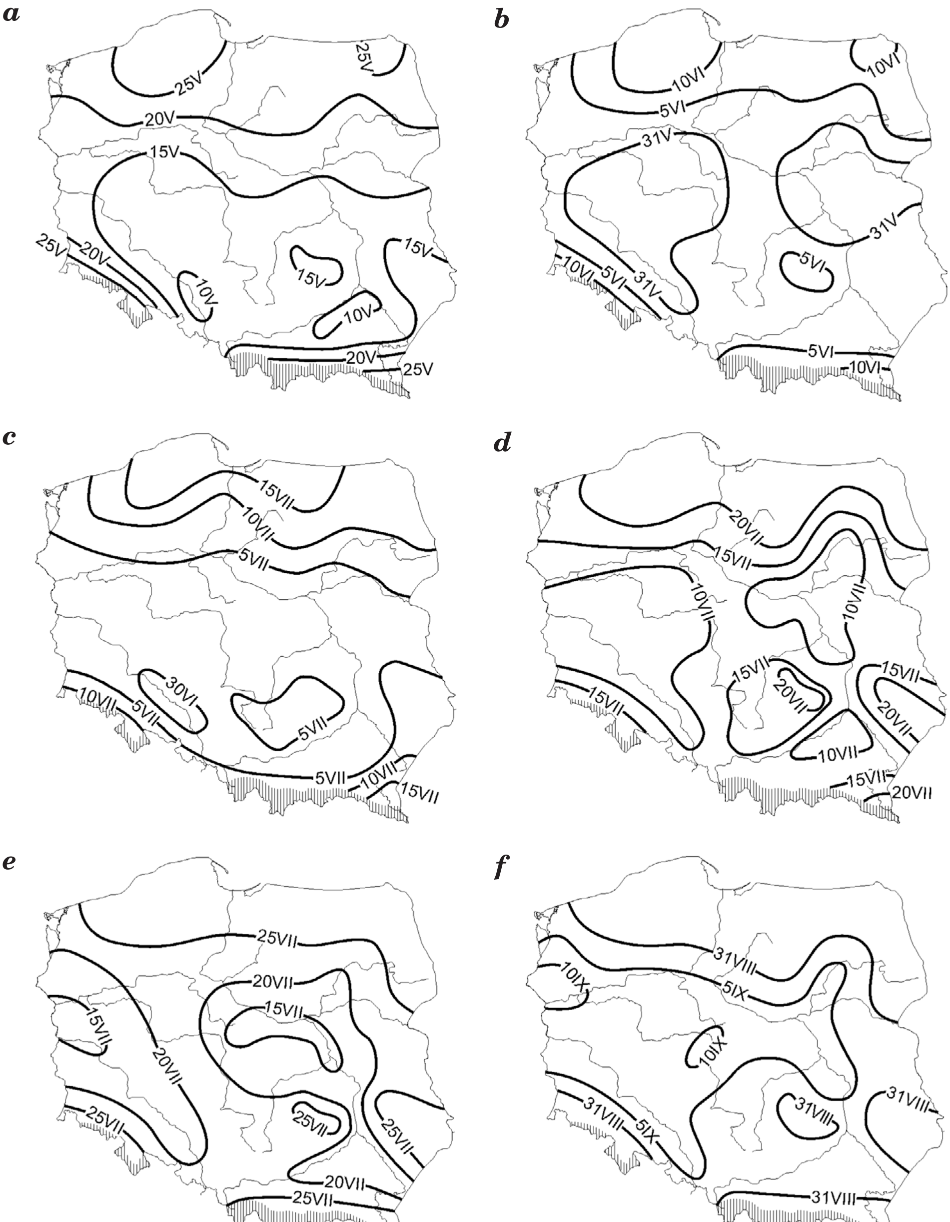

Fig. 5. Spatial distribution of agrotechnical dates (*Sg, Bh, Eh*) and phenological phases (*Ee, Bf, Bfs*) of cucumber in Poland, 1966–2005: *a – Sg*, *b – Ee*, *c – Bf*, *d – Bfs*, *e – Bh*, *f – Eh*
Other explanations, see Figure 1

phenophase, the beginning of flowering, in most of Poland before 5th July, which is consistent with the results of the study by SOKOŁOWSKA (1980). A difference between extreme average dates of the beginning of flowering in Poland amounted to about two weeks. Earliest, on average, before 30th June, cucumbers started flowering in the Silesian Lowland, and latest, on average, after 15th July in the northern and south-eastern boundaries of the country. Area with averagely earlier dates of cucumber fruit-setting, before 10th July, covered central-western part of the country, the Mazovian Lowland and the Sandomierz Basin. After 20th July, fruit-setting occurred in the northern and south-eastern part of the country, in the central part of the Małopolska Upland and in Roztocze. Earliest, on average before 15th July, cucumber fruits were harvested in the Lubusko Land and the Mazovian Lowland; latest, on average after 25th July, in the north and south of Poland and in the region of the Świętokrzyskie Mountains. On the other hand, in the Silesian Lowland, the Myślibórz Lakeland, the Sandomierz Basin and in the Mazovian Lowland and regions adjacent to it harvesting occurred between 15th and 20th July. On average, in the first decade of September last cucumber harvesting took place in central and central-western Poland, excluding the Warta River mouth and the vicinity of Kalisz, and in the third decade of August in the Pomeranian Lakeland, the Masurian Lakeland, the Podlasie Lowland, the Lublin Upland, the Carpathian Foothills, the Sudetian Foothills and in the Kielce region.

Duration of the cucumber growing season in the perspective from sowing to the beginning of harvesting was not highly diversified, unlike duration of the periods from the beginning of harvesting to the end of harvesting and from sowing to the end of harvesting and oscillated in most of Poland between 60 and 70 days; the shortest period was recorded in the Lubusko Land and the Silesian Lowland and the longest one in the Sudetian Foothills, the Carpathian Foothills, the Małopolska Upland, the Lublin Upland, the Podlasie Lowland, the Mazurian Lakeland and elevations of the Pomeranian Lakeland (Figure 6). Duration of the period from the beginning of harvesting to the end of harvesting in Poland, i.e. the period of cucumber fruiting in the years 1966–2005, was characterised by even a three-week difference as it oscillated between 30 and 55 days. In the Pomeranian Lakeland, the Suwałki Lakeland and in submountainous regions situated in the south of the country, duration of the period from the beginning of harvesting to the end of harvesting lasted on average just under 30 days, and in the central-western part of the country even over 55 days. The growing season in the perspective from sowing to the end of cucumber harvesting was on average longer by about 43 days than the period from sowing to the beginning of harvesting and oscillated in most of Poland between 100 and 120 days; it lasted longest in the vicinity of Poznań and Kalisz. In comparison with the cucumber growing season characterised by SOKOŁOWSKA (1980), in the years 1965–1970, it was shorter by about 10 days.

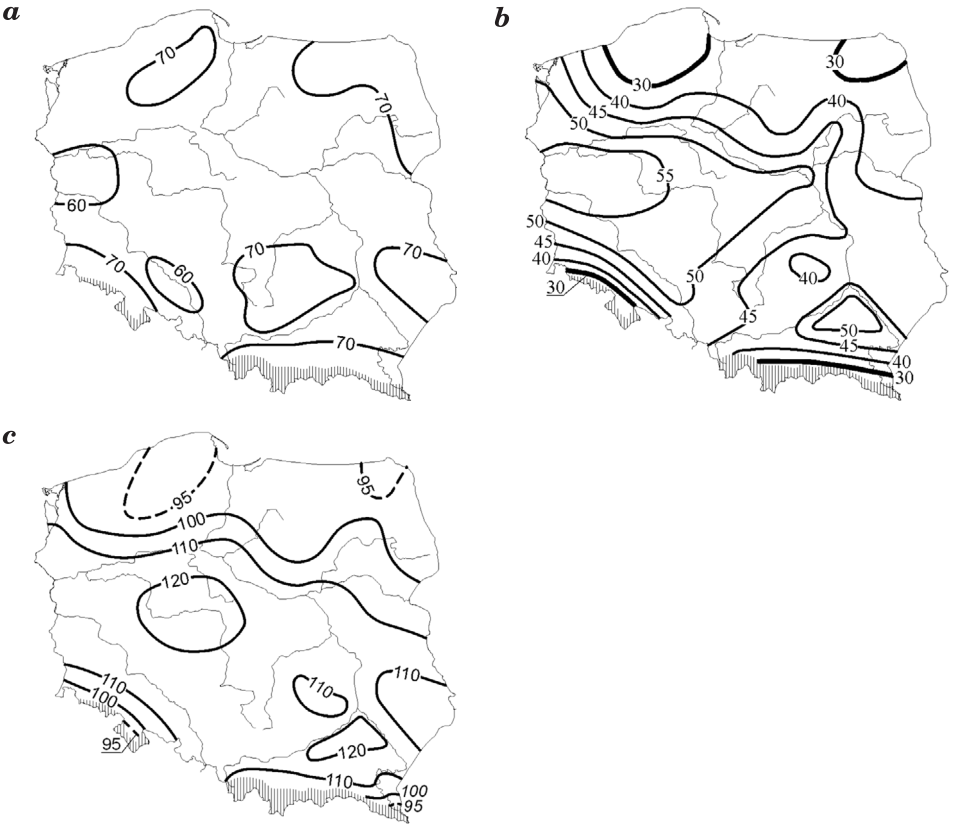

Fig. 6. Spatial distribution of duration of cucumber development stages in Poland, 1966–2005: *a – Sg–Bh, b – Bh–Eh, c – Sg–Eh*
Other explanations, see Figure 1

Effect of duration of development stages on yield

On the basis of the multiple regression analysis describing correlation between cucumber yield (total and marketable) and duration of the periods from sowing to the beginning of harvesting and from the beginning of harvesting to the end of harvesting, it was proved that the former considered period negatively determined the yield and the latter – positively (Table 1). Determination coefficients for the analysed relationships oscillated between 0.42 ($P \le 0.01$), in the case of correlation of the total yield and duration of the period from sowing to the beginning of harvesting and 0.53 ($P \le 0.01$) – the marketable yield and duration of the period from the beginning of harvesting to the end of harvesting. In all the formed regression equations a standard error of equation estimation was lower than the standard deviation of cucumber yield, and the difference between these indexes ($S - Sy$) oscillated between 3.5 and 4.4 t ha^{-1}, with the biggest difference concerning the equation describing correlation between the marketable yield and the period from the beginning of harvesting to the end of harvesting. Average relative forecast error ex post (ARFE), determined for the country as an average from all the stations from 38 years (1966–2005, excluding 2003 and 2004), oscillated between 8.6 and 9.5%, and the lowest error (ARFE) was determined for the equation characterised by both the highest determination coefficient (R^2) and the highest value of the $S - Sy$ index. An additionally used test of evaluation accuracy was determining how many times relative forecast error in the analysed multi-annual period 1966–2005 amounted to $|RFE| \leq 5\%$ (a very good forecast) and $5\% < |RFE| \leq 10\%$ (a good forecast). Among all the considered equations, the highest number of very good forecasts, that is with an error not exceeding 5%, were made for the equation describing correlation between the marketable yield and duration of the period from the beginning of harvesting to the end of harvesting (about 56%), the lowest number – between the total yield and duration of the period from sowing to the beginning of harvesting (about 49%). Good forecasts, i.e., those with an error within 5 and 10%, oscillated between 33.4 and 38.5%.

On the basis of multiple regression equations, presented in Table 1, diagrams were formed, which enabled determination of reduction in the domestic cucumber yield, expressed in percentage of the multi-annual yield,

Table 1

Dependence of cucumber yield on duration of the periods: sowing – the beginning of harvesting (Sg–Bh) and the beginning of harvesting – the end of harvesting (Bh–Eh) in whole Poland, considering a linear trend in the years 1966–2005

Regression equations	R^2	$S - Sy$ (t ha^{-1})	ARFE (%)	Frequency of the occurrence of $\lvert RFE \rvert$ in range	
				0–5 (%)	5–10 (%)
$y_t = -317.718^{***} + 0.195Y^{***} -0.564_{Sg-Bh}^{***}$ (0.24) (0.28)	0.42	3.5	9.5	49.2	33.4
$y_t = -1081.3802^{***} + 0.551Y^{***} + 0.451_{Bh-Eh}^{***}$ (0.31) (0.22)	0.46	3.8	9.2	51.5	35.6
$y_m = -1147.894^{***} + 0.579Y^{***} + 0.367_{Bh-Eh}^{***}$ (0.34) (0.32)	0.53	4.4	8.6	55.7	38.5

R^2 – determination coefficient (%), $S - Sy$ – difference between a standard deviation of a dependent variable and a standard error of equation estimation (t ha^{-1}), Y – linear trend of the yield, i.e., the successive years of the 1966–2005 multiannual period, *** significant at $P \leq 0{,}01$, y_t – total yield (t ha^{-1}), y_m – marketable yield (t ha^{-1}), ARFE – average relative forecast error (%), RFE – relative forecast error (%). The square of partial correlation coefficients of a dependent variables were given in brackets. Other explanations, see Figure 1 with assumed lengthening of the period from sowing to the beginning of harvesting and shortening of the period from the beginning of harvesting to the end of harvesting. For example, potential reduction in the total yield of cucumber in Poland caused by ten-day lengthening of the period from sowing to the beginning of harvesting, that is retardation of fruit ripening, may amount to 15.3%, and fifteen-day lengthening – even 23.8% (Figure 7). There are no reports in the scientific literature on effect of the course of the development rate of the described plant on the quantity of cucumber yield. Existing research studies of this type concern most of all agrotechnical dates and other crop plants (OZER 2003, SUN et al. 2007, ZIOMBRA, FRĄSZCZAK 2008). BORAH (2001), investigating influence of the date of sowing on the quantity of cucumber yield in climatic conditions of India (Assam state), stated that higher yield of this plant occurs with earlier dates of sowing. According to GRONOWICZ et al. (1992), in Poland a delay of the date of potato planting in relation to the optimal date by 14 and 28 days will cause a decrease in yield of tubers respectively by 6 and 27%; on the other hand, according to BOMBIK (1998) a delay of 10 days will reduce the yield by about 7%.

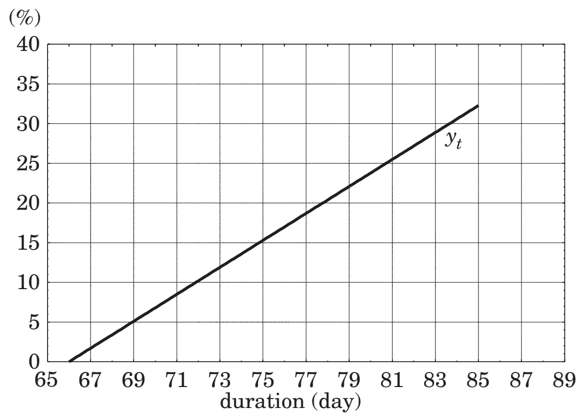

Fig. 7. Potential reduction of the total yield of cucumber (*yt*) caused by lengthening of the period from sowing to the beginning of harvesting in Poland, 1966–2005

Identical lengthening of the period from sowing to the beginning of cucumber harvesting however, may cause different reduction in the quantity of the cucumber yield depending on the region of the country (Figure 8). As a result of ten-day lengthening of the period from sowing to the beginning of harvesting potential reduction in the total yield of cucumber may oscillate between below 3% in the Lubusko Land and in the Wrocław region and even above 18% in northern Poland – in the Pomeranian Lakeland, the Masurian

Lakeland, the Podlasie Lowland and in southern Poland – in the Małopolska Upland, the Lublin Upland, the Sudetian Foothills and the Carpathian Foothills; on the other hand, in the Mazovian Lowland and in the central-western part of the country not more than 9% below the average multi-annual yield of cucumber.

Fig. 8. Potential reduction of the total yield of cucumber caused by assumed ten-day lengthening of the period from sowing to the beginning of harvesting in Poland, 1966–2005

In order to determine risk of cucumber cultivation in field conditions caused by an excessively long period from sowing to the beginning of harvesting, frequency of the occurrence of the period was determined both for the whole country and for its different regions (Figure 9 and Figure 10). For the whole country frequency of the occurrence of the period from sowing to the beginning of harvesting oscillated between 57% in the case of the period lasting 66 days (the average in the years 1966–2005) and 5% – 80 days. On the other hand, in the case of a period longer by 10 days than the average one, the frequency amounted to about 18%. In Poland frequency of the occurrence of assumed ten-day lengthening of the period from sowing to the beginning of cucumber harvesting oscillated in most of Poland between 10 and 20%, and most often in the Pomeranian Lakeland, the Suwałki Lakeland, the Sudetian Foothills and the Carpathian Foothills.

As illustrated in Figure 11 and Figure 12 and in Table 1, cucumber yield may decrease also as a result of shortening of the period from the beginning of harvesting to the end of harvesting. For the whole country, average reduction in the total and marketable yield of cucumber caused by ten-day

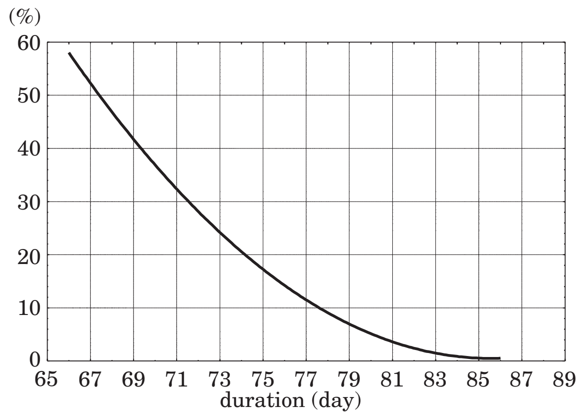

Fig. 9. Frequency of the occurrence (%) of duration of the period from sowing to the beginning of harvesting in Poland, 1966–2005

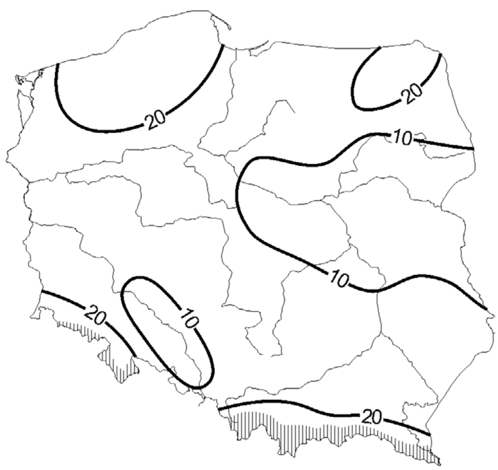

Fig. 10. Spatial distribution of frequency of the occurrence (%) of assumed ten-day lengthening of the period from sowing to the beginning of harvesting in Poland, 1966–2005

shortening of the period from the beginning of harvesting to the end of harvesting amounted to, respectively, 12.3 and 18.1%, and by fifteen-day shortening – respectively 18.6 and 27.3% (Figure 11). Especially unfavourable cultivation conditions during cucumber fruiting occurred, like in the first half of the growing season of the described plant, in the northern and southern parts of the country; the lowest total yield, lower by 18% than the value of the multi-annual average, was harvested in the Suwałki Lakeland, the Sudetian Foothills and the Carpathian Foothills, and the marketable yield, lower by above 24%, apart from the above-mentioned regions also in the Pomeranian Lakeland, the Mazurian Lakeland and in the Podlasie Lowland (Figure 12). The lowest losses in yield caused by assumed ten-day shortening of the period from the beginning of harvesting to the end of harvesting occurred in the Lubusko Land, the Myślibórz Lakeland and in the Silesian Lowland, below 9 and 15% respectively in the case of the total and the marketable yield. In the central strip of Poland reduction in yield oscillated between 9 and 12% in the case of the total yield and between 15 and 18% in the case of the marketable yield.

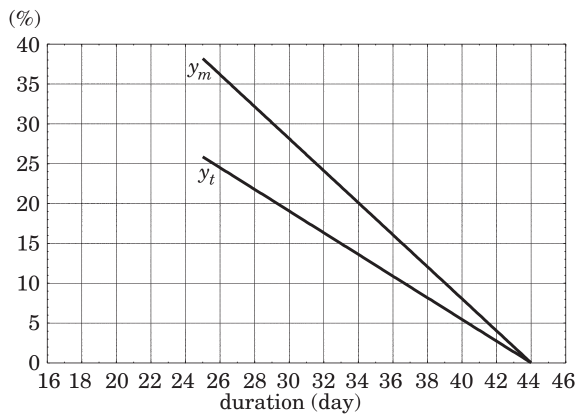

Fig. 11. Potential reduction in the total (y_t) and marketable (y_m) yield of cucumber (%) caused by assumed ten-day shortening of the period from the beginning of harvesting to the end of harvesting in Poland, 1966–2005

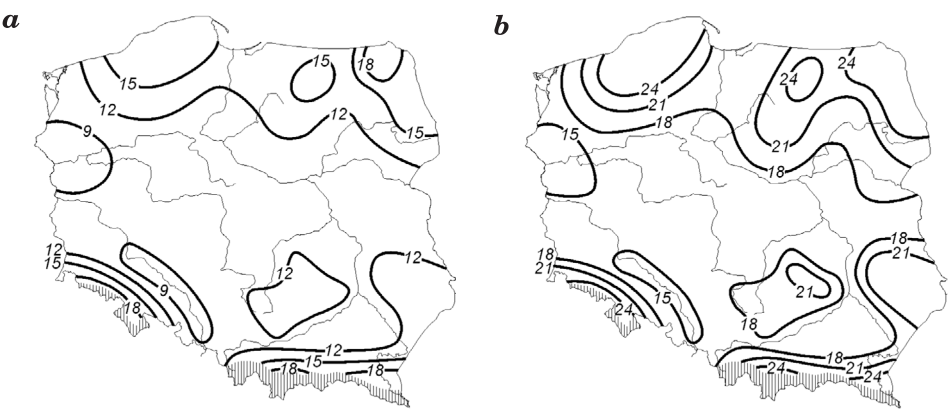

Fig. 12. Spatial distribution of potential reduction in the total (*yt*) and marketable (*ym*) yield of cucumber (%) caused by assumed ten-day shortening of the period from the beginning of harvesting to the end of harvesting in Poland, 1966–2005

In Poland, the assumed ten-day shortening of the period from the beginning of harvesting to the end of harvesting determined in relation to the average multi-annual duration of the analysed period occurred with frequency of about 22% (Figure 13) and oscillated from below 10% in the western part of the country and the Silesian Lowland to even above 40% in its south-western and south-eastern part (Figure 14). The biggest area of the country, that is, central Poland, the Elbląg region and the Sandomierz Basin, was characterised with moderate frequency of the occurrence of the described shortening – from 10 to 20%.

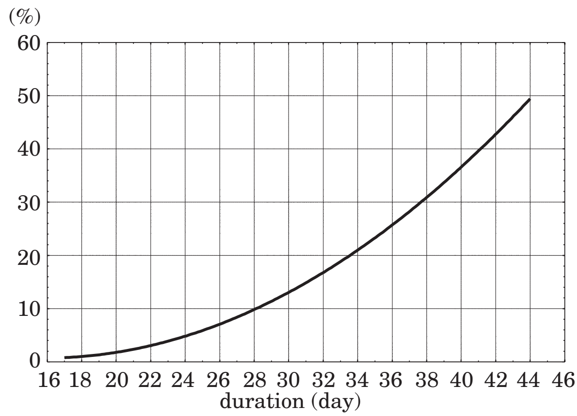

Fig. 13. Frequency of the occurrence (%) of duration of the period from the beginning of harvesting to the end of harvesting in Poland, 1966–2005

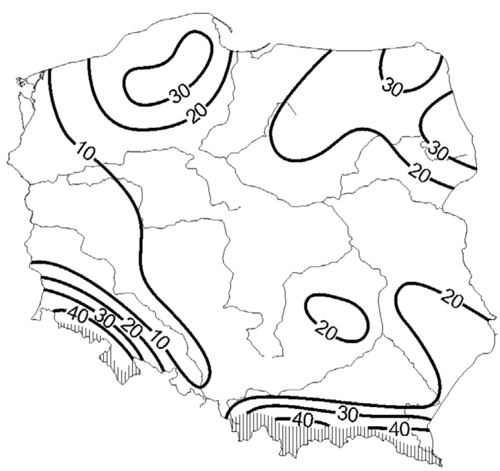

Fig. 14. Spatial distribution of frequency of the occurrence (%) of assumed ten-day shortening of the period from the beginning of harvesting to the end of harvesting in Poland, 1966–2005

In the given cucumber growing season simultaneous lengthening of the period from sowing to the beginning of harvesting and shortening of the period from the beginning of harvesting to the end of harvesting occurred very seldom, with frequency of only 2.5% (own calculations).

There is no scientific literature on risk of cucumber cultivation caused by excessively long or excessively short development periods. One can encounter studies concerning other crop plants and most of all agrotechnical dates, more seldom phenological dates. For example, in Poland frequency of the occurrence of a spring wheat sowing delay by 10 days oscillates between 10 and 20%, and most frequently it occurs in the Masurian Lakeland and in Kaszuby (KOŹMIŃSKI, MICHALSKA 2001).

Conclusions

In Poland, in the years 1966–2005, both agrotechnical and phenological dates and also cucumber development stages were characterised by high temporal and spatial variability, and temporal variability was on average twice as high as spatial variability and oscillated between 2–3 and 7 weeks. All the analysed cucumber dates were characterised by acceleration, year on year (from –0.07 day per 10 years in the case of sowing to –6.4 days per 10 years in the case of the end of harvesting), and the development stages by shortening (the whole growing season by –7.4 days per 10 years).

In the cucumber growing season, simultaneous lengthening of the period from sowing to the beginning of harvesting and shortening of the period from the beginning of harvesting to the end of harvesting by 10 days in relation to the average in the years 1966–2005 may occur on average once in 40 years. Therefore, yield reduction and risk of its occurrence during one growing season may be caused most frequently by lengthening or shortening of the analysed development stages. The worst conditions for cucumber cultivation caused by lengthening of the period from sowing to the beginning of harvesting occurred in the Pomeranian Lakeland, the Suwałki Lakeland and also in the Sudetian Foothills and the Carpathian Foothills, where reduction in the total yield of the plant, below the multi-annual average, may amount to even over 18% and may occur every 5 years. On the other hand, the highest risk of cucumber cultivation caused by shortening of the period from the beginning of harvesting to the end of harvesting occurs in the south-west (the Sudetian Foothills) and in the south-east (the Carpathian Foothills), where reduction of the total and marketable yield of cucumber may amount to, respectively, 18 and 24% and occur even every 2–3 years.

In Poland, in the years 1966–2005, shortening of the following development periods was proved: sowing – the beginning of harvesting by –2.7 days per

10 years ($P \leq 0.01$) and the beginning of harvesting – the end of harvesting by –3.7 days per 10 years ($P \leq 0.01$), which respectively may contribute to decreasing the risk of cucumber cultivation in the period from sowing to the beginning of harvesting and increasing the risk – in the period from the beginning of harvesting to the end of harvesting.

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THE EFFECTS OF SOCIAL HIERARCHY IN A DAIRY CATTLE HERD ON MILK YIELD

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Key words: social hierarchy, dairy cattle, pasture feeding, behavioral observations.

Abstract

The objective of this study was to determine the effects of dominance hierarchy in a dairy cattle herd on milk yield. Observations of social behaviors in a group of 126 Polish Holstein-Friesian cows were carried out for seven days, starting from the first grazing day. In order to estimate the position of each animal in the herd, the interactions and relationships between cows were studied. The indices of aggression, dominance and social rank were calculated. These data were used to calculate the competitive index, which enabled to divide all animals into the following subgroups of dominance: dominant cows, subdominant cows, subordinate cows, submissive cows and marginal cows.

All dairy cows were at a similar age. Their social rank was found to be positively correlated with body weight and condition. Higher-ranking animals were characterized by a higher milk yield. Both social status and performance parameters may provide a basis for selecting animals and placing them into groups, so as to optimize milk production.

HIERARCHIA W STADZIE KRÓW A WYDAJNOŚĆ MLECZNA

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Słowa kluczowe: hierarchia w stadzie, bydło mleczne, żywienie pastwiskowe.

Abstrakt

Celem pracy było poznanie hierarchii w stadzie krów oraz określenie jej związku z wydajnością mleczną. Obserwacje behawioralne dotyczące 126 krów rasy polskiej holsztyńsko-fryzyjskiej prowadzono przez siedem dni, począwszy od pierwszego wyjścia krów na pastwisko. W celu określenia miejsca w stadzie dla każdego osobnika sporządzono siatkę współzależności, a następnie na podstawie

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współczynników: agresywności, dominacji i wzajemnych współzależności obliczono współczynnik hierarchiczny, który pozwolił podzielić stado na krowy dominanty, subdominanty, osobniki podporządkowane, opanowane i marginesowe.

W zbliżonym wiekowo stadzie krów mlecznych wykazano dodatni wpływ masy ciała i kondycji na pozycję w hierarchii. Zwierzęta z wyższych poziomów hierarchii charakteryzowały się większą wydajnością mleczną. Informacje dotyczące hierarchii w stadzie i parametrów użytkowości mlecznej poszczególnych sztuk powinny być uwzględniane w czasie tworzenia optymalnych grup technologicznych, jak również prowadzenia selekcji.

Introduction

Production optimization requires a full understanding of complex behavioral patterns and responses of farm animals (JEZIERSKI 1987, PISULA 2006). The term "behavior" refers to the coordinated actions and reactions of an individual aimed at satisfying biological, psychological and social needs, affected by external factors or internal stimuli (SADOWSKI 2003). Forms of behavior include simple physical actions and complex motor acts, innate or learned, known as behavioral responses or functions. Animals exhibit nine main types of natural behavior related to feeding, excretion, mating (sexual reproduction), protectiveness, subordination, aggressiveness (social hierarchy in the herd), imitation, sense of self-preservation and cognition.

In dairy herds kept in tie-stall barns the order of entry is determined by dominance hierarchy. Cattle are social animals and dominance hierarchy is an important consideration for management decisions. Animals that are to form a herd should be selected based on such factors as their breed, age, sex, height, body weight, the presence of horns and physiological condition (NOWICKI 1978). In order to establish their social position in the herd, animals adopt different strategies indicating dominance or submission, i.e. threatening or avoiding. High dominance rank is associated with certain privileges, including priority of access to the feeder and lying area. In extreme cases animals fight for dominance status in the herd. Social hierarchy in the herd may be determined by observing the attitudes taken by animals (ROGALSKI 1972). In the social hierarchy, individuals are assigned to different (three to five) classes or ranks in the group or herd (KOWALSKI 2000). The most common linear structure comprises five classes: I – dominant cows that displace other animals from feeding and resting areas, and are never harassed by subordinates; II – subdominant cows that often aspire to become leaders, but always lose in direct competition; they show submissive behaviors towards dominants but demonstrate their superiority over lower-ranking animals; III – subordinate cows, servile towards superiors and aggressive towards inferiors; IV – submissive cows, subordinate to representatives of the above classes, aggressive only against the lowest-ranking individuals; in this group submissive and servile attitudes dominate over threatening and aggressive behaviors; V – marginal cows, subordinate to all other animals.

Grazing on pasture gives cows the opportunity to relearn their herd instinct and ability to survive in the natural environment (SKRIJKA 1999). A better understanding of cattle behavior in pasture contributes to implementing a rational grazing system and adjusting rations to the nutritional needs of animals, thus positively affecting the reproductive performance and health status of cows. In view of the recent trends to increase herd size and pasture stocking density, the results of studies of animal behavior may provide a basis for proper organization and intensification of dairy cattle production (WROŃSKI et al. 1988).

The objective of this study was to determine the effects of dominance hierarchy on milk yield in a herd of Polish Holstein-Friesian cattle.

Materials and Methods

The experimental materials comprised 126 Polish Holstein Friesian (PHF) cows (94 primiparous cows and 32 cows in their second lactation) which had their horns removed, kept in a free-stall barn. The basal diet fed to cows was composed of maize and grass silage. Feed was offered immediately after the morning milking (7.00 a.m.) and evening milking (6.00 p.m.). Cows were fed supplemental concentrate via automatic feeding stations, so as to meet their nutrient requirements. From the middle of June until the end of September, the animals could graze the pasture situated at a distance of around 70 m from the barn. The cattle were grazed rotationally, they were moved from one paddock to another each day, and had free access to water.

Behavioral observations were carried out by four persons for seven consecutive days starting from the first grazing day, between 9.00 a.m. and 3.00 p.m. The persons made every effort not to interfere in herd behavior – they stayed at the edge of the pasture and used binoculars to monitor the cattle. All cows had neck straps with identification numbers.

In order to estimate the position of each animal relative to social rank, the interactions and relationships between cows were studied and described using appropriate codes. Particular attention was paid to aggression and submissiveness. All cases of aggressive interactions in the herd were noted, including those related to access to the resources (feed, water, resting place) and non-competitive situations. Depending on their intensity, aggressive interactions were divided into threatening (1 point), pushing (2 points) and violent attacks (3 points). The index of aggression was calculated based on the total score for each animal, obtained over the entire period of observation (JEZIERSKI 1987):

$$\text{index of aggression} = g + 2o + 3a$$

where:
g – threatening,
o – pushing,
a – violent attack.

The aggression index was presented so as to reflect the position of each animal in the dominance hierarchy. The cows were placed in ascending order, from the lowest score to the highest score, and social hierarchy rank was assigned to each animal. The final result was divided by the number of positions in the herd, as follows:

$$\text{index of aggression in the herd} = \frac{\textit{position of a cow} \text{ in } \textit{the herd (score)}}{\textit{number of positions} \text{ in } \textit{the herd}}$$

Based on the number of acts of dominant and subordinate behavior in social interactions, the index of dominance was calculated for each animal (JEZIERSKI 1987):

$$DV = \frac{n_1}{n_1 + n_2}$$

where:
DV – index of dominance,
n_1 – number of animals subordinate to a given individual,
n_2 – number of animals dominant over a given individual.

Subordinate cows would avoid aggression by moving out of the way of dominant partners, standing up from the lying position to let the dominants pass, searching for another place to rest if a given resting area had been chosen by a higher-ranking cow, giving dominant cows their space at the feeder.

Based on the number of acts of dominant and subordinate behavior in the monitored herd, the index of social rank was calculated for each animal:

$$\text{index of social rank} = \frac{a - u}{N}$$

where:
a – number of acts of dominant behavior,
u – number of acts of subordinate behavior,
N – number of cows in the herd.

The values of the indices of dominance and social rank were put in ascending order, and social hierarchy rank was assigned to each animal. The final results were divided by the number of positions in the herd, as follows:

$$\text{index of dominance in the herd} = \frac{\textit{position of a cow} \text{ in the } \textit{herd} \ (\textit{based on DV})}{\textit{number of position} \text{ in the } \textit{herd}}$$

$$\text{index of social rank in the herd} = \frac{\textit{position of a cow} \text{ in the } \textit{herd} \ (\textit{based on a–u})}{\textit{number of positions} \text{ in } \textit{the herd}}$$

The values of the indices of aggression, dominance and social rank were used to calculate the competitive index, which is the outcome of the above indices:

$$\text{competitive index} = \frac{\textit{index of aggression} + \textit{index of dominance} + \textit{index of social rank}}{3}$$

The competitive index, in the above form, objectively reflects dominance hierarchy in the herd and the social position of each cow. Based on the values of this index, the herd was divided into five social groups, according to the relevant definitions (Table 1).

Table 1

Herd division based on the values of the competitive index (KOWALSKI 2000)

Social group	*N* (%)	Competitive index
Dominant cows (I)	3 2.38	0.000–0.100
Subdominant cows (II)	23 18.25	0.101–0.400
Subordinate cows (III)	38 30.16	0.401–0.600
Submissive cows (IV)	58 46.03	0.601–0.850
Marginal cows (V)	4 3.18	0.851–1.000

Milk yield, milk fat content and milk protein content were determined based on milk yield records. The body weights of cows were determined using an electronic scale. Body condition score (BCS) was calculated using a five--point scale proposed by WILDMAN et al. (1982) on the fifth grazing day.

A statistical analysis of the data was performed using STATISTICA 7.0 software. The effects of body weight, body condition and age on the position of cows in dominance hierarchy were determined by a one-factor analysis of variance in a non-orthogonal design. The significance of differences between mean values was estimated by Tukey's test.

Results and Discussion

Social hierarchy in the cattle herd may be determined by observing the attitudes taken by individual cows. Pasture is the best place to monitor manifestations of the natural herd instinct and to recognize dominance relationships in the herd. In the present study, social hierarchy in the herd was determined based on the values of the competitive index and the relevant definitions of social groups (Table 1). Only three cows (2.38%) were found to be dominant. Submissive cows formed the largest group (46.03%) in the herd. Four individuals were classified as marginal. According to NOWICKI (1978), marginal cows cannot use their full production potential. Almost identical social relationships were reported by SAMBRAUS (1975) – in his study eight dominant cows accounted for only 1.52% of the herd. In an experiment conducted by ROGALSKI (1972), the herd was divided into social groups as follows: group I – 13%, group II – 27%, group III – 7%, group IV – 40%, group V – 13%.

The social status of animals in the herd is dependent on the perception and manifestation of their physical traits, and the attitudes they adopt towards one another, rather than on their actual strength. Only animals with appropriate physical attributes and mental capacities can hold a high social position in the herd. There exists a close interdependence between the age, body weight and intelligence of an individual and its social rank. An important role may be also played by the length and sharpness of horns, agility, stress resistance and courage (ROGALSKI 1972). SCHEIN and FOHRMAN (1955) demonstrated a strong correlation between the social position in the herd and the age (r = 0.93) and body weight (r = 0.87) of cows. In our study the social rank of animals was found to be positively correlated with their age, body weight and condition (Table 2). The average body weight of dominant cows was 587.7 kg, and it was on average by 82.2 kg higher than the body weight of marginal cows. Body condition also exerted a significant effect on the position of cows in social hierarchy. Differences between dominant and submissive cows reached 0.6 points on average. Although all cows in the analyzed herd were at a similar age (first and second lactation), the oldest, most experienced and heaviest ones performed the role of leaders. Dominant cows were significantly older ($p \leq 0.05$) than submissive cows.

Table 2

Body weight, body condition and age of cows representing different social groups

Social group	Statistical measure	Body weight (kg)	Body condition (points)	Lactation (1–5)
I	$\bar{x}$ SD	587.7 63.8	3.13 0.75	2.00 0.0
II	$\bar{x}$ SD	564.5^{A} 57.6	2.93^{AB} 0.22	1.21^{a} 0.42
III	$\bar{x}$ SD	524.7 49.1	2.60^{A} 0.26	1.21 0.41
IV	$\bar{x}$ SD	507.2^{A} 51.6	2.53^{B} 0.29	1.10^{a} 0.31
V	$\bar{x}$ SD	505.4 49.4	2.50 0.18	1.25 0.50

Mean values in columns followed by the same superscript letters differ significantly: capital letters – $p \leq 0.01$, small letters – $p \leq 0.05$.

In a newly formed herd, most of the dominance/subordination relationships develop during the first hour. As shown by BOUISSON (1974), 84% of relationships in a group of cattle are established within the first five minutes, and within two hours animals form stable social subgroups. However, it should be stressed that certain parameters of social behavior (e.g. those related to physiological condition or disease occurrence) are relatively variable and may affect dominance hierarchy over time. According to SAMBRAUS (1975), older, usually heavier cows hold higher positions in the social structure and maintain their status even at an older age, when their physical activity is largely reduced. In-calf heifers and juvenile cattle occupy the lowest-ranking position in the herd. Ill animals are always dominated by healthy individuals, even if the latter were subordinate to the former prior to disease occurrence. Temporary isolation or displacement of leaders is ineffective since on coming back they quickly regain their former dominant position (NOWICKI 1978). The removal of the most dominant individual from the herd results in taking the leadership by the next highest-ranking animal. In addition, a herd without a leader is likely to fall apart and is difficult to manage in open spaces.

Higher-ranking cows were characterized by a higher milk yield during lactation of standard length (Table 3). Differences in the average milk yield between groups ranged from 8 to 20%. In the groups of dominant and subdominant cows, milk yield exceeded 6 000 kg in standard-length lactation. The difference in average milk production between dominants and marginal cows reached 1092 kg, but it was statistically non-significant due to a too low number of group I cows. Significant differences were noted between groups II and IV with respect to milk protein content. SCHEIN and FOHRMAN (1955) observed a 5% decrease in milk production in cows that were losers in aggressive interactions. Similar results were reported by JEZIERSKI (1987), who noted an average decrease in milk yield of 4.36% due to factors other than social stress within five days after the exchange of cows between groups. According to SYME and SYME (1979), aggressive interactions and competitive situations should be avoided in cattle herds although there is no unequivocal evidence to support the hypothesis that dominance in the herd can be associated with milk performance traits. The results of the present study, which are consistent with the findings of FRIEND and POLAN (1978), suggest that both social status and performance parameters may provide a basis for selecting animals and placing them into groups, so as to optimize milk production.

Table 3

Effect of dominance hierarchy on milk yield

Social group	Statistical measures	Milk yield for 305 days (kg)	Milk protein content (%)	Milk fat content (%)
I	$\bar{x}$ SD	6580 832	3.22 0.40	4.04 0.78
II	$\bar{x}$ SD	6105 1063	3.59^A 0.36	4.60 0.60
III	$\bar{x}$ SD	5890 924	3.36 0.29	4.36 0.58
IV	$\bar{x}$ SD	5460 658	3.29^A 0.24	4.19 0.42
V	$\bar{x}$ SD	5488 756	3.22 0.22	4.05 0.41

Mean values in columns followed by the same superscript letters differ significantly: capital letters – $p \leq 0.01$.

Conclusions

1. In a herd composed of dairy cows at a similar age, the social rank of animals was found to be positively correlated with their body weight and condition.
2. Higher-ranking cows were characterized by a higher milk yield during lactation of standard length.
3. Both social status and performance parameters may provide a basis for selecting animals and placing them into groups, so as to optimize milk production.

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AN INVESTIGATION OF IRRIGATION METHODS BASED ON THE PARAMETRIC EVALUATION APPROACH IN ARAYEZ PLAIN – IRAN

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K e y w o r d s: Surface irrigation, sprinkle irrigation, drip irrigation, parametric method, soil series.

A b s t r a c t

The main objective of this research is to compare different irrigation methods based upon a parametric evaluation system in an area of 54 000 ha in the Arayez plain – Iran. The results demonstrated that by applying sprinkle irrigation instead of surface and drip irrigation methods, the arability of 35 855.73 ha (66.40%) in the Arayez Plain will improve. In addition by applying drip Irrigation instead of surface and sprinkle irrigation methods, the land suitability of 16 644.27 ha (30.82%) of this Plain will improve. The comparison of the different types of irrigation techniques revealed that the sprinkle and drip irrigations methods were more effective and efficient than the surface irrigation methods for improving land productivity. It is of note however that the main limiting factor in using different irrigation methods in this area are soil texture, salinity & alkalinity, drainage, calcium carbonate content and slope.

OCENA PARAMETRYCZNA SYSTEMÓW NAWADNIANIA NA RÓWNINIE ARAYEZ W IRANIE

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S ł o w a k l u c z o w e: nawadnianie powierzchniowe, nawadnianie deszczownianie, nawadnianie kroplowe, metoda parametryczna, serie glebowe.

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A b s t r a k t

Głównym celem badań było porównanie za pomocą metody parametrycznej różnych systemów nawadniania obszaru o powierzchni 54 tys. ha na równinie Arayez w Iranie. Uzyskane wyniki wykazały, że zastosowanie nawadniania deszczownianego, zamiast powierzchniowego i kroplowego, pozwoli poprawić zdolność produkcyjną gleby na 35 855,73 ha (66,40%) badanego terenu. Zastosowanie nawadniania kroplowego, zamiast powierzchniowego i deszczownianego, zwiększy ponadto przydatność rolniczą 16 644,27 ha (30,82%) gleb analizowanej równiny. Porównanie różnych technik nawadniania wykazało, że nawadnianie deszczowniane i kroplowe, w odniesieniu do produktywności gleby, to systemy efektywniejsze i wydajniejsze niż nawadnianie powierzchniowe. Należy jednak zaznaczyć, że głównymi czynnikami ograniczającymi użycie różnych metod nawadniania na równinie Arayez są: struktura gleby, jej zasolenie i alkaliczność oraz właściwości drenażowe, zawartość węglanu wapnia i spadek terenu.

Introduction

Food security and stability in the world greatly depends on the management of natural resources. Due to the depletion of water resources and an increase in population, the extent of irrigated area per capita is declining and irrigated lands now produce 40% of the food supply (HARGREAVES, MEKLEY 1998). Consequently, available water resources will not be able to meet various demands in the near future and this will inevitably result into the seeking of newer lands for irrigation in order to achieve sustainable global food security. Land suitability, by definition, is the natural capability of a given land to support a defined use. The process of land suitability classification is the appraisal and grouping of specific areas of land in terms of their suitability for a defined use.

According to FAO methodology (1976) land suitability is strongly related to "land qualities" including erosion resistance, water availability, and flood hazards which are in themselves immeasurable qualities. Since these qualities are derived from "land characteristics", such as slope angle and length, rainfall and soil texture which are measurable or estimable, it is advantageous to use the latter indicators in the land suitability studies, and then use the land parameters for determining the land suitability for irrigation purposes. SYS et al. (1991) suggested a parametric evaluation system for irrigation methods which was primarily based upon physical and chemical soil properties. In their proposed system, the factors affecting soil suitability for irrigation purposes can be subdivided into four groups:

– physical properties determining the soil-water relationship in the soil such as permeability and available water content;

– chemical properties interfering with the salinity/alkalinity status such as soluble salts and exchangeable Na;

– drainage properties;
– environmental factors such as slope.

BRIZA et al. (2001) applied a parametric system (SYS et al. 1991) to evaluate land suitability for both surface and drip irrigation in the Ben Slimane Province, Morocco, while no highly suitable areas were found in the studied area. The largest part of the agricultural areas was classified as marginally suitable, the most limiting factors being physical parameters such as slope, soil calcium carbonate, sandy soil texture and soil depth.

BAZZANI, INCERTI (2002) also provided a land suitability evaluation for surface and drip irrigation systems in the province of Larche, Morocco, by using parametric evaluation systems. The results showed a large difference between applying the two different evaluations. The area not suitable for surface irrigation was 29.22% of total surface and 9% with the drip irrigation while the suitable area was 19% versus 70%. Moreover, high suitability was extended on a surface of 3.29% in the former case and it became 38.96% in the latter. The main limiting factors were physical limitations such as the slope and sandy soil texture.

BIENVENUE et al. (2003) evaluated the land suitability for surface (gravity) and drip (localized) irrigation in the Thies, Senegal, by using the parametric evaluation systems. Regarding surface irrigation, there was no area classified as highly suitable (S_1). Only 20.24% of the study area proved suitable (S_2, 7.73%) or slightly suitable (S_3, 12. 51%). Most of the study area (57.66%) was classified as unsuitable (N_2). The limiting factor to this kind of land use was mainly the soil drainage status and texture that was mostly sandy while surface irrigation generally requires heavier soils. For drip (localized) irrigation, a good portion (45.25%) of the area was suitable (S_2) while 25.03% was classified as highly suitable (S_1) and only a small portion was relatively suitable (N_1, 5.83%) or unsuitable (N_2, 5.83%). In the latter cases, the handicap was largely due to the shallow soil depth and incompatible texture as a result of a large amount of coarse gravel and/or poor drainage.

MBODJ et al. (2004) performed a land suitability evaluation for two types of irrigation i. e, surface irrigation and drip irrigation, in the Tunisian Oued Rmel Catchment using the suggested parametric evaluation. According to the results, the drip irrigation suitability gave more irrigable areas compared to the surface irrigation practice due to the topographic (slope), soil (depth and texture) and drainage limitations encountered with in the surface irrigation suitability evaluation.

BARBERIS and MINELLI (2005) provided land suitability classification for both surface and drip irrigation methods in Shouyang county, Shanxi province, China where the study was carried out by a modified parametric system. The results indicated that due to the unusual morphology, the area suitability for the surface irrigation (34%) is smaller than the surface used for the drip irrigation (62%). The most limiting factors were physical parameters including slope and soil depth.

DENGIZE (2006) also compared different irrigation methods including surface and drip irrigation in the pilot fields of central research institute, lkizce research farm located in southern Ankara. He concluded that the drip irrigation method increased the land suitability by 38% compared to the surface irrigation method. The most important limiting factors for surface irrigation in study area were soil salinity, drainage and soil texture, respectively whereas, the major limiting factors for drip or localized irrigation were soil salinity and drainage.

LIU et al. (2006) evaluated the land suitability for surface and drip irrigation in the Danling County, Sichuan province, China, using a Sys's parametric evaluation system. For surface irrigation the most suitable areas (S_1) represented about (24%) of Danling County, (33%) was moderately suitable (S_2), (%9) was classified as marginally suitable (S_3), (7%) of the area was founded currently not suitable (N_1) and (25%) was very unsuitable for surface irrigation due to their high slope gradient. Drip irrigation was everywhere more suitable than surface irrigation due to the minor environmental impact that it caused. Areas highly suitable for this practice covered 38% of Danling County; about 10% was marginally suitable (the steep dip slope and the structural rolling rises of the Jurassic period). The steeper zones of the study area (23%) were either approximately or totally unsuitable for such a practice.

ALBAJI et al. (2008) carried out a land suitability evaluation for surface and drip Irrigation in the Shavoor Plain, in Iran. The results showed that 41% of the area was suitable for surface irrigation; 50% of the area was highly recommend for drip irrigation and the rest of the area was not considered suitable for either irrigation method due to soil salinity and drainage problem.

ALBAJI et al. (2009) compared the different irrigation methods based on the parametric evaluation approach in Abbas Plain: Iran. The results demonstrated that by applying sprinkle irrigation instead of surface and drip irrigation methods, the arability of 21 250 ha (72.53%) in the Abbas Plain will improve. In addition by applying drip irrigation instead of surface and sprinkle irrigation methods, the land suitability of 6275 ha (21.42%) of this plain will improve. The comparison of the different types of irrigation techniques revealed that the sprinkle and drip irrigation methods were more effective and efficient than the surface irrigation methods for improving land productivity. It is of note, however, that the main limiting factor in using either surface and/or sprinkle irrigation methods in this area is soil texture and the main limiting factor in using drip irrigation methods were soil calcium carbonate content and soil texture.

NASERI et al. (2009) investigated the land suitability for different irrigation systems in Lali Plain, Iran. The results showed that 1732 ha (48.5%) of the studied area was highly suitable for all of the irrigations methods, whereas 384 ha (10.8%) of the study area was unsuitable for surface irrigation methods. Also, for sprinkler and drip irrigation systems the unsuitable lands did not exist in this zone.

The main objective of this research is to evaluate and compare land suitability for surface, sprinkle and drip irrigation methods based on the parametric evaluation systems for the Arayez Plain, in the Khuzestan Province, Iran.

Materials and Methods

The present study was conducted in an area about 54 000 hectares in the Arayez Plain, in the Khuzestan Province, located in the Southwest of Iran during 2007–2008. The study area is located 80 km Northwest of the city of Ahwaz, 31° 18’ to 32° 30’ N and 47° 30’ to 47° 55’ E. The Average annual temperature and precipitation for the period of 1965–2004 were 25.9°C and 264 mm, respectively. Also, the annual evaporation of the area is 2380 mm (*Khuzestan Water and Power Authority*. 2005). The Karkheh River supplies the bulk of the water demands of the region. The application of irrigated agriculture has been common in the study area. Currently, the irrigation systems used by farmlands in the region are furrow irrigation, basin irrigation and border irrigation schemes.

The area is composed of three distinct physiographic features i.e. Piedmont Alluvial Plains, Coalescing Alluvial-Colluvial Fans and Plateaux, of which the Piedmont Alluvial Plains physiographic unit is the dominating features. Also, twenty four different soil series were found in the area. The semi-detailed soil survey report of the Arayez plain (*Khuzestan Water and Power Authority*. 2003). was used in order to determine the soil characteristics. The land evaluation was determined based upon topography and soil characteristics of the region. The topographic characteristics included slope and soil properties such as soil texture, depth, salinity, drainage and calcium carbonate content were taken into account. Soil properties such as cation exchange capacity (CEC), percentage of basic saturation (PBC), organic mater (OM) and pH were considered in terms of soil fertility. SYS et al. (1991) suggested that soil characteristics such as OM and PBS do not require any evaluation in arid regions whereas clay CEC rate usually exceeds the plant requirement without further limitation, thus, fertility properties can be excluded from land evaluation if it is done for the purpose of irrigation.

Based upon the profile description and laboratory analysis, the groups of soils that had similar properties and were located in a same physiographic unit, were categorized as soil series and were taxonomied to form a soil family as per the Keys to Soil Taxonomy (2000)[14]. Ultimately, twenty four soil series were selected for the surface, sprinkle and drip irrigation land suitability.

In order to obtain the average soil texture, salinity and $CaCo_3$ for the upper 150 cm of soil surface, the profile was subdivided into 6 equal sections and weighting factors of 2, 1.5, 1, 0.75, 0.50 and 0.25 were used for each section, respectively (SYS et al. 1991).

For the evaluation of land suitability for surface, sprinkle and drip irrigation, the parametric evaluation system was used (SYS et al. 1991). This method is based on morphology, physical and chemical properties of soil.

Six parameters including slope, drainage properties, electrical conductivity of soil solution, calcium carbonates status, soil texture and soil depth were also considered and rates were assigned to each as per the related tables, thus, the capability index for irrigation (*Ci*) was developed as shown in the equation below:

$$Ci = A \cdot \frac{B}{100} \cdot \frac{C}{100} \cdot \frac{D}{100} \cdot \frac{E}{100} \cdot \frac{F}{100}$$

where *A, B, C, D, E*, and *F* are soil texture rating, soil depth rating, calcium carbonate content rating, electrical conductivity rating, drainage rating and slope rating, respectively. In Table 1 the ranges of capability index and the corresponding suitability classes are shown.

Table 1
Suitability classes for the irrigation capability indices (*Ci*) classes

Capability index	Definition	Symbol
> 80	highly suitable	S_1
60–80	moderately suitable	S_2
45–59	marginally suitable	S_3
30–44	currently not suitable	N_1
< 29	permanently not suitable	N_2

In order to develop land suitability maps for different irrigation methods, a semi-detailed soil map (Figure 1) prepared by Albaji was used, and all the data for soil characteristics were analyzed and incorporated in the map using ArcGIS 9.2 software.

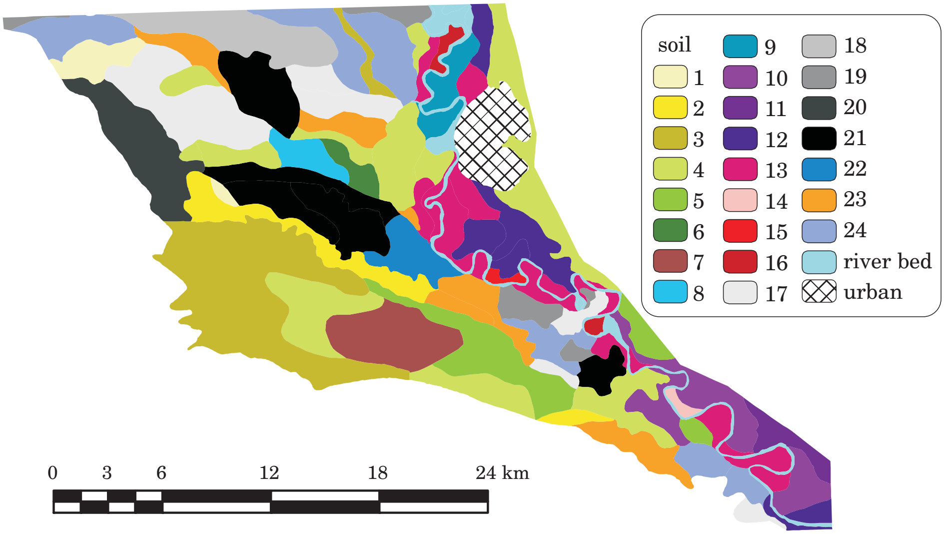

Fig. 1. Soil map of the study area

The digital soil map base preparation was the first step towards the presentation of a GIS module for land suitability maps for different irrigation systems. The Soil map was then digitized and a database prepared. A total of 24 different polygons or land mapping units (LMU) were determined in the base map. Soil characteristics were also given for each LMU. These values were used to generate the land suitability maps for surface, sprinkle and drip irrigation systems using Geographic Information Systems.

Results

Over much of the Arayez Plain, the use of surface irrigation systems has been applied specifically for field crops to meet the water demand of both summer and winter crops. The major irrigated broad-acre crops grown in this area are wheat, barley, and maize, in addition to fruits , melons, watermelons and vegetables such as tomatoes and cucumbers. There are very few instances of sprinkle and drip irrigation on large area farms in the Arayez Plain.

Twenty four soil series or land units and fifty four series phases were derived from the semi-detailed soil study of the area. The land units are shown in Figure 1 as the basis for further land evaluation practice. The soils of the area are of Aridisols, order. Also, the soil moisture regime is Aridic while the soil temperature regime is Hyperthermic (*Khuzestan Water and Power Authority*. 2003).

As shown in Table 2 and Table 3 for surface irrigation, the soil series coded 13, 15, and 20 (5637.81 ha – 10.45%) were highly suitable (S_1); soil series coded 2, 6, 9,12 and 16 (7300 ha – 13.47 %) were classified as moderately suitable (S_2), and soil series coded 8, 17, 23 and 24 (9150 ha – 16.95%) were found to be marginally suitable (S_3). soil series coded 1, 3, 4, 5, 10, 11, 14, 18, 19 and 21 (27 581.46 ha – 51.11%) were classified as currently not-suitable (N_1).Also, soil series coded 7 and 22 (9150 ha – 16.95%) were found to be permanently not-suitable (N_2) for any surface irrigation practices.

Table 2

Ci values and suitability classes of surface, sprinkle and drip irrigation for each land units

Codes of land units	Surface irrigation		Sprinkle irrigation		Drip irrigation	
	Ci	suitability classes	*Ci*	suitability classes	*Ci*	suitability classes
1	38.47	N_{1S}*	51.33	S_{3S}**	53.20	S_{3S}***
2	73.10	S_{2T}	77.16	S_{2S}	72.20	S_{2S}
3	43.87	N_{1N}	45.00	S_{3N}	40.00	N_{1SN}
4	40.28	N_{1SW}	47.24	S_{3SW}	45.22	S_{3SW}
5	35.80	N_{1SNW}	42.27	N_{1SNW}	40.46	N_{1SNW}
6	67.13	S_{2S}	72.67	S_{2S}	64.60	S_{2S}
7	23.87	N_{2SNW}	29.26	N_{1SNW}	28.90	N_{2SNW}
8	52.21	S_{3SN}	57.37	S_{3SN}	51.00	S_{3SN}
9	67.52	S_{2S}	73.10	S_{2S}	68.40	S_{2S}
10	35.54	N_{1N}	38.47	N_{1N}	36.00	N_{1SN}
11	41.77	N_{1SNW}	51.64	S_{3SN}	51.00	S_{3SN}
12	63.18	S_{2W}	76.95	S_{2S}	76.00	S_{2S}
13	87.75	S_1	90.00	S_1	80.00	S_1
14	43.87	N_{1N}	45.00	S_{3N}	40.00	N_{1SN}
15	87.75	S_1	90.00	S_1	80.00	S_1
16	65.81	S_{2S}	81.00	S_1	76.00	S_{2S}
17	48.26	S_{3S}	63.00	S_{2S}	68.00	S_{2S}
18	39.60	N_{1TS}	53.55	S_{3TS}	61.20	S_{2S}
19	39.60	N_{1TS}	53.55	S_{3TS}	61.20	S_{2S}
20	81.22	S_1	83.36	S_1	76.00	S_{2S}
21	36.45	N_{1S}	50.01	S_{3S}	53.20	S_{3S}
22	16.20	N_{2TS}	20.65	N_{2TS}	20.52	N_{2S}
23	44.55	S_{3S}	59.85	S_{2S}	68.00	S_{2S}
24	47.02	S_{3S}	61.42	S_{2S}	68.00	S_{2S}

*, ** – limiting factors for surface and sprinkle irrigations: S (soil texture), N (salinity & alkalinity), W (drainage) & T (slope).
*** – limiting factors for drip irrigation: S (Calcium Carbonate, soil texture), N (salinity & alkalinity), W (drainage) & T (Slope).

The analysis of the suitability irrigation maps for surface irrigation (Figure 2), indicate that the some part of the cultivated area in this plain (located in the west and east) are deemed as being highly suitable land due to deep soil, good drainage, texture, salinity and proper slope of the area.

Table 3

Distribution of surface, sprinkle and drip irrigation suitability

Suitability	Surface irrigation			Sprinkle irrigation			Drip irrigation		
	land unit	area (ha)	ratio (%)	land unit	area (ha)	ratio (%)	land unit	area (ha)	ratio (%)
S_1	13, 15, 20	5 637.81	10.45	13, 15, 16, 20	6 812.81	12.62	13, 15	3475	6.45
S_2	2, 6, 9, 12, 16	7300	13.47	2, 6, 9, 12, 17, 23, 24	14 725	27.23	2, 6, 9, 12, 16, 17, 18, 19, 20, 23, 24	21 237.81	39.29
S_3	8, 17, 23, 24	9150	16.95	1, 3, 4, 8, 11, 14, 18, 19, 21	24 706.53	45.78	1, 4, 8, 11, 21	12 944.27	23.97
N_1	1, 3, 4, 5, 10, 11, 14, 18, 19, 21	27 581.46	51.11	5, 7, 10	5350	9.91	3, 5, 10, 14	12 012.19	22.27
N_2	7, 22	28 30.73	5.24	22	905.73	1.68	7, 22	2 830.73	5.24
*Mis Land		1500	2.78		1500	2.78		1500	2.78
Total		54 000	100		54 000	100		54 000	100

* Miscellaneous Land: (hill, sand dune and river bed)

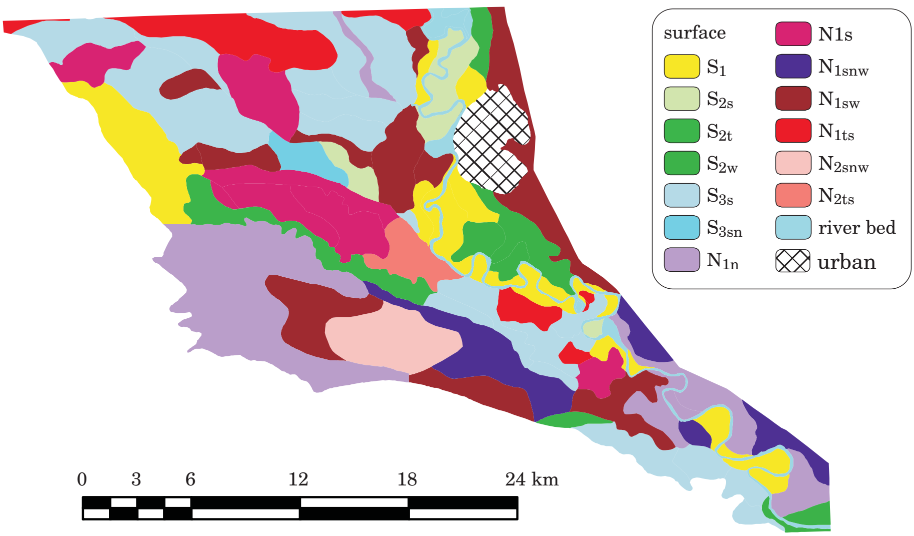

Fig. 2. Land suitability map for surface irrigation: S_1 – highly suitable, S_{2s} – moderately suitable, S_{2t} – moderately suitable, S_{2w} – moderately suitable, S_{3s} – marginally suitable, S_{3sn} – marginally suitable, N_{1n} – currently not suitable, N_{1s} – currently not suitable, N_{1snw} – currently not suitable, N_{1sw} – currently not suitable, N_{2snw} – currently not suitable, N_{2ts} – permanently not suitable

The moderately suitable area is located to the center and east of this area due to sandy loam soil texture. Other factors such as drainage, depth, salinity and alkalinity have no influence on the suitability of the area what soever. The map also indicates that some portions of the cultivated area in this plain was evaluated as marginally suitable because of the loamy sand soil texture and gently slope. The current non-suitable land can be observed in the largest portion of the plain because of sever salinity, alkalinity and drainage limitations. The permanently non-suitable land covered the smallest part of this plain, due to very sever salinity, alkalinity and drainage limitations. For almost the total study area elements such as soil depth and $CaCO_3$ were not considered as limiting factors.

In order to verify the possible effects of different management practices, the land suitability for sprinkle and drip irrigation was evaluated (Table 2 and Table 3).

For sprinkle irrigation, soil series coded 13, 15, 16 and 20 (6812.81 ha – 12.62%) were highly suitable (S_1) while soil series coded 2, 6, 9, 12, 17, 23 and 24 (14725 ha – 27.23%) were classified as moderately suitable (S_2). Also, soil series coded 1, 3, 4, 8, 11, 14, 18, 19 and 21 (24 706.53 ha – 45.78%) were marginal suitable (S_3). soil series coded 5, 7 and 10 (5350 ha – 9.91%) were found to be currently non-suitable (N_1). Further, only soil series coded 22 (2150 905.73 ha – 1.68%) was classified as permanently not-suitable (N_2) for sprinkle irrigation.

Regarding sprinkler irrigation, (Figure 3) the highly suitable area can be observed in the some part of the cultivated zone in this plain (located in the west and the east) due to deep soil, good drainage, texture, salinity and proper slope of the area. As seen from the map, some portion of the cultivated area in this plain was evaluated as moderately suitable for sprinkle irrigation because of the loamy sand soil texture. Other factors such as drainage, depth, salinity and slope never influence the suitability of the area. The map also indicates that the largest parts (45.78%) of the cultivated area in this zone was evaluated as marginally suitable because of the sandy soil texture and gently slope. The current non-suitable lands are located only in the south and southwest of the plain and their non-suitability of the land is due to the sever salinity, alkalinity and drainage limitations. The permanently not-suitable lands just exist in the smallest part of this area because of very sever salinity, alkalinity and drainage limitations For almost the entire study area soil depth and $CaCO_3$ were never taken as limiting factors.

For drip irrigation, soil series coded 13 and 15 (3475 ha – 6.45%) were highly suitable (S_1) while soil series coded 2, 6, 9, 12, 16, 17, 18, 19, 20, 23 and 24 (21 237.81 ha – 39.29%) were classified as moderately suitable (S_2). Further, soil series coded 1, 4, 8, 11 and 21 (12 944.27 ha – 23.97%) were found to be

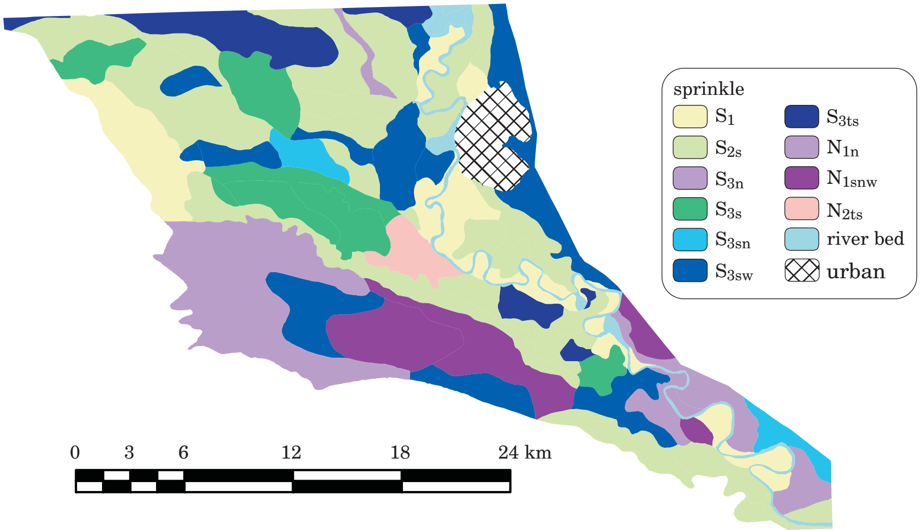

Fig. 3. Land suitability map for sprinkle irrigation: S_1 – highly suitable, S_{2s} – moderately suitable, S_{3n} – marginally suitable, S_{3s} – marginally suitable, S_{3sn} – marginally suitable, S_{3sw} – marginally suitable, S_{3ts} – marginally suitable, N_{1n} – currently not suitable, N_{1snw} – currently not suitable, N_{2ts} – permanently not suitable

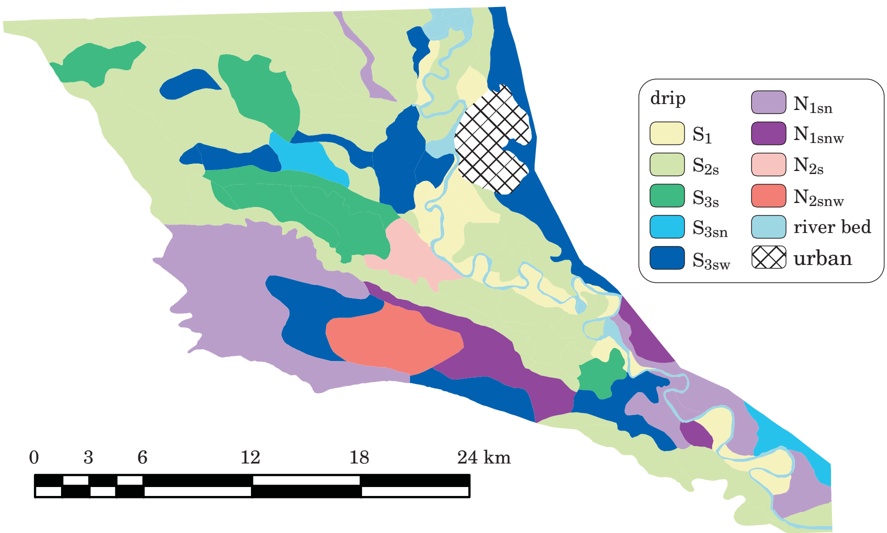

Fig. 4. Land suitability map for drip irrigation: S_1 – highly suitable, S_{2s} – moderately suitable, S_{3s} – marginally suitable, S_{3sn} – marginally suitable, S_{3sw} – marginally suitable, N_{1sn} – currently not suitable, N_{1snw} – currently not suitable, N_{2s} – permanently not suitable, N_{2snw} – permanently not suitable

slightly suitable (S_3). Soil series coded 3, 5, 10 and 14 (12012.19 ha – 22.27%) were classified as currently non-suitable (N_1). Also, soil series coded 7 and 22 (2830.73 ha – 5.24%) were permanently not-suitable (N_2) for any drip irrigation systems.

Regarding drip irrigation (Figure 4), the highly suitable lands covered the small part of the plain. The slope, soil texture, soil depth, calcium carbonate, salinity and drainage were in good conditions. The moderately suitable lands could be observed over the largest portion of the plain (north, center and south parts) due to the medium content of calcium carbonate and loamy sand soil texture. The marginally suitable lands were found in the some part of the area.The limiting factors for this land unit was the medium content of calcium carbonate. Current non-suitable lands and permanently non-suitable land exist in the southwest and south of this area because of very sever salinity,

Table 4

The most suitable land units for surface, sprinkle and drip irrigation systems by notation to capability index (*Ci*) for different irrigation systems

Codes of land Units	The maximum capability index for irrigation (*Ci*)	Suitability classes	The most suitable irrigation systems	Limiting factors*
1	53.2	S_{3S}	drip	S
2	77.16	S_{2S}	sprinkle	S
3	45	S_{3N}	sprinkle	N
4	47.24	S_{3SW}	sprinkle	SW
5	42.27	N_{1SNW}	sprinkle	SNW
6	72.67	S_{2S}	sprinkle	S
7	29.26	N_{1SNW}	sprinkle	SNW
8	57.37	S_{3SN}	sprinkle	SN
9	73.10	S_{2S}	sprinkle	S
10	38.47	N_{1N}	sprinkle	N
11	51.64	S_{3SN}	sprinkle	SN
12	76.95	S_{2S}	sprinkle	S
13	90	S_1	sprinkle	no exist
14	45	S_{3N}	sprinkle	N
15	90	S_1	sprinkle	no exist
16	81	S_1	sprinkle	no exist
17	68	S_{2S}	drip	S
18	61.2	S_{2S}	drip	S
19	61.2	S_{2S}	drip	S
20	83.36	S_1	sprinkle	no exist
21	53.2	S_{3S}	drip	S
22	20.65	N_{2TS}	sprinkle	S
23	68	S_{2S}	drip	S
24	68	S_{2S}	drip	S

* limiting factors for sprinkle irrigations: S (soil texture), N (salinity & alkalinity), W (drainage) & T (slope).

Limiting factors for drip irrigation: S (Calcium Carbonate, soil texture), N (salinity & Alkalinity), W (drainage) & T (slope).

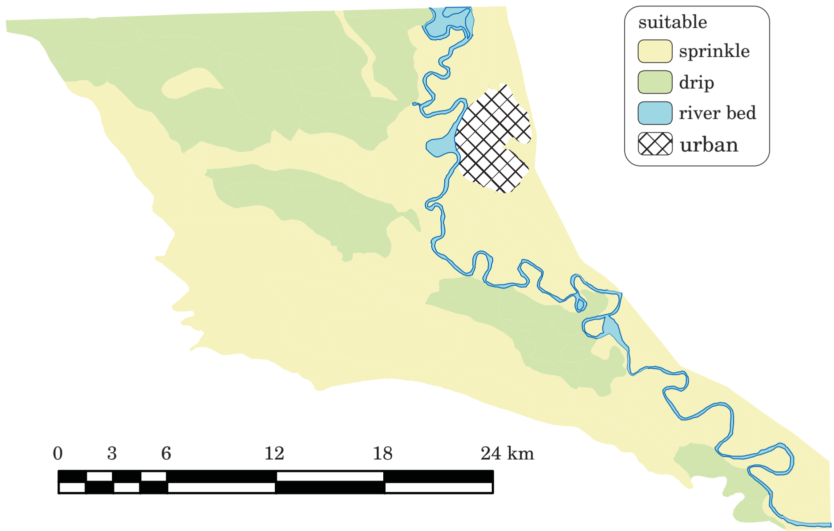

Fig. 5. The most suitable map for different irrigation systems

alkalinity and drainage limitations. For the entire study area only soil depth, was never considered as limiting factors.

For the comparison of the capability indices for surface, sprinkle and drip irrigation, Table 2 and Table 4 indicated that in soil series coded 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 20 and 22 applying sprinkle irrigation systems was more suitable than drip and surface irrigation systems. In soil series coded 1, 17, 18, 19, 21, 23 and 24 applying drip irrigation systems was the most suitable option as compared to sprinkle and surface irrigation systems. Figure 5 shows the most suitable map for surface, sprinkle and drip irrigation systems in the Arayez plain as per the capability index (Ci) for different irrigation systems. As seen from this map, the largest part of this plain was suitable for sprinkle irrigation systems and some parts of this area was suitable for drip irrigation systems.

The results of Table 2 and Table 4 indicated that by applying sprinkle irrigation instead of drip and surface irrigation methods, the land suitability of 35 855.73 ha (66.40%) of the Arayez Plain's land could be improved substantially. However by applying drip Irrigation instead of surface and sprinkle irrigation methods, the suitability of 16 644.27 ha (30.82%) of this Plain's land could be improved. The application of surface irrigation instead of sprinkle and drip irrigation methods would not provide land suitability improvement in this plain. The comparison of the different types of irrigation revealed that sprinkle irrigation was more effective and efficient then the drip and surface irrigation methods and improved land suitability for irrigation purposes. The second best option was the application of drip irrigation which was considered as being more practical than the surface irrigation method. To sum up the most suitable irrigation systems for the Arayez Plain' were sprinkle irrigation, drip irrigation and surface irrigation respectively. Moreover, the main limiting factors in using sprinkle and surface irrigation methods in this area were soil texture, salinity & alkalinity, drainage and slope, and the main limiting factors in using drip irrigation methods were the soil's calcium carbonate content, soil texture, salinity & alkalinity, drainage and slope.

Discussion

Several parameters were used for the analysis of the field data in order to compare the suitability of different irrigation systems. The analyzed parameters included soil and land characteristics. The results obtained showed that sprinkle and drip irrigation systems are more suitable than surface irrigation method for most of the study area. The major limiting factors for both sprinkle and surface irrigation methods were soil texture, salinity & alkalinity, drainage and slope, however for drip irrigation method, soil's calcium carbonate content, soil texture, salinity & alkalinity, drainage and slope, were restricting factors. The results of the comparison between the maps indicated that the introduction of a different irrigation management policy would provide an optimal solution in as such that the application of sprinkle and drip irrigation techniques could provide beneficial and advantageous. This is the current strategy adopted by large companies cultivating in the area and it will provide to be economically viable for Farmers in the long run.

Such a change in irrigation management practices would imply the availability of larger initial capitals to farmers (different credit conditions, for example) as well as a different storage and market organization. On the other hand, because of the insufficiency of water in arid and semi arid climate, the optimization of water use efficiency is necessary to produce more crops per drop and to help resolve water shortage problems in the local agricultural sector. The shift from surface irrigation to high-tech irrigation technologies, e.g. sprinkle and drip irrigation systems, therefore, offers significant water-saving potentials. On the other hand, since sprinkle and drip irrigation systems typically apply lesser amounts of water (as compared with surface irrigations methods) on a frequent basis to maintain soil water near field capacity, it would be more beneficial to use sprinkle and drip irrigations methods in this plain.

Conclusions

The surface irrigation system, characterized by excessive water use, is currently applied in the Arayez Plain. Water deficiency in arid and semi-arid climate zones is a serious concern, and the irrigation systems used in such areas should be efficient and optimized so as to reduce the amount of water used. The objective of the study was to select the most suitable irrigation method for the Arayez Plain, Iran, where agricultural irrigation systems are commonly applied. Surface, sprinkle and drip irrigation techniques were compared using a parametric evaluation system, based on an analysis of soil properties. The results of this study showed that sprinkle and drip irrigation systems are more suitable for the majority of soils in the Arayez Plain than the surface irrigation technique; hence, the changing of current irrigation methods from gravity (surface) to pressurized (sprinkle and drip) in the study area are proposed.

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PRELIMINARY CHARACTERISTICS OF THE TROPHIC CONDITION OF LAKES LOCATED IN THE NATURE RESERVE "BEAVER SANCTUARY ON THE PASŁĘKA RIVER"

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Key words: eutrophication, clinograde oxygen curve, nitrogen, phosphorus, electrolytic conductivity, primary production.

Abstract

Studied were the following lakes: Pasłęk, Wymój, Sarąg, Łęguty and Isąg, located in the nature reserve "Beaver Sanctuary on the Pasłęka River". The hypothesis was that lakes located in a nature protection area are subject to eutrophication in a slow rate, however, the research did not confirm it. All lakes are very fertile, as shown by the concentrations of total nitrogen, total phosphorus, electrolytic conductivity and the high negative correlation between chlorophyll a and water transparency. In the peak of the summer stagnation oxygen profile is represented by the clinograde curve typical for eutrophic lakes while free carbon dioxide distribution in the water column is shown by a "reversed" clinograde curve, also typical for fertile reservoirs.

WSTĘPNA CHARAKTERYSTYKA TROFICZNA JEZIOR POŁOŻONYCH NA TERENIE REZERWATU PRZYRODY „OSTOJA BOBRÓW NA RZECE PASŁĘCE"

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Słowa kluczowe: eutrofizacja, krzywa tlenowa klinogradowa, azot, fosfor, przewodność elektrolityczna, produkcja pierwotna.

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A b s t r a k t

Badaniami objęto jeziora: Pasłęk, Wymój, Sarąg, Łęguty oraz Isąg znajdujące się w rezerwacie przyrody „Ostoja bobrów na rzece Pasłęce". Przypuszczano, że położenie tych zbiorników na obszarze chronionym powoduje, iż proces eutrofizacji zachodzi w nich wolno. Badania nie potwierdziły tych przypuszczeń. Wszystkie jeziora są zbiornikami o wysokiej żyzności, o czym świadczy m.in. wysoka koncentracja ogólnych form azotu i fosforu, wartości przewodności elektrolitycznej oraz wysoka ujemna korelacja między zawartością chlorofilu a przezroczystością wody. W szczytowym okresie stagnacji letniej rozkład tlenu w pionie obrazowała krzywa tlenowa klinogradowa typowa dla jezior eutroficznych, zaś rozmieszczenie wolnego dwutlenku węgla w słupie wody miało charakter „odwrotnej" w stosunku do tlenowej klinogrady, co również jest cechą jezior żyznych.

Introduction

Ageing of lakes is a process that has been continuing consistently for approximately 10–12 thousand years which is also when most of the Polish lakes occurred. Input of mineral and organic substance from the catchment is regarded as the main reason for this phenomenon (GROCHOWSKA, TANDYRAK 2008).

In natural conditions, without any interference of man, eutrophication progresses very slowly (even thousands years). The rate of the process depends mainly on the environmental conditions, such like land configuration, type of ground, sorptive capacity of soils, green cover. Equally important are lake morphometry and climatic conditions (precipitation, annual distribution of air temperature) which determine the water mass dynamics – the main stimulus for matter circulation in a reservoir (GROCHOWSKA, TANDYRAK 2006, GROCHOWSKA et al 2006, KAJAK 2001).

Since the mid 1950s, man's impact on the nature has been increasing, the result of which are numerous permanent transformations, often regarded as negative. They are especially visible in the water reservoirs and displayed by algal blooms, deteriorated water transparency, deoxygenation of water or occurrence of unwanted decomposition products near the bottom, like ammonium and hydrogen sulphide (GROCHOWSKA, TANDYRAK 2007, LOSSOW, GAWROŃSKA 2000).

Taking into consideration the fact that input of substances from catchments transformed by man is one of the crucial factors influencing fertility of lakes, it could be argued that lakes localised in nature protection areas, like national parks or nature reserves, should be characterised by very good water quality and slower ageing.

The aim of this work was to make an introductory assessment of the trophic conditions of lakes Pasłęk, Wymój, Sarąg, Łęguty and Isąg situated in the nature reserve "Beaver Sanctuary on the Pasłęka River".

Materials and Methods

The nature reserve "Beaver Sanctuary on the Pasłęka River" was established in 5.01.1970 by the decree of Minister of Forestry and Forestry Industry (Monitor Polski, no 2, poz. 20, 21) in order to preserve the beaver sanctuaries. In the historical voivodships olsztyńskie and elbląskie the reserve covered the area of 4258.8 ha. At present, the River Pasłęka is protected within the Nature 2000 framework as a special area of habitat protection and covers the area of 6233.4 ha.

The reserve includes the River Pasłęka from its springs in the boggy meadows near the Gryźliny village to the Braniewo town limits, and the lakes situated on the river, namely Pasłęk, Wymój, Sarąg, Łęguty and Isąg. In addition, protected is the 100-m wide belt alongside the river banks and near the lakes – provided the adjacent area is state-owned or the 10-m wide strip if the ground comprises private property (ENDLER et al 2003a).

Pasłęka flows directly to the sea. It is 211 km long with the average sloping of 1.09%. The drainage basin area is 2230 km^2 and makes the drainage divide between the Vistula and the Niemen Rivers (ENDLER et al 2003b). In the physical and geographical classification, Pasłęka belongs to Eastern Europe, the East European Lowland, the sub-province East Baltic Lakeland, the macro-region Mazurskie Lakeland and the mezo-region Olsztyńskie Lakeland (KONDRACKI 1998). Since the very beginning, Pasłęka has been a natural border between the historic regions called Warmia and Mazuria (BAŁDOWSKI 1982).

Lakes Pasłęk, Wymój, Sarąg, Łęguty and Isąg, the trophic condition of which is the subject of this paper, are very variable with respect to morphometric properties (Tab. 1) and catchment development (Figure 1).

Lake Pasłęk is situated approximately 20 km southwest of Olsztyn, at 152.9 m above the sea level. The geographical co-ordinates are: 53°36'21" N and 20°19'21" E. The surface area is 8.5 ha and the max. depth equals 5.0 m. The total catchment of the lake covers the area of 8.4 km^2 and is mostly arable land (52%). In the direct vicinity of the lake (1.8 km^2) prevails mixed forest.

Lake Wymój is situated approximately 15 km from Olsztyn, at 122.4 m above the sea level. Its geographical co-ordinates are: 53°41'36" N and 20°21'03" E. It occupies the area of 47.6 ha and the max. depth is 16.0 m, whereas the mean depth is 5.1 m. The total catchment area equals 22.6 km^2 and the area draining directly to the lake is 0.6 km^2. The whole area surrounding the lake is mostly grown by forests (52%).

Lake Sarąg, situated 14 km west of Olsztyn, direction Ostróda, sits at 113.1 m above the sea level. The geographical co-ordinates are: 53°41'36" N and 20°16'48" E. The lake has large surface area of 183,0 ha but rather low

Table 1

Detailed morphometric data and lake parameters (after IRŚ, Olsztyn)

Parameter	Lake name				
	Pasłęk	Wymój	Sarąg	Łęguty	Isąg
Water table surface area (ha)	8.5	47.3	183.0	60.9	395.7
Maximum depth (m)	5.0	16.0	16.5	22.7	54.5
Mean depth (m)	–	5.1	6.9	8.5	14.2
Relative depth	0.017	0.020	0.012	0.030	0.027
Depth index	–	0.30	0.38	0.30	0.26
Volume (thousand m^3)	–	2413.8	12627.0	5234.0	56189.4
Max. length (km)	0.45	1.30	3.20	1.29	4.94
Maximum width (km)	0,30	0.5	1.1	0.8	1,1
Elongation	1.5	2.6	2.9	1.5	4.5
Shoreline length of the lake bowl (km)	1.1	3.1	9.3	3,7	17.5
Shoreline development	1.1	1.3	1.9	2.5	2.5

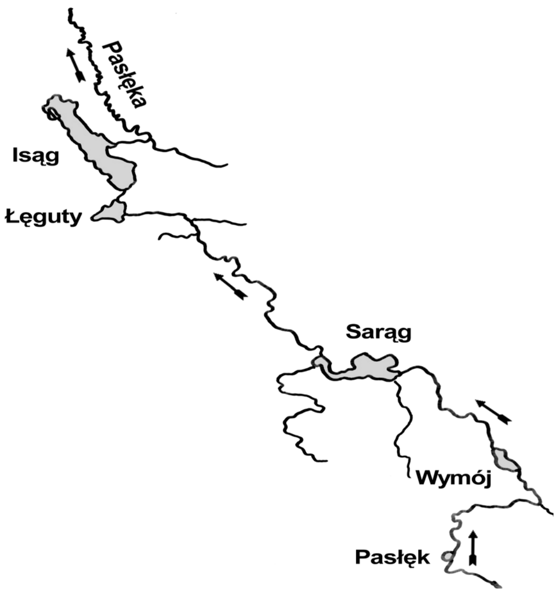


Fig. 1. The map of research area

maximal depth 16.5 m. The mean depth is 6.9 m. The total catchment area of Sarąg is considerable in size: 187.2 km^2. In the direct catchment of 10.5 km^2 prevailing are forests, covering 89.3% (GROCHOWSKA, TEODOROWICZ 2006).

The next lake localized in the nature reserve is Lake Łęguty. Located 20 km west of Olsztyn, between the villages Biesal and Łukta, it sits at 96.3 m above the sea level. The centre of the lake can be described by the following co-ordinates: 53°45'05" N and 20°09'00" E. The lake has the surface area of 60.9 ha and the max. depth of 22.7 m. The total catchment is 241.5 km^2, in 36% grown with forests and 35% cultivated. The direct neighbourhood which is 1.1 km^2 is dominated by forest (56%).

The last study object is a picturesque Lake Isąg which can be found 25 km west of Olsztyn, at 93.3 m above the sea level. The geographical co-ordinates are: 53°46'09" N and 20°08'02" E. Isąg has the surface area of 395.6 ha and a considerable max. depth of 54.5 m; the mean depth is 14.2 m. The total catchment equals 246.7 km^2 and the land draining directly to the lake equals 4.9 km^2. The direct surroundings are mostly forests (58.3%).

The lakes were examined three times: in the spring (April 26), in the summer (August 24) and in the autumn (October 21) in 2005. Water samples for full range chemical analyses were taken from the sub-surface water layer (1 m under the water table) and from the near-bottom water layer (1 m above the bottom). In the summer, additional samples were taken from metalimnion, over the deepest site of each lake determined with the help of the bathymetric charts and gps. In addition, temperature and oxygen profiles were determined at every meter of the depth. For water sampling a 3.5-l Ruttner apparatus was used with an in-built mercury thermometer (reading accuracy 0.2°C). Chemical analyses of the water were performed in accordance with the methods of HERMANOWICZ et al (1999).

Trophic condition of the lakes was assessed on the ground of the criteria provided by PATALAS (1960b), ZDANOWSKI (1983), HILLBRICHT-ILKOWSKA, WIŚNIEWSKI (1994), FARAŚ-OSTROWSKA, LANGE (1998).

Description of the results and discussion

Water mixing is an important parameter to be considered while assessing the trophic state of a lake. Intensity of the circulation movements determines turnover of nutrients and temperature of the deep water layers. Water movements provide for the nutritional and oxygen needs of organisms but also carry away the metabolism products (AMBROSETTI, BARBANTI 2002).

It is commonly believed that in lakes with lower water dynamics eutrophication is slower and the reservoirs are more resistant to man's influence (GROCHOWSKA, TANDYRAK 2006, WETZEL 2001).

The lakes localised in the nature reserve "Beaver Sanctuary on the Pasłęka River" differ by the morphometric properties (Table 1), thus by the water mass dynamics (GROCHOWSKA et al. 2006). Therefore, the normal conclusion is that eutrophication in these lakes would occur with various intensity.

According to OLSZEWSKI'S (1959) division of lakes dynamics based on the epilimnion range and the duration and intensity of the turnover, Lake Pasłęk is a shallow reservoir with hindered water circulation. According to the criteria of PATALAS (1960a) that refer the theoretical mixing range to the maximal depth, the lake features the static properties of type IV. In the lakes of such kind, the division into thermal layers can be incomplete, as observed in the study in the peak of the summer stagnation 2005. In Lake Pasłęk, the epilimnion was 1 m thick and the max. gradient in the underneath metalimnion was 4.2°C m^{-1} (Table 2).

Table 2

Summer temperature profiles in lakes Pasłęk, Wymój, Sarąg, Łęguty and Isąg

Pasłęk		Wymój		Sarąg		Łęguty		ISĄG	
depth (m)	temperature (°C)	depth (m)	temperature (°C)	depth (m)	temperature (°C)	depth (m)	temperature (°C)	depth (m)	temperature (°C)
0	20.8	0	21.2	0	21.1	0	20.6	0	20.4
1	20.4	1	20.6	1	21.1	1	20.6	1	20.4
2	19.2	2	18.2	2	21.0	2	20.6	2	20.4
3	17.2	3	16.8	3	17.8	3	20.6	3	20.3
4	14.8	4	16.2	4	16.9	4	20.6	4	20.3
5	10.6	5	14.8	5	16.4	5	20.6	5	20.3
–	–	6	11.8	6	15.4	6	16.2	6	20.3
–	–	7	8.7	7	13.9	7	9.8	7	20.1
–	–	8	7.4	8	10.4	8	8.8	8	20.0
–	–	9	5.6	9	8.8	9	7.2	9	17.0
–	–	10	5.4	10	8.1	110	7.0	10	14.1
–	–	11	5.2	11	7.7	11	6.6	11	11.1
–	–	12	5.0	12	7.3	12	6.2	12	8.0
–	–	13	4.8	13	7.2	13	6.1	13	8.0
–	–	14	4.8	14	7.1	14	6.0	14	7.8
–	–	15	4.7	15	7.0	15	5.7	15	7.5
–	–	16	4.7	16	7.0	16	5.4	20	7.0
–	–	–	–	–	–	17	5.4	25	6.8
–	–	–	–	–	–	18	5.4	30	6.8
–	–	–	–	–	–	19	5.4	35	6.7
–	–	–	–	–	–	20	5.4	40	6.6
–	–	–	–	–	–	21	5.4	45	6.6
–	–	–	–	–	–	22	5.4	50	6.6

The research of GROCHOWSKA et al. (2006) conducted in 1999, as well as the current studies, have revealed that Lake Wymój is characterised by the limited water dynamics. According to OLSZEWSKI'S criteria (1959) it belongs to bradymictic reservoirs or, following the classification of PATALAS (1960a), it is the static type V. In August 2005 the epilimnion was 21°C and 1 m thick while the thermocline had the max. gradient of 3.1°C m^{-1}. Temperature measured in the cold hypolimnion was only 4.7°C near the bottom (Table 2).

Lake Sarąg is characterised by the average water dynamics and belongs to eumictic reservoirs (OLSZEWSKI 1959) or to the static type III (GROCHOWSKA et al. 2006, PATALAS 1960a). In the peak of the summer 2005 the lake stratified into a 3-m epilimnion with the temp. of 21°C, a metalimnion with the max. gradient of 3.5°C m-1 and a hypolimnion with the temp. from 7.0 to 8.8°C (Table 2).

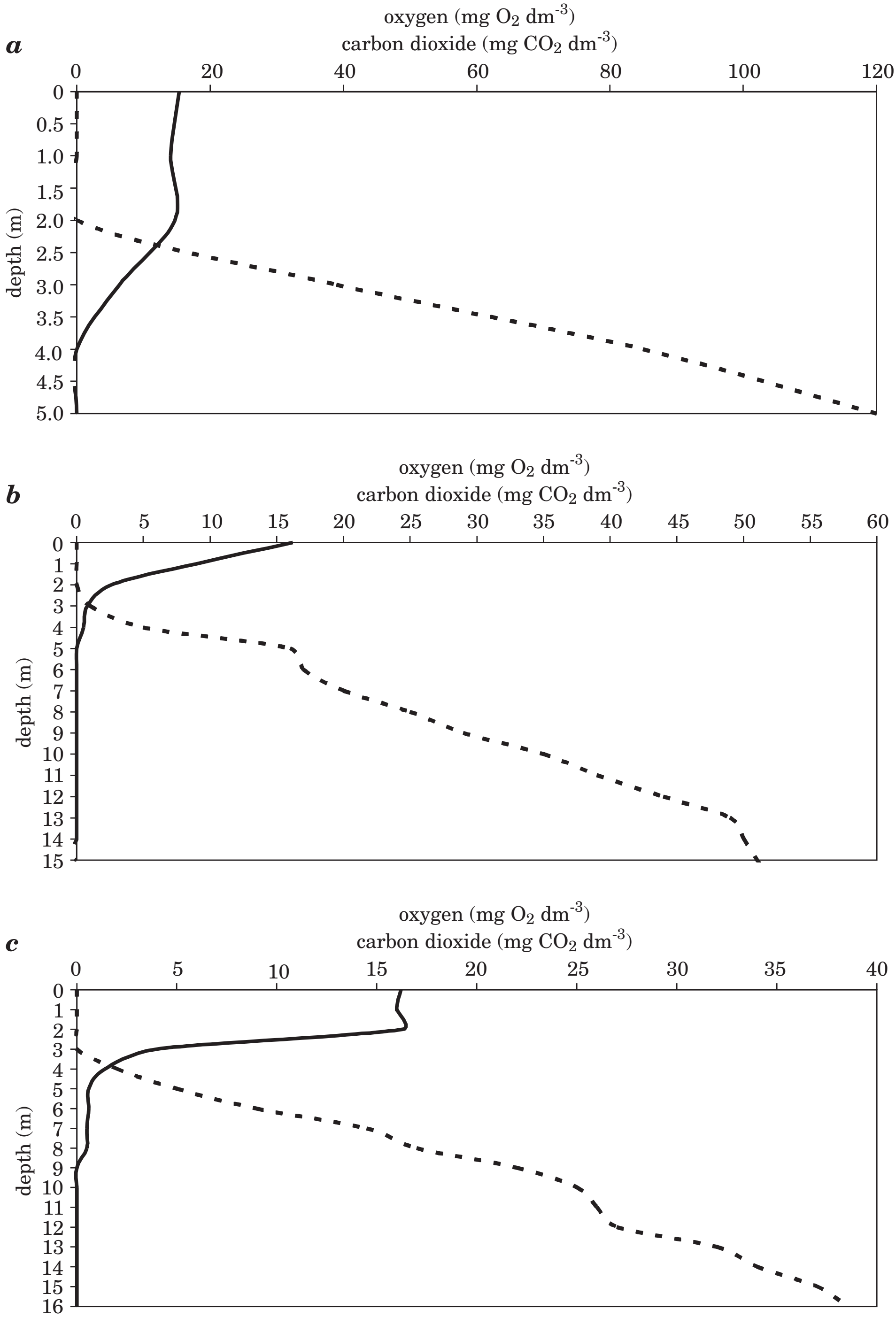
Lake Łęguty sits in a deep land hollow which is the reason for limited wind access. It has the attributes of a bradymictic reservoir (OLSZEWSKI 1959) or the static type V reservoir (PATALAS 1960a). In the summer, the epilimnion was 5 m deep (temp. 20.6°C) and the thermocline below had the max. gradient of 4.4°C m^{-1}. Temperature measured in the hypolimnion near the bottom was 5.4°C (Table 2).

The largest discussed, Lake Isąg, is eumictic (OLSZEWSKI 1959) or the static type III (PATALAS 1960a). In the peak of the summer stagnation determined were the epilimnion of 8 m with the temperature from 20.4 to 20.0°C, the metalimnion of the max. gradient 3.0°C m^{-1} and a voluminous hypolimnion from 12 m depth to the bottom with temperature in the range 8.6–6.6°C (Table 2).

As shown above, water mass dynamics in the analysed lakes are average through poor and allow assuming that the processes of matter circulation in these lakes are not very intense and do not favour primary production. However, the conducted research has not confirmed such assumption. GROCHOWSKA et al. (2006) reports that oxygen settings in a lake depend to a large degree on the intensity of water mixing and the eutrophication level. In many classification systems oxygenation is one of the key criteria for the trophic condition determination (LOSSOW et al. 1979, WETZEL 2001). In the peak of summer stagnation in oligotrophic lakes oxygen content is similar across the whole water column (orthograde oxygen curve). In mezotrophic lakes the maximum or the minimum of oxygen concentration occurs in metalimnion (heterograde oxygen curve, negative or positive). Lastly, in eutrophic lakes oxygen is distributed unevenly across the vertical profile: concentrations near the surface are very high, the drop in metalimnion is very rapid (oxycline), the deficits in the deeper layers are absolute (clinograde oxygen curve) (CHOIŃSKI 1995).

In all discussed lakes, oxygen content in the summer decreased toward the bottom with simultaneous super-oxygenation of the trophogenic water layers (Figure 2).

In Lake Pasłęk, in August, the content of oxygen in the surface water layer was 15.4 mg O_2 dm^{-3} (169.5% saturation). At 3 m depth only 6.4 mg O_2 dm^{-3}


a
oxygen (mg O2 dm-3)
carbon dioxide (mg CO2 dm-3)
0 20 40 60 80 100 120
depth (m)
0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0
b
oxygen (mg O2 dm-3)
carbon dioxide (mg CO2 dm-3)
0 5 10 15 20 25 30 35 40 45 50 55 60
depth (m)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
c
oxygen (mg O2 dm-3)
carbon dioxide (mg CO2 dm-3)
0 5 10 15 20 25 30 35 40
depth (m)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16

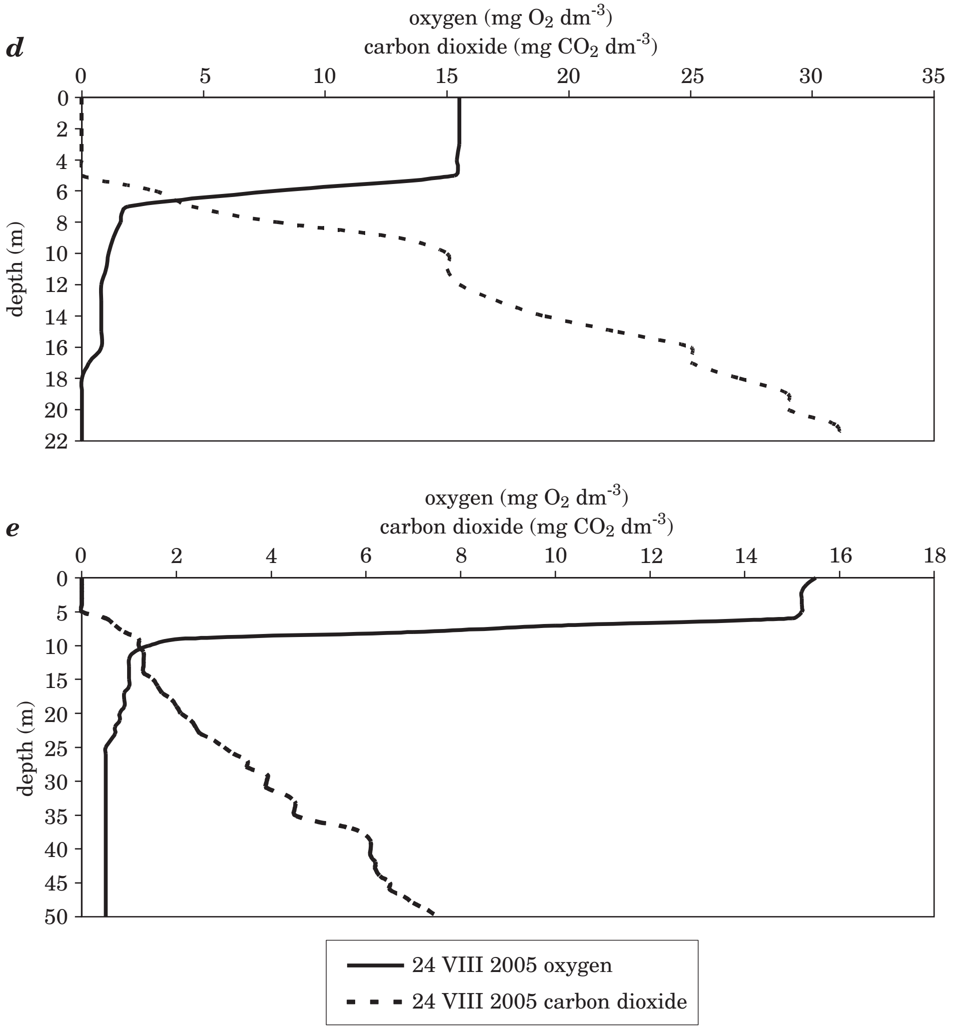


Fig. 2. Summer variation of oxygen and carbon dioxide contents in waters of lakes: *a* – Pasłęk, *b* – Wymój, *c* – Sarąg, *d* – Łęguty, *e* – Isąg

was measured (67.1% saturation) and starting from 4 m depth downward the water was oxygen-deficient (Figure 2a). In the same time, in the upper water layer in Lake Wymój determined was 15.5 mg O_2 dm^{-3} (172.0% saturation) with a rapid drop underneath (oxycline with the max. gradient of 7.2 mg O_2 dm^{-3}). From 6 m depth anoxic conditions occurred (Figure 2b). Comparable situation was observed in Lake Sarąg in which oxygen near the surface was 16.2 mg O_2 dm^{-3} (180.0% saturation). Below was a sharp oxycline with the max. gradient of 12.3 mg O_2 dm^{-3} and from 8 m depth to the bottom oxygen was absent (Figure 2c). In the surface water layers of Lake Łęguty oxygen concentrations oscillated around 15.0 mg O_2 dm^{-3} (170.0% saturation), a large decrease was determined deeper down and a complete deficiency at 18 m depth (Figure 2d). Slightly better were the oxygen conditions observed in Lake Isąg. The epilimnion to 6 m depth was well oxygenated 15.5–15.0 mg O_2 dm^{-3} (approx. 169.0% saturation) and below the concentrations gradually fell to reach the value 0.5 mg O_2 dm^{-3} unchanging from 25 m depth to the bottom (Figure 2e).

Based on the analysis of the oxygen profiles observed in the discussed lakes in the peak of the summer stagnation (oxygen concentrations across the vertical profile represented by an obvious clinograde curve of ABERG and RHODE (1942), it can be unambiguously stated that lakes Pasłęk, Wymój, Sarąg, Łęguty and Isąg are heavily eutrophic.

The super saturation with oxygen in the surface layers of the examined lakes was most certainly connected to intensive primary production (KALFF 2002, WETZEL 2001). The simultaneously observed oxygen deficits in the near bottom waters were related to the lytic processes and life processes by the aquatic organisms. Carbon dioxide is strongly correlated to production and decomposition processes. Its distribution in water is different from that of oxygen. Near the surface it is rather scarce but the amount increases with the depth. KAJAK (2001) and CHOJNACKI (1998) found that reduction of free carbon dioxide occurring in the surface waters during the vegetation period is due to intensive primary production and utilization of mineral substances by the autotrophs. The increase toward the bottom is due to the intensive processes of destruction and respiration. This finding has been confirmed in the discussed study. In the summer, free carbon dioxide didn't occur in the surface water layers whereas near the bottom the content reached 120.0 mg CO_2 dm^{-3} in Lake Pasłęk, 52.5 mg CO_2 dm^{-3} in Lake Wymój, 38.5 mg CO_2 dm^{-3} in Lake Sarąg, 31.0 mg CO_2 dm^{-3} in Lake Łęguty, and 7.5 mg CO_2 dm^{-3} in Lake Isąg (Figure 2 a, b, c, d, e). Vertical variability of the carbon dioxide concentrations in the summer in the studied lakes featured the shape of a "reversed" clinograde, as compared to the oxygen clinograde curve. KAJAK (2001) argues that such regularity is the property of very fertile lakes.

The content of free carbon dioxide develops following the pH values, i.e., an increase of the first causes reduction of the second (DOJLIDO 1995). The results obtained in the studies of lakes Pasłęk, Wymój, Sarąg, Łęguty and Isąg have confirmed that. When photosynthesis was intense and free carbon dioxide was absent from the surface water layers the reaction of the water was high: 8.78 pH in Lake Pasłęk, 8.93 pH in Lake Wymój, 9.09 pH in Lake Sarąg, 8.30 pH in Lakes Łęguty and Isąg. On the other hand, when the maximal summer concentrations of CO_2 were detected, the reaction was lower:

Table 3

Selected chemical water parameters of lakes Pasłęk, Wymój, Sarąg, Łęguty and Isąg

Parameter		Pasłęk			Wymój			Sarąg			Łęguty			Isąg		
		spring	summer	autumn	spring	summer	autumn	spring	summer	autumn	spring	summer	autumn	spring	summer	autumn
Reaction (pH)	surface	8.64	8.78	7.82	8.91	8.93	7.86	8.74	9.09	7.88	8.90	8.30	8.00	9.39	8.30	7.89
	bottom	7.69	7.23	7.84	7.70	7.28	7.88	7.70	7.43	7.89	7.37	7.33	7.65	8.04	7.65	7.60
Conductivity (μS cm^{-1})	surface	396	362	438	330	280	354	379	279	342	327	330	392	336	314	343
	bottom	471	599	429	413	436	445	397	419	430	403	432	429	360	369	372
Total phosphorus (mg P dm^{-3})	surface	0.098	0.182	0.188	0.199	0.121	0.182	0.146	0.193	0.252	0.123	0.213	0.415	0.135	0.120	0.150
	bottom	0.165	0.202	0.129	0.348	1.296	1.898	0.121	1.369	1.574	0.114	0.629	0.813	0.176	0.311	0.336
Total nitrogen (mg N dm^{-3})	surface	2.01	1.21	2.50	2.16	0.91	1.70	2.47	1.80	2.0	6.90	2.74	2,71	4.65	2.65	1.55
	bottom	2.61	8.97	2.41	3.51	8.47	5.33	2.44	4.67	5.58	3.92	4.47	3.95	2.80	2.49	1.86

7.23 pH in Lake Pasłęk, 7.28 pH in Lake Wymój, 7.70 pH in Lake Sarąg, 7.33 pH in Lake Łęguty and 7.65 pH in Lake Isąg (Table 3).

Among the most important parameters indicating the trophic condition there is also the penetration of sun rays determined as the visibility of Secchi disc (HÅKANSON et al. 2005). Water transparency is determined by the amount of suspensions and increases along with the abundance of mineral substances that stimulate higher production of organic compounds (VREDE 2005). Secchi disc visibility in most of the examined lakes was very low and assumed the following pattern: Lake Pasłęk from 1.1 to 1.8 m, Lake Wymój from 0.75 to 0.8 m, Lake Sarąg from 0.5 to 0.95 m, Lake Łęguty from 1.05 to 2.30 m, and Lake Isąg from 1.25 to 3.80 m (Figure 3). As already mentioned, transparency of the water depends, among others, on the amount of suspensions thus on the intensity of production. The obtained results confirm the earlier observations by BOROWIAK (2000) and allow concluding that the amount of phytoplankton biomass is the limiting factor for solar radiation penetration in the lake water. The lowest water transparency in lakes Wymój and Sarąg was observed in the peak of the summer stagnation which occurred in parallel to the considerable supersaturation with oxygen in the surface waters, the highest reaction and the absence of free carbon dioxide – all being the parameters indicating intensive photosynthesis (Figure 2a, b, Figure 3, Table 3).

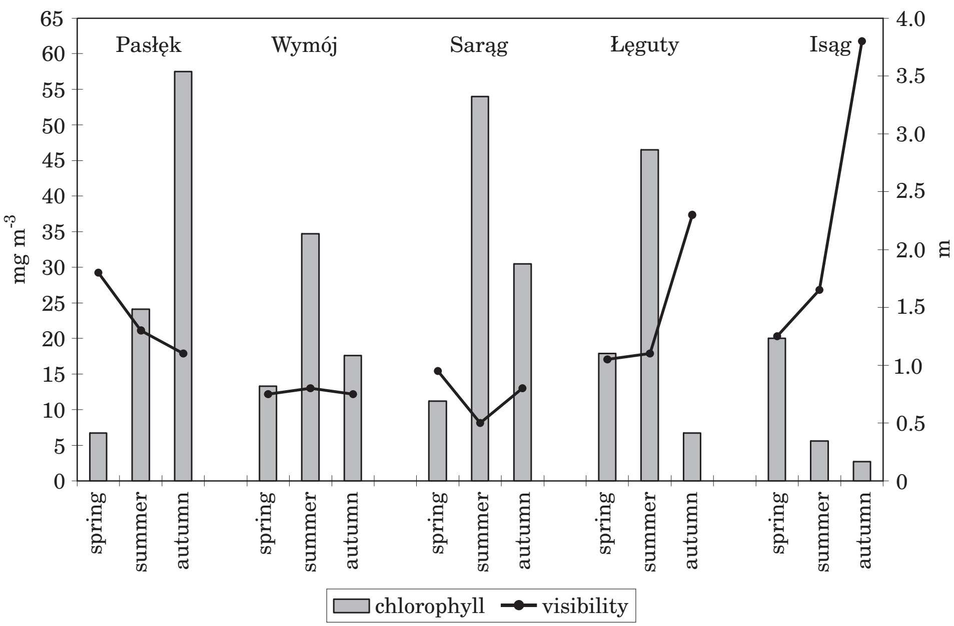


Fig. 3. Changes of chlorophyll a content and Secchi disc visibility in water of lakes located in the nature reserve "Beaver Sanctuary on the Pasłęka River"

In lakes Łęguty and Isąg comparable situation occurred in the spring (April) – Figure 2 d, e, Figure 3, Table 3). Only in Lake Pasłęk the relationships weren't noted (Figure 3, Table 3). In addition, during the studies observed was a very high negative correlation (r = 0.91 in Lake Pasłęk, r = 0.98 in Lake Wymój, r = 0.99 in Lake Sarąg) and a high negative correlation (r = 0.69 in Lake Łęguty, r = 0.74 in Lake Isąg) between the water transparency and the content of chlorophyll a (the best indicator of the intensity of primary production). Increase of the pigment caused by intensive photosynthesis limited the water transparency (Figure 3). Such regularity indicates the high fertility of the examined reservoirs.

Taking into consideration the classification of lakes of FARAŚ-OSTROWSKA and LANGE (1998) based on the depth of Secchi disc visibility, the analysed lakes can be classified as eutrophic – water transparency is below 4 m depth (Figure 3).

When assessing the eutrophication level, it is very important to determine the content of nutrients in the water, especially of nitrogen and phosphorus (BAJKIEWICZ-GRABOWSKA 2002, HILLBRICHT-ILKOWSKA 1999, VREDE 2005).

In Lake Pasłęk, the total nitrogen concentrations ranged from 1.21 to 8.97 mg N dm^{-3} with the higher values occurring usually in the deeper water layers (Table 3). The content of total phosphorus in this lake ranged from 0.098 to 0.202 mg P dm^{-3}. In April and September the values were vertically stratified, with an increase toward the bottom and a reversed trend in the autumn (Table 3). With reference to the nitrogen content, Lake Pasłęk can be described as nitrogen-fertile, type POLY (PATALAS 1960c) whereas according to the classification of HILLBRICHT-ILKOWSKA, WIŚNIEWSKI (1994) based on the visibility of Secchi disc and total phosphorus content and chlorophyll a content, it is eutrophic. Finally, according to ZDANOWSKI'S (1983) criteria, referring to the spring content of phosphorus, Lake Pasłęk can be classified as polytrophic, type IV.

In Lake Wymój, the concentrations of total nitrogen were also very high: from 0.91 to 8.47 mg N dm^{-3}, values characteristic for lakes rich in nitrogen, type POLY (PATALAS 1960b). According to the classification of HILLBRICHT-ILKOWSKA, WIŚNIEWSKI (1994), the lake is heavily eutrophied while following the criteria of ZDANOWSKI (1983) it is polytrophic, type IV because of the total phosphorus content from 0.121 to 1.898 mg P dm^{-3} (Table 3).

The same trophic status, when judged on the content of nitrogen and phosphorus, have lakes Sarąg, Łęguty and Isąg in which the content of total nitrogen developed in the following way: 1.80–5.58 mg N dm^{-3} (Sarąg), 2.74–6.90 mg N dm^{-3} (Łęguty) and 1.55–4.65 mg N dm^{-3}. Notably, the higher values in lakes Sarąg and Łęguty were usually measured near the bottom whereas in Lake Isąg in the surface water layers (Table 3). The content of total phosphorus in these lakes ranged from 0.121 to 1.369 mg P dm^{-3} (Sarąg), from 0.114 to 0.813 mg P dm^{-3} (Łęguty), and from 0.120 to 0.336 mg P dm^{-3} (Isąg) – Table 3 with a tendency to increase toward the bottom.

For the more complete assessment of the eutrophication level, electrolytic conductivity was determined in the studied lakes. This parameter represents inorganic substance from dissociation in the water and indicates the level of water contamination with mineral compounds (CIEŚLIŃSKI 1999, TANDYRAK et al. 2006). MARSZELEWSKI (2005), having examined the lakes in Northern Poland, allocated the group of eutrophic reservoirs with the conductivity in the range from 200 to 400 μS cm^{-1}. In this respect, lakes Pasłęk, Wymój, Sarąg, Łęguty and Isąg can be described as eutrophic or heavily eutrophic, as the measured values were contained in the range 279–599 μS cm^{-1} (Table 3).

MAŚLANKA (1998) argues that in high-fertility lakes, stratified thermally in the summer, the seasonal differences in conductivity are visible and displayed by the high values in the tropholytic layer. In all analysed lakes, the vertical stratification of electrolytic conductivity was observed with an increase toward the bottom (Table 3). JANKOWSKI and RZĘTAŁA (1997) hypothesise that high conductivity values might be the effect of the lakes inclusion in the discharge system or the underground feeding, especially from the deep underground water layers. The high values noted in the examined lakes and typical for eutrophic lakes may be related to the flow-through character of these reservoirs. The River Pasłęka which connects the lakes carries in a lot of mineral substances as it drains a vast area with different types of development (GROCHOWSKA, TEODOROWICZ 2006).

Concluding, all discussed lakes are eutrophic, irrespective of their localization in the nature reserve which is a nature protection area. Unfortunately, their catchments are extensive and dominated by arable land or built-up areas which negatively affects the level of mineral and organic substances in the lakes. Eventually, the eutrophication processes are intensified. Finally, the localization of the lakes is very attractive to tourists and anglers.

Conclusions

1. The analysed lakes are characterised by average or hindered water mass dynamics thus the processes of matter turnover are not intense and may not favour the increase of primary production. However, oxygen settings observed in these lakes in the peak of the summer stagnation and displayed by the evident clinograde oxygen curve of ABERG, RHODE (1942) visibly indicate strong eutrophication in lakes Pasłęk, Wymój, Sarąg, Łęguty and Isąg. The super saturation with oxygen in the surface water layers is most probably

caused by intensive primary production while the parallel oxygen deficits noted in the near-bottom water result from the lytic processes and life processes of the aquatic organisms.

2. Vertical variability of the carbon dioxide concentrations in the summer in the examined lakes assume the shape of a "reversed" curve compared to the oxygen clinograde. Such regularity is a feature of high-fertility lakes.

3. Taking into consideration the classification of lakes given by FARAŚ-OSTROWSKA, LANGE (1998) based on Secchi disc visibility, the examined lakes can be classified as eutrophic – the water transparency was below 4 m.

4. With regard to nitrogen content, the lakes can be described as rich in nitrogen, type POLY, whereas according to the classification of HILLBRICHT-ILKOWSKA, WIŚNIEWSKI (1994) based on Secchi disc visibility and the amount of total phosphorus and chlorophyll a the lakes are eutrophic.

5. In the division provided by ZDANOWSKI (1983) referring to the spring content of phosphorus, lakes Pasłęk, Wymój, Sarąg, Łęguty and Isąg can be classified as polytrophic, type IV of the trophic state.

6. With regard to electrolytic conductivity of the analysed lake waters varying between 279 and 599 $\mu S\ cm^{-1}$, lakes Pasłęk, Wymój, Sarąg, Łęguty and Isąg are eutrophic or even strongly eutrophic.

Translated by MONIKA SZEWCZYK

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EVALUATION OF ALFA DIVERSITY OF AN ANTHROPOGENIC FOREST THREATENED BY PESTICIDE TOMB*

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Key words: alfa species diversity, antropogenic forest, pesticide tombs.

Abstract

This study was aimed at evaluating the point diversity of an anthropogenic forest threatened by a pesticide tomb. Herein, the concept of diversity is consistent with that of WHITTAKER (1977). A lack of significant differences in the diversity index, species abundance and species contribution between the phytocoenoses of the examined community with *Sambucus nigra-Picea abies* and that of *Sambuco racemosi-Pieceetum* indicates a modifying role of the pesticide tomb in species distribution within the analyzed phytocoenoses.

Diversity in species distribution of phytocoenoses *Sambuco racemosi-Piceetum* and *Sambucus nigra-Picea abies* in the ordination space determined by ecological index numbers points to a modifying effect of the pesticide tomb.

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OCENA α-RÓŻNORODNOŚCI ANTROPOGENICZNEGO LASU WOKÓŁ MOGILNIKA PESTYCYDOWEGO

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Słowa kluczowe: α-różnorodność gatunkowa, antropogeniczny las, mogilnik pestycydowy.

Abstrakt

Badania miały na celu ocenę α-różnorodności gatunkowej antropogenicznego lasu położonego w sąsiedztwie mogilnika pestycydowego. Wykazano brak istotnych różnic w zakresie indeksu różnorodności, bogactwa gatunkowego i udzialu gatunków w fitocenozach badanych zbiorowisk *Sambucus nigra-Picea abies i Sambuco racemosi-Pieceetum*. Stwierdzono istnienie czynników modyfikujących siedliska badanych fitocenoz. Przypuszczalnie jest to wpływ mogilnika pestycydowego, który może powodować zmiany w składzie gatunków badanych fitocenoz w analizowanych zbiorowiskach roślinnych.

Introduction

One of key threats to the natural environment in Poland are hazardous wastes, especially those deposited in tombs. In Warlity Wielkie, near Ostróda, a pesticide tomb was in use until November 3, 2003. It is one of the 16 landfill sites of non-utilized pesticides in the province of Warmia and Mazury in the years 1960–1970. The tomb was used as a landfill of 54 tonnes of toxic substances disposed in 36 silos and 2 unprotected cavities.

Since 2003, complex analyses of edaphic and aquatic habitats have been carried out on this area (SKIBNIEWSKA et al. 2002, SZAREK et al. 2003, GRZYBOWSKI et al. 2004, GRZYBOWSKI et al. 2005, ZMYSŁOWSKA et al. 2005).

This study was aimed at evaluating the point diversity of an anthropogenic forest threatened by a pesticide tomb. Herein, the concept of diversity is consistent with that of WHITTAKER (1977).

Study Area

The forest area under study is situated within the Ostróda – Warlity Fishing Farm, approx. 800 m from the nearby village of Warlity Wielkie (Figure 1). The area covers 6.5 ha. The habitat type is typical former farmland forested area, artificially planted with trees.

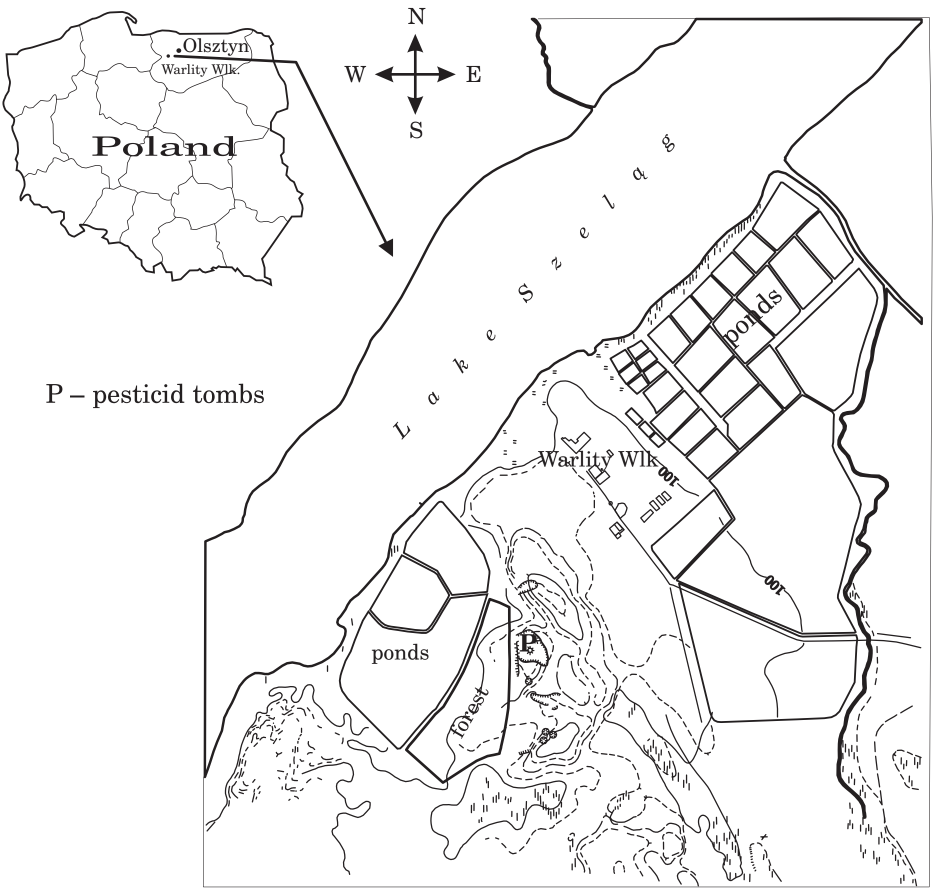

Fig. 1. Location of the study area

On the eastern side, the forest is adjoined by a hill on top of which in 1968–2004 a pesticide tomb was built. It covered an area of 0.7 ha. The pesticide tomb under study was situated in sandy formations and even a small leakage of the chambers posed a threat to contamination of ground waters and the neighboring ecosystems, including the forest (Figure 1). On the western wall, the forest is adjoined by three fishing ponds, followed by the largest lake in the basin of the Drwęca River – Szeląg Wielki.

Material and Methods

A site survey was carried out in the summer of 2006–2007. The basis for the ecological characteristics were 16 phytosociological releves performed with the BRAUN-BLANQUET method (1964). The releves covered an area of 400–600 m^2 (Figure 2).

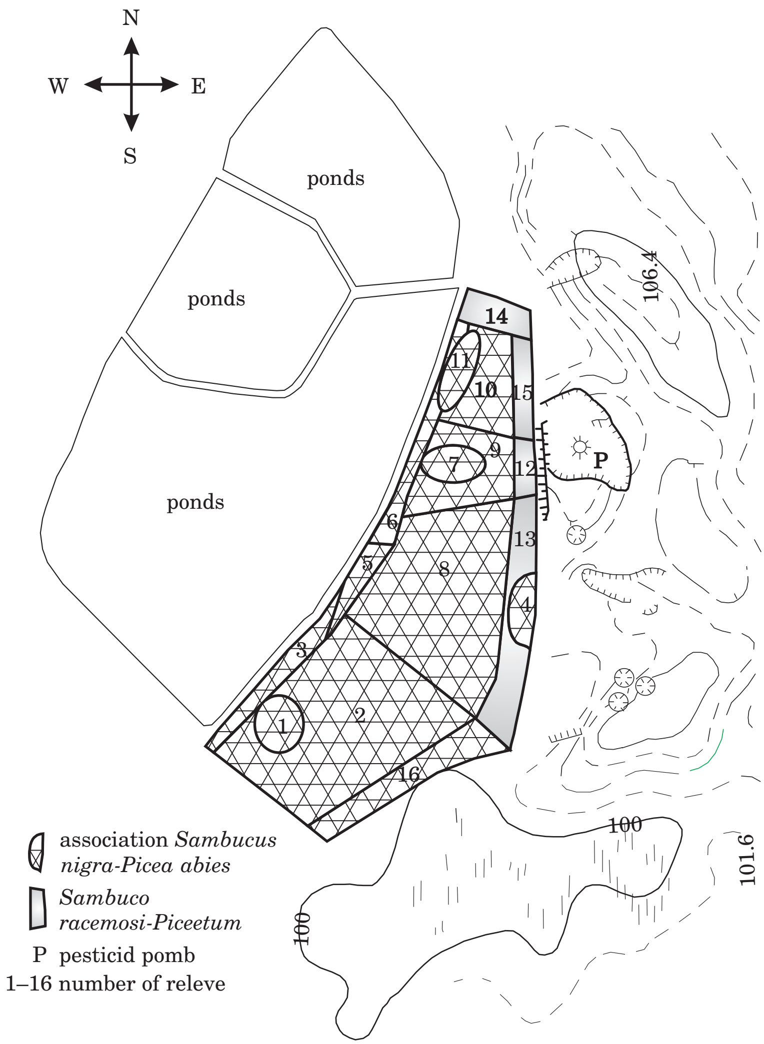

Fig. 2. Location of the phytosociological releves within the study area in the vivinity of the pesticide tomb

The nomenclature of vascular plants was adopted after RUTKOWSKI (2004). The names of bryophyte species were given according to *Die Moos – und Farnpflanzen Europas* (1995).

In this paper, use is made of a division of spruce forests proposed by SOKOŁOWSKI (1980). The remaining syntaxonomic units were adopted according to the common nomenclature by MATUSZKIEWICZ (2001).

For a numerical analysis of the phytosociological pictures, the quantitative degrees in the BRAUN-BLANQUET scale (1964) were transformed into the quantitative degrees in the scale proposed by JANSÉN (1975) following the recommendations of MAAREL VAN DER (1979).

To analyze the internal differentiation at the level of phytosociological releves, use was made of the *Complete Link* method belonging to the group of hierarchic agglomeration methods (GRZYBOWSKI, ENDLER 1999). To calculate the matrix of distances between sites, an Euclidian measure was used. The effect of the analysis is a dendrogram graphically depicting the significance of similarities between the phytocoenoses.

The evaluation of diversity was conducted based on a Shannon-Wiener index (SHANNON, WEAVER 1949). The Shannon-Wiener diversity index (H) is defined as a negative sum of the product of probability of subsequent species significance in a set (pi), a logarithm of that probability.

$$H = -\sum p_i \log p_i$$

with 2 adopted as logarithm base.

The probability of subsequent species significance in the set (p_i) is understood as a quotient n_i/N, where n_i is a coefficient of significance of a given species, ad N denotes the sum of significance coefficients of all species.

Species distribution in phytocenosis was described by means of a Pielou Evenness index (J) (MAGURRAN 1988). The Pielou Evenness index (J) is defined as a ratio of observed diversity to the maximal diversity at a given number of species s:

$J = \frac{H_{obs}}{H_{\max}}$ where the maximum diversity H_{max} after transforming the formula into the Shannon-Wiener diversity index:

$J = \frac{H_{obs}}{\text{lig } s}$, the value of Pielou Evenness reaches maximally 1 when the observed diversity equals the maximum diversity, namely when all species have equal contribution in the phytocenosis.

Calculations of diversity were conducted with the use of Multi Variate Statistical Package (MVSP) ver. 3.1.

To determine statistically significant differences in terms of species abundance, diversity index and contribution of species in phytocoenoses between the analyzed communites of *Sambucus nigra-Picea abies* and *Sambuco racemosi-Piceetum,* the mean values of all indices were calculated.

Next, it was determined whether the observed differences between mean values of indices were statistically significant. To this end, use was made of a non-parametric U-test from Statistica 7.1 package (StatSoft, Inc. 2005). To avoid a second order error (to adopt a null hypothesis – on a lack of differences between means; URLICH 2004), Student's t-test was applied additionally which assumes normal distribution of results or differences between results. The Student's t-test was computed by means of Statistica 7.1 package (StatSoft, Inc. 2005).

The U-test is a non-parametric equivalent of the Student's t-test (ŁOMNICKI 2003, STANISZ 1998).

Ecological preferences of species were determined with the use of index numbers by Zarzycki and Ellenberg (ELLENBERG 1974, ZARZYCKI et al. 2002), in addition ordination was performed based on Canonical Correspondence Analysis [CCA].

The CCA is a method postulated by Braak ter (1986, 1987,1988a,b). It enables determining the standard of variability of analyzed data, which is explained to the greatest extent by considered habitat variables. First, weighted means were computed for all indices characterizing preferences of all species present on phytosociological relevés: soil humidity (*W*), trophism (*Tr*), soil acidity (*R*), mechanical soil content (*D*), organic matter content (*H*) (ZARZYCKI et al. 2002) and nitrogen content of soil (*N*) (ELLENBERG 1974).

In CCA calculations use was made of Multi Variate Statistical Package (MVSP) ver. 3.1.

Results

On the examined area there were identified 161 species of vascular plants and 24 species of bryophytes.

Similarity between the relevés is depicted in a dendrogram (Figure 3) that differentiates the set of phytosociological relevés into two groups according to the phytosociological classification performed.

From the phytosociological viewpoint, the analyzed forest was classified to two syntaxonomic units: a community with *Sambucus nigra-Picea abies* and a community of *Sambuco racemosi-Pieceetum* Jut.-Trzeb. 1980 (Table 1, Table 2).

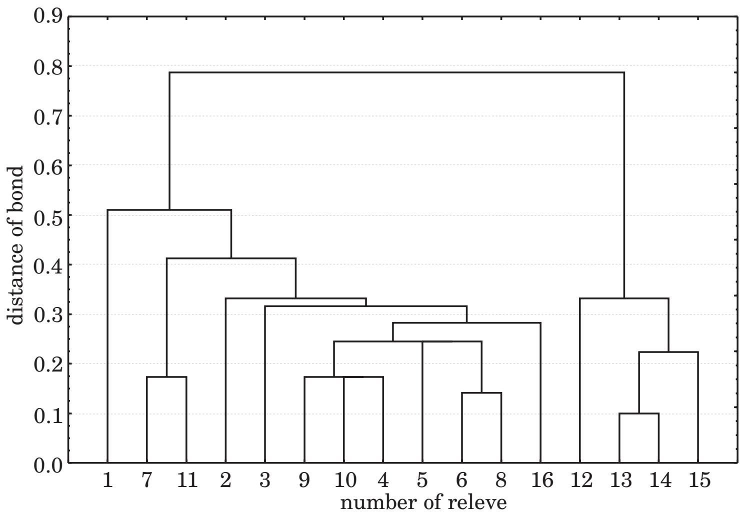

Fig. 3. Dendrogram of similarity between the releves of the studied forest area

Table 1

Community *Sambucus nigra-Picea abies*

Successive number		1	2	3	4
Number of releve		12	13	14	15
Date		06. 2006	06. 2006	06. 2007	06. 2006
Area of releve in m^2		200	600	400	400
Cover of plants layer (%) a		100	100	100	100
b		80	60	80	80
c		60	60	60	60
d		20	20	10	20
Total number of species in 1 releve		38	27	46	53
1		2	3	4	5
Ch. *Sambucus nigra-Picea abies*					
Sambucus nigra	b	3	4	3	1
Picea abies	a	5	5	3	5
Picea abies	c	.	.	+	+
Ch. *Myceli-Piceion*					
Mycelis muralis	c	1	.	2	1
Plagiomnium affine	d	2	1	1	.
Ch. *Vaccinio-Piceetea*					
Sorbus aucuparia	b	.	.	1	+
Calamagrostis arundinacea	c	.	.	.	1
Betula pendula	a	.	.	.	1
Ch. *Tilio-Piceion*					
Milium effusum	c	.	.	1	.
Dryopteris filix-mas	c	.	.	1	1
Aegopodium podagraria	c	3	2	2	4

cont. table 1

1		2	3	4	5
Ch. *Querco-Fagetea*					
Acer platanoides	a	1	.	3	2
Acer platanoides	b	.	.	2	.
Acer platanoides	c	1	.	1	1
Tilia cordata	a	.	.	1	.
Corylus avellana	b	2	1	2	2
Corylus avellana	c	.	.	1	1
Fagus sylvatica	c	.	.	+	+
Epilobium montanum	c	+	.	.	1
Poa nemoralis	c	1	2	.	1
Accompanying species					
Quercus robur	a	.	.	2	2
Quercus robur	b	.	.	1	.
Quercus robur	c	1	.	+	1
Pteridium aquilinum	c	.	.	2	1
Maianthemum bifolium	c	+	+	.	.
Rubus idaeus	b	2	.	2	2
Frangula alnus	b	.	.	+	2
Frangula alnus	c	.	1	2	+
Veronica chamaedrys	c	.	1	3	1
Urtica dioica	c	.	.	3	2
Fragaria vesca	c	1	.	2	.
Galeopsis tetrahit	c	2	.	2	2
Sambucus racemosa	b	1	1	1	+
Chelidonium majus	c	2	+	2	+
Equisetum pratense	c	+	1	1	1
Galium aparine	c	2	.	2	2
Poa pratensis	*c*	*1*	*1*	.	*1*
Geum urbanum	c	1	.	3	2
Anthriscus sylvestris	c	.	+	2	1
Arrhenatherum elatius	c	.	2	1	2
Avenula pubescens	c	1	.	1	2
Saponaria officinalis	c	+	+	+	.
Convolvulus arvensis	c	+	+	+	.
Lapsana communis	c	1	.	+	1
Melilotus officinalis	c	1	.	+	1
Stellaria media	c	.	.	2	2
Agrostis gigantea	c	.	1	.	1
Poa trivialis	c	1	1	.	.
Dactylis glomerata	c	.	.	1	1
Holcus mollis	c	1	.	.	2
Calamagrostis stricta	c	1	.	.	1
Plantago major	c	3	3	.	.
Leonurus cardiaca	c	+	+	.	.
Artemisia vulgaris	c	+	.	.	+
Myosotis sylvatica	*c*	.	.	+	+
Filipendula ulmaria	c	.	.	+	+
Galeopsis bifida	c	.	.	1	+
Cirsium vulgare	c	.	.	2	.
Geranium robertianum	c	.	.	2	.
Verbascum nigrum	c	.	.	.	2

cont. table 1

1		2	3	4	5
Bryophytina					
Brachythecium retabulum	d	2	2	2	+
Eurhynchium hians	d	.	.	.	3
Plagiomnium undulatum	d	1	.	.	.
Eurhynchium praelongum	d	.	1	.	.
Plagiothecium succulentum	d	.	.	.	1
Eurhynchium striatum	d	+	.	.	.
Eurhynchium schleicheri	d	+	.	.	.
Sporadic species: *Moehriniga trinervia* 3 (+), *Ranunculus ficaria* 4 (+), *Scrophularia nodosa* 3 (+), *Silene latifolia* 1 (1), *Festuca arundinacea* 1 (1), *Cirsium arvense* 1 (1), *Galeopsis speciosa* 2 (1), *Vicia sativa* 2 (1), *Rumex acetosa* 2 (+), *Rumex sanguineus* 2 (+), *Valeriana officinalis* 3 (1), *Ranunculus acris* 3 (+), *Hypericum perforatum* 3 (+), *Levisticum officinale* 3 (+), *Verbascum thapsus* 4 (1), *Alliaria petiolata* 4 (1), *Rumex crispus* 4 (1), *Agrimonia eupatoria* 4 (1), *Conyza canadensis* 4 (1), *Epilobium angustifolium* 4 (+), *Senecio sylvaticus* 4 (+), *Euphorbia cyparissias* 4 (+).					

Table 2

Community *Sambuco racemosi-Piceetum* Jut.-Trzeb. 1980

Successive number		1	2	3	4	5	6	7	8	9	10	11	12	Constancy
Number of releve		1	7	11	2	3	9	10	4	5	6	8	16	
Date		06. 2006	06. 2006	06. 2006	06. 2006	06. 2006	06. 2006	06. 2006	06. 2006	06. 2006	06. 2006	06. 2007	06. 2007	
Area of releve in m^2		200	600	200	200	300	400	400	300	200	200	300	500	
Cover of plants layer (%) a		100	100	100	100	100	100	100	100	100	100	100	100	
b		70	60	60	70	70	60	40	60	60	50	60	40	
c		90	90	80	90	90	80	80	90	80	90	90	80	
d		30	30	30	20	30	40	50	30	20	40	40	40	
Total number of species in 1 releve		73	80	42	67	75	40	39	67	52	61	59	39	
1		2	3	4	5	6	7	8	9	10	11	12	13	14
Ch. *Sambuco racemosi – Piceetum*														
Sambucus racemosa	b	3	1	1	3	3	2	2	2	4	3	2	2	V
Ch. *Vaccinio-Piceion*														
Picea abies	a	4	4	3	5	5	5	5	5	5	5	5	5	V
Picea abies	c	.	+	1	+	.	2	1	.	1	+	+	+	IV
Mycelis muralis	c	1	.	.	+	+	.	1	2	2	1	1	3	IV
Plagiomnium affine	d	2	+	.	1	1	1	+	1	+	.	1	.	IV
Ch. *Vaccinio-Picetea*														
Sorbus aucuparia	b	+	+	1	2	+	1	2	.	1	1	1	.	V
Calamagrostis arundinacea	c	.	.	3	2	.	1	.	1	1	1	2	.	III
Pleurozium schreberi	d	2	3	.	3	2	2	2	.	2	3	3	.	IV
Betula pendula	a	.	.	4	.	+	1	.	.	+	.	.	.	II
Betula pendula	b	.	1	.	.	.	1	1	.	.	.	1	.	II
Betula pendula	c	.	.	.	.	.	1	1	.	.	.	.	.	I
Betula pubescens	a	.	.	+	.	.	.	.	.	.	.	.	.	I
Betula pubescens	c	+	.	.	.	1	.	.	.	1	1	.	.	II

cont. table 2

1		2	3	4	5	6	7	8	9	10	11	12	13	14
Populus tremula	a	.	.	.	.	+	.	.	.	.	.	.	.	I
Populus tremula	b	+	.	.	.	.	.	.	.	.	.	.	.	I
Populus tremula	c	.	.	1	.	.	.	.	.	.	.	.	.	I
Ch. *Dicrano-Pinion*														
Pinus sylvestris	a	.	.	.	2	2	.	.	.	.	+	.	.	II
Dicranum polysetum	d	.	.	.	.	.	.	.	.	.	2	.	.	I
Ch. *Pino-Quercion*														
Veronica officinalis	c	1	1	+	+	+	+	+	.	1	1	1	.	V
Polytrichum formosum	d	1	.	.	.	.	1	.	.	.	.	2	.	II
Ch. *Alnetea Glutinosae*														
Alnus glutinosa	a	.	.	1	.	.	.	.	.	.	.	.	.	I
Salix cinerea	b	.	.	2	.	.	.	.	.	.	.	.	.	I
Ribes nigrum	b	.	1	1	.	.	.	.	.	.	.	.	.	I
Solanum dulcamara	c	+	.	.	.	+	.	.	.	+	+	.	.	II
Ch. *Tilio-Piceion*														
Milium effusum	c	.	.	.	1	.	.	.	1	.	1	.	2	II
Dryopteris filix-mas	c	1	1	1	1	.	.	1	1	1	.	1	1	IV
Aegopodium podagraria	c	.	.	.	.	.	.	.	2	.	.	.	1	I
Ch. *Querco-Fagetea*														
Acer platanoides	a	.	.	.	.	.	.	5	.	.	.	.	.	I
Acer platanoides	b	.	.	.	.	.	.	2	.	.	1	2	.	II
Acer platanoides	c	+	+	+	1	+	1	1	2	.	1	2	.	V
Tilia cordata	b	.	+	.	.	.	.	.	3	.	.	1	.	II
Tilia cordata	c	.	.	.	.	.	.	.	.	.	.	1	.	I
Corylus avellana	b	.	.	.	.	+	.	.	3	.	.	2	3	II
Corylus avellana	c	+	.	.	.	.	.	.	2	.	.	.	.	I
Fagus sylvatica	b	.	+	.	.	.	1	1	2	+	+	1	.	III
Fagus sylvatica	c	1	+	.	.	+	1	.	1	1	.	+	.	III
Euonymus europaeus	b	.	.	.	.	.	.	.	.	.	.	.	1	I
Moehriniga trinervia	c	1	1	.	.	.	.	.	.	2	.	1	.	II
Circaea alpine	c	.	.	.	+	.	.	.	.	.	.	.	.	I
Ranunculus ficaria	c	1	1	1	1	1	1	1	1	+	+	+	1	V
Epilobium montanum	c	1	.	+	1	1	+	+	.	+	+	.	.	IV
Scrophularia nodosa	c	.	.	.	.	+	.	.	.	.	.	1	.	I
Poa nemoralis	c	2	2	.	1	1	.	.	1	1	.	1	.	III
Acer pseudoplatanus	c	.	1	.	.	.	.	.	.	.	.	.	.	I
Ulmus glabra	a	.	.	.	.	.	.	.	.	.	.	2	2	I
Ulmus gabra	b	.	.	.	.	.	.	.	.	.	.	.	1	I
Accompanying species														
Quercus robur	a	.	.	1	.	.	.	.	.	.	.	.	.	I
Quercus robur	b	.	.	1	.	.	+	.	.	.	.	.	.	I
Quercus robur	c	+	+	.	+	+	2	1	1	.	+	1	.	IV
Oxalis acetosella	c	.	+	.	1	.	1	.	.	3	3	2	.	III
Pteridium aquilinum	c	1	1	2	1	1	.	2	+	+	1	1	1	V
Maianthemum bifolium	c	.	.	.	.	.	1	1	.	.	.	1	+	II
Festuca ovina	c	.	.	.	1	.	.	.	.	.	.	.	.	I
Rubus idaeus	b	3	3	3	3	3	3	.	2	1	3	3	2	V
Frangula alnus	b	+	+	2	.	+	.	.	.	+	1	2	2	IV
Frangula alnus	c	.	1	1	1	+	2	2	1	1	1	1	.	V
Veronica chamaedrys	c	+	1	2	+	+	.	.	+	1	1	2	.	IV
Urtica dioica	c	1	2	.	1	2	.	.	3	3	3	3	3	IV

cont. table 2

1		2	3	4	5	6	7	8	9	10	11	12	13	14
Fragaria vesca	c	1	2	1	1	1	1	.	1	2	3	3	+	V
Epilobium angustifolium	c	.	.	2	.	.	1	+	+	1	1	.	.	III
Galeopsis pubescens	c	1	.	1	4	3	.	2	.	.	.	.	.	III
Galeopsis tetrahit	c	.	.	2	2	.	.	2	4	.	.	.	.	II
Sambucus nigra	b	1	+	+	1	1	2	+	1	1	1	+	+	V
Stellaria media	c	3	2	.	.	3	1	2	2	2	1	3	2	V
Galium aparine	c	1	3	2	+	1	1	2	4	3	3	2	3	V
Dactylis glomerata	c	1	1	+	+	1	.	+	+	+	+	1	.	V
Holcus mollis	c	2	2	2	1	1	2	2	.	1	1	1	.	V
Saponaria officinalis	c	+	+	.	+	+	+	.	+	+	+	+	+	V
Chelidonium majus	c	.	+	.	1	4	.	.	2	+	1	+	3	IV
Poa trivialis	c	2	2	.	1	1	2	2	1	1	.	.	.	IV
Geum urbanum	c	2	+	.	.	1	+	1	2	.	+	1	2	IV
Arrhenatherum elatius	c	2	2	2	.	1	2	.	.	2	2	1	.	IV
Artemisia vulgaris	c	1	1	+	+	1	.	.	.	+	+	+	+	IV
Athyrium filix-femina	c	+	+	.	+	.	.	.	+	+	+	+	+	IV
Equisetum pretense	c	+	+	.	+	+	+	1	+	.	+	+	.	IV
Cardamine pratensis	c	+	+	+	+	+	+	.	.	+	+	+	.	IV
Berula erecta	c	+	+	.	+	+	+	.	.	+	+	+	.	IV
Anthriscus sylvestris	c	.	1	.	.	1	.	.	1	1	1	.	2	III
Avenula pubescens	c	2	.	.	.	1	.	.	1	1	.	.	2	III
Cirsium vulgare	c	.	.	.	+	+	.	.	+	1	.	1	.	III
Glechoma hederacea	c	1	1	.	.+	.	+	+	.	.	.	+	.	III
Filipendula ulmaria	b	1	.	1	1	1	.	1	.	+	1	1	.	III
Silene latifolia	c	1	1	1	1	+	.	.	+	.	+	.	.	III
Myosotis sylvatica	c	1	+	.	.	.	.	1	+	+	+	.	+	III
Alliaria petiolata	c	+	.	.	.	+	.	.	+	.	.	+	2	III
Medicago lupulina	c	+	+	.	.	+	.	.	.	+	+	.	.	III
Carex hirta	c	2	2	2	.	.	.	.	.	.	.	.	.	II
Calamagrostis stricta	c	.	2	.	1	1	.	.	.	.	1	.	.	II
Poa palustris	c	2	2	.	.	1	.	.	.	.	.	.	.	II
Achillea millefolium	c	1	1	.	.	.	.	.	1	.	1	.	.	II
Senecio sylvaticus	c	+	1	.	1	.	.	.	.	.	.	.	.	II
Anthoxanthum odoratum	c	2	2	.	.	1	.	.	.	.	.	1	.	II
Poa pratensis	c	.	2	.	.	.	2	.	1	.	.	.	2	II
Convolvulus arvensis	c	.	+	.	.	+	.	.	.	.	.	.	+	II
Viola arvensis	c	+	.	.	+	+	.	.	.	.	.	.	.	II
Geranium robertianum	c	.	.	.	.	1	.	.	.	2	1	.	.	II
Agrostis gigantea	c	.	.	.	.	1	.	.	.	.	1	1	1	II
Rumex acetosella	c	.	.	.	+	+	.	.	.	.	+	.	.	II
Plantago major	c	.	.	3	.	.	+	3	.	.	.	.	1	II
Eupatorium cannabinum	c	1	.	.	1	.	.	.	.	1	1	.	.	II
Circaea lutetiana	c	.	.	.	.	+	.	.	.	+	+	.	.	II
Rumex sanguineus	c	.	.	.	+	+	.	.	.	+	.	.	+	II
Crataegus monogyna	b	.	+	.	.	+	.	.	.	.	+	.	.	II
Crataegus monogyna	c	1	+	.	.	.	.	.	1	.	.	.	.	II
Rosa canina	b	.	3	.	.	+	.	.	.	.	.	2	.	II
Myosotis arvensis	c	+	.	.	.	.	.	.	+	.	.	+	.	II
Phalaris arundinacea	c	.	.	2	1	.	2	.	.	.	.	.	.	II
Cirsium arvense	c	.	.	.	+	.	.	.	+	.	.	1	.	II
Agrimonia eupatoria	c	.	1	.	.	.	.	.	+	.	+	.	.	II

cont. table 2

1		2	3	4	5	6	7	8	9	10	11	12	13	14
Potentilla argentea	c	.	1	.	.	.	.	.	.	.	+	+	.	II
Knautia arvensis	c	.	+	.	.	.	.	.	+	.	+	1	.	II
Ajuga reptans	c	+	.	.	1	.	.	.	+	.	.	.	.	II
Ranunculus repens	c	1	1	.	.	.	.	.	.	.	.	.	.	I
Matricaria inodora	c	1	1	.	.	.	.	.	.	.	.	.	.	I
Elymus repens	c	.	2	.	.	.	.	.	.	.	.	.	.	I
Trisetum flavescens	c	.	2	.	.	.	.	.	.	.	.	.	.	I
Alopecurus pratensis	c	.	2	.	.	.	.	.	.	.	.	.	.	I
Festuca pratensis	c	.	2	.	1	.	.	.	.	.	.	.	.	I
Avena fatua	c	.	2	2	.	.	.	.	.	.	.	.	.	I
Lolium multiflorum	c	.	.	2	.	.	.	.	.	.	.	.	.	I
Festuca gigantea	c	.	.	.	1	.	.	.	.	.	1	.	.	I
Deschampsia caespitosa	c	.	.	.	.	1	.	.	1	.	.	.	.	I
Trifolium arvense	c	.	.	.	.	1	.	.	1	.	.	.	.	I
Syringa vulgaris	b	.	.	.	.	.	.	.	3	.	.	.	.	I
Syringa vulgaris	c	.	.	.	.	.	.	.	2	.	.	.	.	I
Bromus hordaceus ssp. Hordaceus	c	.	.	.	.	.	.	.	2	.	.	.	.	I
Ulmus minor	a	.	.	.	.	.	.	.	.	.	.	.	2	I
Ulmus minor	b	.	.	.	.	.	.	.	.	.	.	.	1	I
Bryophytina														
Brachythecium retabulum	d	1	.	2	2	1	2	+	2	2	.	2	1	V
Rhytidiadelphus squarrosus	d	2	2	1	1	+	1	2	.	.	.	1	.	IV
Brachythecium oedipodium	d	.	.	.	.	2	.	3	.	.	+	.	.	II
Scleropodium purum	d	.	1	.	.	2	.	.	.	.	+	.	.	II
Eurhynchium hians	d	.	.	.	.	.	.	.	1	.	.	.	2	II
Plagiomnium undulatum	d	+	.	.	.	.	.	.	1	+	1	.	.	II
Plagiothecium denticulatum	d	1	.	+	.	.	+	.	.	.	.	.	.	II
Brachythecium starkei	d	.	.	.	+	.	.	.	.	.	1	.	.	II

Sporadic species: *Trientalis europaea* 4 (+), 5 (+), *Hylocomium splendens* 2 (+), *Hieracium vulgatum* 4 (+), *Viburnum opulus* 11 (+), *Campanula rotundifolia* 1(+), 2 (1), *Crataegus laevigata* 1 (+), *Chenopodium album* 1(+), *Ranunculus acris* 1(+), *Chenopodium polyspermum* 1 (+), 4 (+), *Vicia tetrasperma* 1 (+), *Valeriana officinalis* 1(+), 2 (+), *Trifolium pratense* 1 (+), 2 (+), *Trifolium repens* 1 (+), 2 (+), *Hypericum perforatum* 2 (1), 10 (+), *Hieracium pilosella* 2 (+), 4 (+), *Lathyrus pratensis* 2 (+), *Vicia cracca* 2 (+), 7 (1), *Plantago lanceolata* 2(+), *Coronilla varia* 2 (+), *Hieracium murorum* 3 (1), *Galeopsis bifida* 4 (1), *Sisymbrium altissimum* 4 (1), *Juncus effusus* 4 (+), *Hypericum maculatum* 4 (+), *Vicia grandiflora* 4 (+), *Galium mollugo* 5 (1), 8 (+), *Agrostis stolonifera* 5(1), *Cirsium oleraceum* 5 (+), 11 (1), *Succisella inflexa* 5 (+), *Lapsana communis* 5 (+), 8 (+), *Arctium tomentosum* 5 (+), 9 (+), *Sium latifolium* 5 (+), *Solidago graminifolia* 5 (+), *Linaria vulgaris* 6 (+), *Vicia hirsuta* 7 (1), *Lamium album* 8 (1), *Rhamnus catharticus* 8 (+), *Rumex acetosa* 8 (+), *Euphorbia cyparissias* 8 (+), *Verbascum thapsus* 8 (+), *Atriplex patula* 8 (+), *Conyza canadensis* 8 (+), *Plantago major* ssp. *intermedia* 8 (+), *Polygonum minus* 8 (+), *Scabiosa canescens* 8 (+), *Galeopsis speciosa* 9 (1), *Heracleum sphondylium* ssp. *sphondylium* 12 (1), *Plagiomnium cuspidatum* 12 (1), *Cirriphyllum piliferum* 7 (+), 11 (+), *Mnium stellare* 7 (+), *Eurhynchium angustirete* 4 (+), *Ditrichum pusillum* 6 (+)

Both the communities are anthropogenic in character. The prevailing part of species building the identified phytocoenoses are anthropophytes.

Diversity of samples representing a community was interpreted after WHITTAKER (1977) as an internal α-diversity, also referred to as point diversity.

The results obtained (Table 3) demonstrate that species abundance of the *Sambucus nigra-Picea abies* (Table 1) community ranges from 27 to 58 species in a phytocenosis. In addition, in that community the value of Shannon index fluctuates between 4.6 and 5.8. The results indicate a correlation between the value of diversity index and the number of species and the Pielou Evenness index. The highest value of diversity index was reported for the relevés with the highest number of species (No. 14, 15).

Table 3

Diversity indices of an *Sambuco racemosi-Piceetum* and *Sambucus nigra-Picea abies* communities

No. Releve	Shannon-Wiener Index (H)	Mean	Pielou Evenness (J)	Mean	Num. Spec.	Mean
Sambuco racemosi-Piceetum						
1	6.06		0.979		73	
7	6.201		0.978		81	
11	5.371		0.978		45	
2	5.944		0.976		68	
3	6.095	5.72325	0.975	0.975417	76	60
9	5.334		0.977		44	
10	5.25		0.974		42	
4	5.942		0.973		69	
5	5.621		0.972		55	
6	5.834		0.972		64	
8	5.843		0.977		63	
16	5.184		0.974		40	
Sambucus nigra-Picea abies						
12	5.15		0.974		39	
13	4.624	5.28075	0.972	0.97625	27	44.25
14	5.596		0.977		53	
15	5.753		0.982		58	

In the community of *Sambuco racemosi-Piceetum* species abundance ranges from 40 to 81 species in a phytocenosis (Table 2), and the value of Shannon index from 5.2 to 6.2. The results point to a correlation between the value of diversity index and species number and the value of Pielou Evennes index. The highest value of diversity index was observed for relevés with the highest number of species (No. 7, 3, 1), and the lowest one – for those with the lowest number of species (No. 16, 10, 9, 11).

Table 4

U-Mann-Whitney test and Student's t-test

U-Mann-Whitney. Grouping. var. stadium, marked results are significant at p <.05000										
Specification	Rank sum	Rank sum	U	Z	p level	Z	p level	No. cases per group	No. cases per group	2*1str.
Index (H)	117.0000	19.00000	9.00000	1.819017	0.068910	1.819017	0.068910	12	4	0.078022
Evenness (J)	101.0000	35.00000	23.00000	-0.12127	0.903479	-0.12244	0.902548	12	4	0.952747
Num. Spec.	117.0000	19.00000	9.00000	1.819017	0.068910	1.819017	0.068910	12	4	0.078022
Student's t-test; grouping: stadium (sheet1) group 1: 1 group 2: 2										
Specification	mean	mean	t	Df	P	no. cases per group	no. cases per group	SD	SD	F quotient
Index (H)	5.72325	5.28075	1.944655	14	0.072187	12	4	0.35724	0.50689	2.013291
Evenness (J)	0.97542	0.97625	-0.48962	14	0.631987	12	4	0.00243	0.00435	3.205392
Num. Spec.	60.00000	44.25000	1.909717	14	0.076876	12	4	14.35270	14.03270	1.046128

Simultaneously, attention was paid to various representation of species in a phytocenosis: relevé No. 8 had higher diversity than relevé No. 6 despite a lower number of species. Similar relations were observed between relevés No. 2 and No. 4 (Table 1). It results from more even spatial distribution of species in phytocoenoses No. 8 and No. 2 as compared to phytocoenoses No. 6 and No. 4. This is also indicated by a higher value of evenness indices for phytocoenoses No. 8 and No. 2 as compared to those No. 6 and No. 4.

The mean value of the diversity index and the mean number of species were higher in the case of *Sambuco racemosi-Piceetum* community, as compared to the *Sambucus nigra-Picea abies* one (Table 1). In turn, the mean values of the Pielou Evenness was higher in the community of *Sambucus nigra-Picea abies* in respect of the mean value of that index reported in the community of *Sambuco racemosi-Piceetum* (Table 3).

The U-Mann-Whitney test and Student's t-test carried out in the study confirmed that the observed differences in the diversity index, species abundance and species contribution in phytocoenoses between communities of *Sambuco racemosi-Piceetum* and those of *Sambucus nigra-Picea abies* were statistically significant (Table 4).

Variables applied in the CCA explain only ca. 43.6% of the total diversity of plants (Table 5). Canonical coefficients of all habitat variables evaluated by a measure of Variance Inflation Factor [VIF < 20 (Braak ter 1986)] are stable and suitable for interpretation.

Table 5

CCA ordination of the phytocoenoses threatened by a pesticide tomb

Variable	Weighted mean	Weighted SD	Variance Inflation Factor VIF
W	3.299	0.079	2.362
Tr	3.548	0.151	14.355
R	3.574	0.145	11.007
D	3.826	0.082	2.144
H	3.125	0.044	2.44
N	6.683	0.506	5.574

Specification	axis 1	axis 2	axis 3	axis 4	axis 5	axis 6	total interia
Eigenvalues	0.285	0.211	0.188	0.134	0.12	0.109	2.401
Percentage	11.862	8.801	7.844	5.578	5.005	4.523	–
Cum. Percentage	11.862	20.663	28.507	34.086	39.09	43.613	–
Cum. Constr. Percentage	27.199	47.379	65.364	78.154	89.63	100	–
Spec.-env. Correlations	0.98	0.977	0.988	0.924	0.967	0.982	–
Sum of all eigenvalues	–	–	–	–	–	–	2.401

Note: only the first 6 axes are environmentally constrained

Phytocoenoses of both communities are observed to separate along I axis gradient (Figure 4). On the right side of the ordination space with a higher contribution of erytopic cosmopolitan species, phytocoenoses adjoining the tomb can be distinguished (13, 16, 12, 14, 15, 4). All relevés of *Sambucus nigra-Picea abies* are observed herein (12, 13,14, 15). On the left side of the ordination space with a higher moisture content there are grouped phytocoenoses bordering with a drainage ditch being the closest to the fishing ponds (3, 5, 6, 11) and those located in the central area of the forest examined (1, 2, 7, 8, 9, 10).

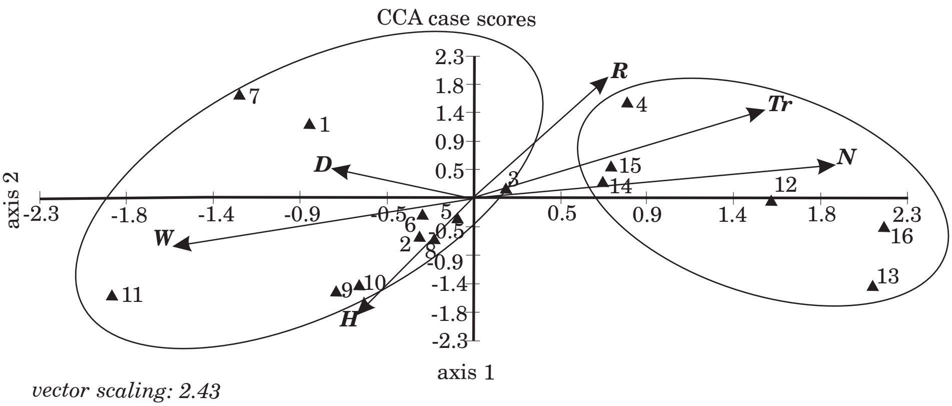

Fig. 4. CCA ordination diagram of the phytocenoses threatened by a pesticide tomb: 1–16 – releve; *W* – soil moisure value, *Tr* – trophy value, *R* – soil acidity (pH) value, *D* – soil granulometric value, *H* – organic matter content value, *N* – nitrophylity value

Discussion

The communities with *Sambucus nigra-Picea abies* usually occupy fertile, humus, damp and not very insolated habitats (ENDLER 1987). Soils they grown on are of character of artificially transformed soils with various degree of the soil-forming process advancement, or soils with a changed soil profile, as was the case of the examined habitat (GRZYBOWSKI et al. 2006). Phytocoenoses of *Sambuco racemosi-Pieceetum* are reported most often at forest ducts and on felling sites (SOKOŁOWSKI 1980). On the examined area, they also occurred close to a forest duct leading from a tomb to ponds (Figure 2). They requirements for soil and moisture content are medium, they are found most often on fresh, fertile argillaceous soils (SOKOŁOWSKI 1980). The analysis of the point diversity at a level of phytosociological relevés (Figure 2) confirmed the accuracy of the adopted phytosociological division, consistent with concepts of GRZYBOWSKI et al. (2006).

Investigations of species diversity carried out in the communities of *Sambuco racemosi-Piceetum* and *Sambucus nigra-Picea abies* did not demonstrate any statistically significant differences in terms of the diversity index, species abundance and species contribution. It has been confirmed by the ecological characteristics of the community with *Sambucus nigra-Picea abies* and community of *Sambuco racemosi-Pieceetum* (GRZYBOWSKI et al. 2005), which demonstrated that the phytocoenoses assayed were alike in terms of habitat factors.

Analyses of the preferences of species occurring in the phytocoenoses of *Sambuco racemosi-Piceetum* and *Sambucus nigra-Picea abies* distributed along a gradient determined by edaphic index numbers enabled selecting groups of phytocoenoses located in the very direct proximity of the pesticide tomb. This confirms results of investigations into the content of heavy metals in selected plant species in an environmental gradient around a pesticide tomb (GRZYBOWKI et al. 2005a,b) in which higher contents of heavy metals were observed in species growing in phytocoenoses adjacent to a pesticide tomb. Also soil analyses pointed to increasing effects of the tomb on soils of phytocoenoses located in its close vicinity (ZMYSŁOWSKA et al. 2005).

Conclusions

1. A lack of significant differences in the diversity index, species abundance and species contribution between the phytocoenoses of the examined community with *Sambucus nigra-Picea abies* and that of *Sambuco racemosi-Pieceetum* indicates a modifying role of the pesticide tomb in species distribution within the analyzed phytocoenoses.

2. Diversity in species distribution of phytocoenoses *Sambuco racemosi-Piceetum* and *Sambucus nigra-Picea abies* in the ordination space determined by ecological index numbers points to a modifying effect of the pesticide tomb.

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THE REPRODUCTION OF NEON TETRA, *PARACHEIRODON INNESI* (MYERS, 1936), UNDER CONTROLLED CONDITIONS

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K e y w o r d s: spawning, controlled conditions, aquarium fish, tetras, *Characidae*.

A b s t r a c t

A study on reproduction of neon tetra has been carried out under controlled conditions. Neon tetra is very popular aquarium fish. It was observed that spawners of this species produce viable gametes during a few (5–6) spawning periods only. From the breeding perspective fish of that species should be reproduced again shortly after the completed spawning and time between spawns should be 15 to 20 days. Keeping the fish between spawning periods more than 20 days results in a significant deterioration of quality of gametes, expressed by the decreased number of 12-day-old larvae. It was shown that before spawning spawners should be kept in water at 22°C. The negative effect of keeping the reproducers in water at 25°C accumulated with time.

ROZRÓD NEONA INNESA, *PARACHEIRODON INNESI* (MYERS, 1936), W WARUNKACH KONTROLOWANYCH

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S ł o w a k l u c z o w e: tarło, warunki kontrolowane, ryby ornamentalne, bystrzyki, *Characidae*.

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Abstract

Przeprowadzono badania nad rozrodem neona Innesa w warunkach kontrolowanych. Neon Innesa jest bardzo popularną rybą akwariową. Odnotowano, że od tarlaków tego gatunku jest możliwe uzyskanie dobrej jakości gamet podczas kilku (5–6) kolejnych tareł. Z hodowlanego punktu widzenia ryby powinno się rozmnażać krótko po skończonym rozrodzie, a kolejne tarła powinny odbywać się między 15 a 20 dniem. Przetrzymywanie ryb między kolejnymi tarłami dłużej niż 20 dni skutkuje znacznym obniżeniem jakości gamet, wyrażonej jako zmniejszona liczba 12-dniowych larw. Uzyskane wyniki wskazują, iż tarlaki między tarłami powinny być przetrzymywane w wodzie o temperaturze 22°C. Odnotowano nasilenie się negatywnego efektu przetrzymywania ryb w temperaturze 25°C.

Introduction

The aquaculture of commercial, ornamental and aquarium fishes are strictly depending from methods of reproduction and fry rearing. In case of freshwater fishes, the reproduction under controlled conditions was usually done using hormonal stimulation (BRZUSKA 2000, 2005, 2006, KUCHARCZYK et al. 2008a). The necessity of application hormonal stimulation is especially good visible when wild cyprinids are reproduced (KUCHARCZYK et al. 1997a, b, c, 2005, SZABO 2003, KOUŘIL et al. 2007, KREJSZEFF et al. 2008, TARGOŃSKA et al. 2008, ŻARSKI et al. 2009). The last published research showed, that in domesticated stock is possible to reproduce fish without application of spawning agents (KREJSZEFF et al. 2009). In other species, i.e. percids, the fish can spawn without hormonal stimulation, but application of spawning agent involves spawning synchronization (KUCHARCZYK et al. 1996, 1998).

Aquaculture of ornamental fish species is an important part of fisheries (TLUSTY 2002, BALON 2004, CEK, GOKCE 2005, CHELAPPA et al. 2005). Breeding aquarium fish is developing particularly dynamically in Asia although recently an extensive development has also been observed in some European countries. Characidae is one of the groups of decorative fish commonly bread worldwide. They live mainly in the tropical waters of South America. The best-known representatives of that group are tetras, which cultured stocks are usually domesticated (ELIAS 2003, BALON 2004).

The neon tetra *Paracheirodon innesi* (Myers, 1936) is one of the most valuable species in the ornamental fish trade (WIETZMAN, FINK 1987). Most fish of this species available in the market are imported from South-East Asia, where they are raised in the fish farms, or from South America, where they are collected from the wild (CHAPMAN et al. 1998). Annually 12–15 million neon-tetras collected from the wild are exported; this is about 80% of the total market of ornamental fish of the Amazon State (CHAO 2001). This situation led to the fear that this species may be doomed to extinction (BAYLEY, PETRERE 1989). For this reason the propagation methods of different aquarium fish in captivity should be developed and published (OLIVIER, KEISER 1997, GOSH et al. 2007).

The tetras (*Characidae*), including neon tetra are one of the most popular groups of fishes that are kept in modern aquariums. They are generally colourful and small in size and most of them only grow to 3–5 cm of total length and can be kept in small tanks, which are more suitable for the beginning hobbyist (KUCHARCZYK et al. 2008b, KUPREN et al. 2008). Neon tetra is much less sensitive than cardinal tetra *Paracheirodon axelrodi* (SCHULTZ 1956) and more popular as aquarium fish. Generally, tetras prefer soft, slightly acid water which resembles to natural conditions. The water of streams and rivers in Amazon region are poor in nutrients and minerals but rich in humic acids (JUNK, SOARES 2001). The reproduction of these species in captivity is not easy, but aquarists have been trying to reproduce them since the middle of XX century. The neon tetra was first described by Myers at 1936, but was discovered by Rabaut short time earlier in the Amazon, near Tabatinga town (ELIAS 2003, BALON 2004).

The high market pressure stimulated the development of breeding and rearing methods of tetras (KUCHARCZYK et al. 2008b, KUPREN et al. 2008), but because the aquaculture of this species is a valuable business, only some limited data concerning such information like methods of spawning are printed (CHAPMAN et al. 1998).

The aim of this study was to reproduce of neon tetra under controlled conditions.

Material and Methods

Spawners

Fish for broodstock were obtained from domesticated stock from one of the Czech fish farm and transported to the Laboratory of Aquaculture at Department of Lake and River Fisheries, Warmia and Mazury University in Olsztyn. The collected fish (over 600 specimens) were about 1 cm of total length. Initially they were reared at 1 m^3 tank (KUJAWA et al. 1999). Later, the fish were reared during four months at constant temperature (22°C) in recirculated water system (KUJAWA et al. 2000). The water parameters are presented in Table 1. Fish were fed two times daily with frozen natural food: zooplankton, Chironomids and mosquito larvae.

Table 1
Characteristics of water quality for rearing and spawning of neon tetra

Characteristics	Type of aquarium	
	rearing	spawning
Temperature (°C)	22	25
Total hardness (°n)	4–5	0
Permanent hardness (°n)	2–3	0
pH	6.9–7.4	5.5–6.5
NH_3, NO_2^- (mg dm^{-3})	< 1.0	0
Conductivity (μS)	48–116	28–30
Addition of humic acid	no	yes: 0.04%

Initial spawning

Prior to spawning the fish were segregated according to sex for a period of three weeks and fed three times a day intensively. When the fish reached 2.5–3.5 cm of total length, they were moved to the spawning tanks in order to prepare them to the first spawning. The spawn was stimulated by manipulation of environmental conditions, which was described in details in Table 1. A spawning substrate (nylon brush) was used for egg deposition. The females which spawned were used to further experiments. The first spawn (called as "mass") was made in 90 small aquariums (7 dm^3 each). 3 females and 3 males were moved to each tank. Between the experimental spawnings all of the spawners were kept separately (males and females).

Physicochemical parameters of water used for neon tetra spawning were constant. For that purpose water prepared was obtained from the process of reversed osmosis, and the water with carbon hardness 0°dH and total hardness at 0°n was obtained. The addition of humic acid was done. The temperature of water in spawning tanks was 25°C. All fish, except in experiment 3, were kept at 22°C between the spawning acts. On the bottom of the tank spawn grilles with mesh size of 5 mm were placed. The tanks were aerated. The spawning tanks were placed in dark as neon tetra eggs are sensitive to light. Three times a day the tanks were checked whether spawning took place. After completed spawning the fish were caught. The 12-day-old fry was counted on the basis of 5 return samples. At this age fish might be counted without influence on their mortality and on the other hand, they are not sensitive to intensive light at this time.

Experiment 1. The aim of the first experiment was the investigation the effect of consecutive spawning acts on the number of obtained larvae. For that purpose 10 reproductive pairs (1 male and 1 female) were used. Spawners were placed in the late afternoon into the small tanks (7 dm^3 each). Spawning usually began on the next (or second) day around dawn and lasted from one to four hours. The pairs were removed immediately after completed spawning. Every 15 days they were moved to spawning tanks again. The number of fry was counted when the larvae were 12-day-old after hatching. The neon tetra larvae were fed 5 times daily using SF origin artemia nauplii (LIM et al. 2002).

Experiment 2. In the second experiment the investigation concerned the duration of the most appropriate period between spawning from the breeding perspective. For that purpose 10 reproductive pairs that successfully completed the first spawning were moved every 5 days to spawning tanks (7 dm^3). After completed spawning the procedure was the same as in experiment 1.

Experiment 3. The third experiment investigated the influence of the temperature (22 and 25°C) of water in which fish were kept before spawning on the results of spawning. For that purpose two sets of fish (10 reproductive pairs each) were used. They were moved to the spawning tanks three times, at 15-day intervals. After completed spawning the procedure was the same as in experiment 1.

Experiment 4. The last experiment the investigation of the influence of broodfish pairs number on spawning results. For this reason 1, 2, 3, 4, 5 or 10 tetra pairs were moved to the spawning tanks (7 dm^3 each). After completed spawning the procedure was the same as in experiment 1. Experiment was made in triplicate.

Statistics

The obtained results were analyzed statistically. The differences in the number of 12-day-old larvae between groups in individual experiments were processed by variance analysis and Tuckey's *post-hoc* test at significance level of 5%. The correlation between the number of larvae and the consecutive spawning as well as intervals between individual spawning acts and number of pairs were subjected to regression analysis.

Results

Whatever type of experiment was conducted the percentage of ovulating females was high, ranging from 90% to 100%. Neon tetra spawners produced viable gametes during seven following spawns (Figure 1), including the first – mass spawning. The highest number of 12-day old larvae was obtained after spawn No. 3 and 2. From spawn No. 5 the number of larvae dramatically decreased. From spawning No. 7 and three next ones no single viable individual was obtained.

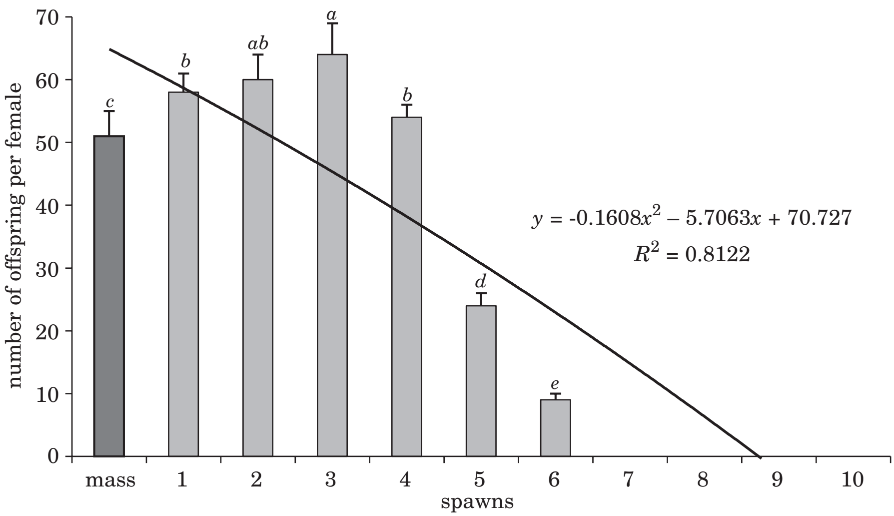

Fig. 1. The influence of the number of completed spawning acts on the average numbers of 12-day-old larvae obtained from one pair of the neon tetra spawners. The data marked by the same letter index within individual spawning acts do not differ statistically

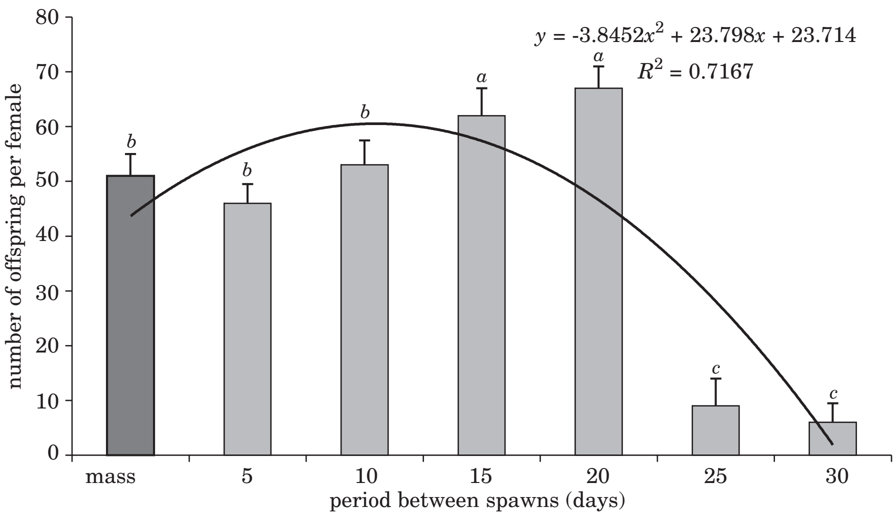

Fig. 2. The influence of the length of interval between spawning acts on the average numbers of 12-day-old larvae obtained from one spawning pair of neon tetra. The data marked by the same letter index within individual spawning acts do not differ statistically

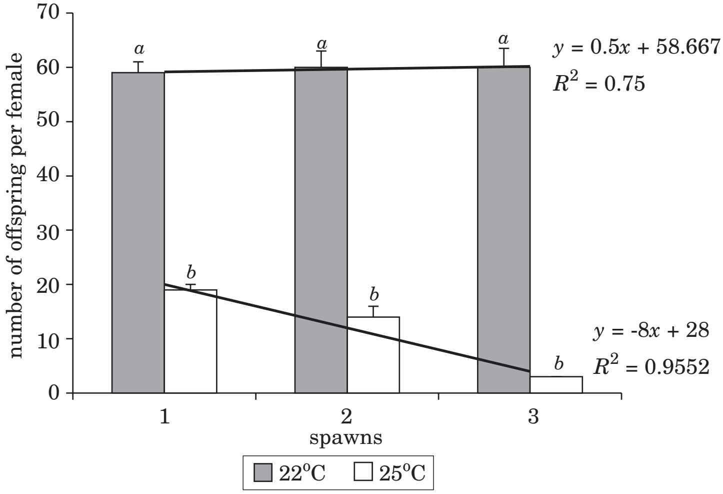

Fig. 3. The influence of the temperature of water used for keeping the neon tetra spawners on the average numbers of 12-day-old larvae obtained from a single spawning pair. The data marked by the same letter index within individual spawning acts do not differ statistically

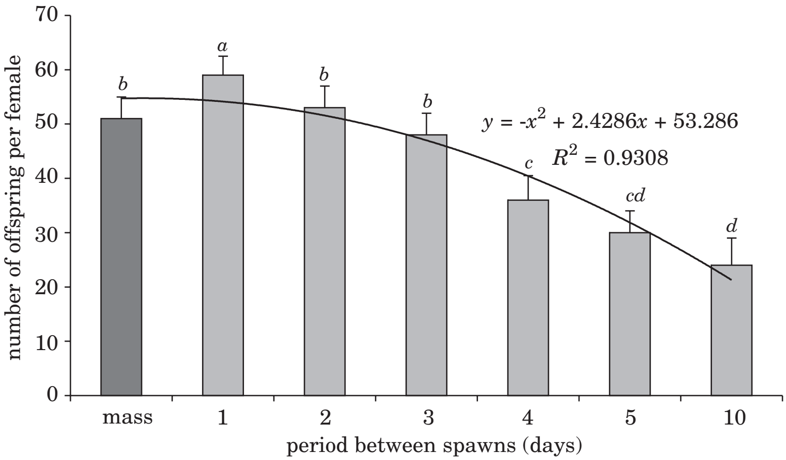

Fig. 4. The influence of the number of breeder pairs on the average number of 12-day-old larvae obtained from of the neon tetra spawners. The data marked by the same letter index within individual spawning acts do not differ statistically

Figure 2 presents the numbers of 12-day-old larvae (per female) obtained from spawning acts, performed at fixed time intervals (after 5, 10, 15, 20, 25 and 30 days) from the first (mass) spawning. It was demonstrated that the interval between individual reproductive acts in case of neon tetra should be from 15 to 20 days. Keeping the fish longer than 20 days before consecutive spawning resulted in a significant decrease of the hatch numbers obtained.

For example, when comparing the number of larvae obtained in case of 20 and 30-day interval between spawning acts an almost 6 times decrease in the number of larvae was noted.

It was also showed that the level of temperature, in which spawners were kept before spawning act is important for the number of obtained viable larvae (Figure 3). Keeping the fish at the higher of the tested temperatures (25°C) had a significant influence on decreasing the numbers of offspring obtained as compared to the results obtained when the fish before spawning were kept in water at 22°C. Accumulation of the negative effect of the temperature in case of keeping the spawners at 25°C for a longer time was also demonstrated.

The results of the influence of number of breeders pairs on quantity of 12-day-old larvae are presented in Figure 4. The highest number of larvae per female (about 60) was noted when a single pair was used for spawning. But, i.e., when 10 pairs were moved to the spawning tanks, the total production of larvae was over 280.

During all the experiments no spawners mortality was recorded.

Discussion

The industrial catching of ornamental fishes from the wild influenced their significant decline (RAGHAVAN et al. 2007). The main problem is that in many cases the collection of fish from the wild is cheaper than their breeding in captivity. Also spawn of wild fish is more difficult in captivity. This situation should be changed by fish domestication (BALON 2004, KREJSZEFF et al. 2009). Many aquarium fishes were spawned in captivity after manipulation of environmental conditions only (KUCHARCZYK et al. 2008b). The same situation was noted in the case of neon tetra, where increasing the temperature, darkness and preparing water was enough for stimulation of final maturation of gametes.

In modern aquaculture obtaining high quality gametes, which allows both obtaining the required number of larvae for initial rearing and planning of production, is one of the most important problems to be solved. It is also highly important from the economic perspective. This applies not only to fishes reared for consumption but also other fish including the decorative and aquarium species. Numerous factors influence the effects of reproduction, which are in this study understood as spawning and obtaining a specific number of larvae from the spawn. They include, among others, the fish diet and environmental conditions. According to BROOKS et al. (1997) the differences between species in the observed influence of environmental conditions on effectiveness of fish reproduction and quality of gametes produced by them were described.

In some cases the environmental conditions which the spawners are kept in can also affect offspring rates of survival and growth as well as the resistance to stress (BROOKS et al. 1997, TARGOŃSKA 2007).

The viable offspring of neon tetra can be obtained during a few initial reproductive acts only (counting from the first, controlled spawning). Later, although the fish performed the reproduction and laid eggs, the obtaining of viable offspring is not possible. A similar situation was noted in other Characidae, i.e. Buenos Aires tetra (*Hyphessobrycon anisitsi* Eigenmann, 1907) (KUCHARCZYK et al. 2008b). On the basis of the data obtained from the presented experiments it can be concluded that during further reproduction, the eggs were laid but hatched larvae were not obtained. The developing eggs usually died during the initial hours of incubation. That observation is confirmed by numerous observations reported by aquarium owners and it is a characteristic of Characidae. During these studies not a single viable hatch was obtained from spawning No. 7 and next. Considering the number of spawning pairs and the data published by SCHEURMAN (1990) on fecundity of this species it should be estimated that not a single larvae hatched from around 2000–3000 eggs. Similar data (except fecundity) was obtained for Buenos Aires tetra by KUCHARCZYK et al. (2008b).

The number of obtained fry per one female, in the present experiment ranged between 50 and 60. These data are similar to those published by CHAPMAN et al. (1998). Neon tetra reared in the laboratory by those authors produced a significantly higher number of larvae (82 larvae/female) than broodstock collected from the wild or cultured (28 larvae/female). But in the present work the 12-day-old larvae were counted not new-hatched larvae.

The influence of some factors (positive or negative) on the effect of fish reproduction can accumulate over time. That was confirmed, among others, by TARGOŃSKA (2007) during studies on the influence of feeding of reproducers on the effects of reproduction of genus *Symphysodon*. The accumulation of negative influence of high water temperature in which spawners were kept was also found in case of the studied species of tetras: neon (present paper) and Buenos Aires tetra, when extended keeping of fish in water at 25°C caused a decrease in the number of offspring (KUCHARCZYK et al. 2008b). The influence of water temperature on reproductive capability has been described for many fish species (KRAAK, PANKHURST 1996). A similar relation between the temperature at which the spawners were kept before reproduction and survival of the embryos and larvae was observed in case of *Menidia beryllina* (Cope, 1867), when the fish were kept under controlled conditions (HUBBS, BRYAN 1974).

The results of studies indicate that keeping spawners of neon tetra in excessively high temperature and for excessively long intervals between consecutive spawning actions can significantly influenced on effects of reproduction. It was demonstrated that during selection of reproducers to the spawning stock the number of completed spawning actions and the time between them should also be considered. The results presented in this paper fill the information gap concerning biotechnology of aquarium fish reproduction, which is quite significant also for species highly popular in aquaculture and for economic point of view (HAKUĆ-BŁAŻOWSKA et al. 2009) during this species culture.

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THE INFLUENCE OF TEMPERATURE ON SUCCESSFUL REPRODUCTIONS OF BURBOT, *LOTA LOTA* (L.) UNDER HATCHERY CONDITIONS

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Key words: spawning, thermal manipulation, wild population, hormonal stimulation, burbot *Lota lota.*

Abstract

The aim of this study was to define an influence of water temperature on successful reproduction of burbot under the hatchery conditions. Research was conducted during four successive spawning seasons where wild spawners were used. In the first three years of study fish were kept in three different (natural) thermal conditions. In the fourth year it was confirmed that the highest efficacy of synchronization of the spawning could be reached only under controlled thermal regimes. That year one group of spawners was kept at 6°C before spawning and then a sudden decrease of the temperature to 1°C was applied. Restrictively controlled thermal regime during reproduction of burbot in captivity caused the most synchronous spawning of females (2 days-period) in contrast to control group (17 days-period) and even hormonally stimulated (4 days-period). Eggs survival in thermally manipulated group was very high (over 85% in the eyed-egg-stage). This research proved that manipulation of water temperature is the most important technique which should be applied in controlled reproduction of burbot and it is suggested that the temperature is the major factor during final maturation of burbot females. Also, confirmed the fact that incubation of burbot eggs in temperature over 5°C causes its high mortality (100% in the eyed-egg-stage).

WPŁYW TEMPERATURY NA SUKCES ROZRODCZY MIĘTUSA, *LOTA LOTA* (L.) W WARUNKACH WYLĘGARNICZYCH

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Słowa kluczowe: rozród, manipulacje termiczne, dzika populacja, stymulacja hormonalna, miętus *Lota lota.*

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Abstrakt

Celem pracy było określenie wpływu warunków termicznych na sukces rozrodczy miętusa w warunkach wylęgarniczych. Badania prowadzono podczas czterech kolejnych sezonów rozrodczych na dzikiej populacji miętusa. W pierwszych trzech latach badań ryby przetrzymywano w trzech różnych (naturalnych) warunkach termicznych. W czwartym roku potwierdzono w sposób eksperymentalny, że można osiągnąć bardzo wysoką efektywność rozrodczą po zastosowaniu wyłącznie manipulacji termicznych. W tym celu jedną z grup przetrzymywano przed tarłem w wodzie o temperaturze 6°C, a następnie gwałtownie obniżono temperaturę do 1°C. Restrykcyjne manipulacje termiczne w trakcie przetrzymywania tarlaków miętusa wpłynęły na największą synchronizację rozrodu (2 dni) w porównaniu z grupą kontrolną (17 dni) lub nawet stymulowaną hormonalnie (4 dni). Przeżywalność embrionów w „termicznie manipulowanej" grupie była bardzo wysoka (ponad 85% w stadium zaoczkowania). Wyniki wskazują na to, iż najważniejszym elementem procedury rozrodczej miętusa jest manipulacja termiczna, a temperatura jest głównym czynnikiem powodującym finalne dojrzewanie gamet. Potwierdzono także wysoką śmiertelność embrionów (100% w stadium zaoczkowania) w wodzie o temperaturze powyżej 5°C.

Introduction

The burbot, *Lota lota* (L.) is one of the most perspective species in coldwater aquaculture. It is the only freshwater species, which belongs to the order *Gadiformes* (NELSON 1994). Rivers, lakes and brackish waters, which constitute feeding areas for adult specimens, are places where burbot is present (SCOTT, CROSSMAN 1973, PULLIAINEN et al. 1992). Burbot is a predator whose main food are invertebrates and fish (JACOBSON, JÄRVI 1976, PÄÄKKÖNEN, MARJOMÄKI 2000). It belongs to a group of reproductive lithopelagophils (KJELLMAN, ELORANTA 2002) and can also be classified as a cold stenothermal species, adapted to life in cold environment (TIITU, VORNANEN 2002). The optimal temperature for burbot feeding is below 12°C (Rass 1983). Spawning season, which is frequently proceeded by long migration (PARAGAMIAN 2000, SCHRAM 2000, SLAVIK, BARTOS 2002, PARAGAMIAN et al. 2005) occurs mainly in the middle of the winter, when spawners often reproduce under the ice cover. Semi buoyant eggs are release in the depth of 0.5–1.5 m (SCOTT, CROSSMAN 1973, LEHTONEN 1998, MCPHAIL, PARAGAMIAN 2000), usually in temperature below 4°C (MANN 1996). The first days of incubation occur in similar temperatures as well, reducing mortality rates and developmental defects (KUJAWA et al. 1999b). PULLIAINEN, KORHONEN (1993) reported that some of adult burbots (sometimes even 50%) do not approach breeding every year. Fecundity depends on the female size, which may produce from 100 000 to over 3 000 000 eggs (NIKOLSKIJ 1950, VOSTRADOVSKA 1963, BAILEY 1972). Females of burbot reach maturity at the age of four years, while males usually one year earlier (VOSTRADOVSKA 1963).

At present, the importance of burbot is mostly ecological. As one of the top predators in ecosystem, they often compete with other top predators such as pike or large salmonids (KIRILLOV 1988). Presently the burbot is threatened in almost all range of his distribution. Hence, the large interest in their restitution and production of fry in aquaculture in order to prevent this species extinction (BABIAK et al. 1998, HARDY et al. 2008). Due to this situation many studies have been initiated on different aspects of biotechnology and burbot reproduction (KOUŘIL et. al. 1985, KUCHARCZYK et al.1998b, LAHNSTEINER et al. 2004) and fry rearing (KUJAWA et al. 1999c, WOLNICKI et al. 2001, 2002, PÄÄKKÖNEN et al. 2003, SHIRI HARZEVILI et al. 2003, 2004, BINNER et al. 2008, ŻARSKI et al. 2009a).

Reproductive processes in fish and development during early ontogeny stages are controlled and regulated by environmental factors like the photoperiod and temperature of water (LAM 1983, STACEY 1984, KUCHARCZYK et al. 1997b, 1998c, KUJAWA et al. 1997). However, for many teleosts the photoperiod is a dominant and the most important factor in the reproductive cycle (BROMAGE et al. 2001), while the temperature is playing the major role in final gamete maturation, ovulation and spawning (ANGUIS, CAÑAVATE 2005). The influence of temperature on egg quality and synchronization of ovulation, which strictly corroborates with day-length, has also been observed (BYE 1984, DAVIES, BROMAGE 2002). In artificial reproduction of many freshwater fish species, the hormonal induction of final gametes maturation is needed (KUCHARCZYK et al. 1997a,c,d, 2008, SZCZERBOWSKI et al. 2009). Only in limited number of species. i.e. Eurasian perch (KUCHARCZYK et al. 1996, 1998a) or some domesticated (i.e. KREJSZEFF et al. 2009) or aquarium fishes (i.e. KUCHARCZYK et al. 2010) it is possible to prepare spontaneous spawning in captivity.

The aim of this study was to investigate the influence of water temperature on successful spawning of burbot in captivity.

Materials and Methods

Spawners of burbot were captured every year (on four consecutive years) in the Szczeciński Bay (Northern-West Poland). Each season over one hundred breeders were collected and transported to the hatchery. Fish were held in captivity from the beginning of November. Females' weight varied from 0.8 kg to over 3.0 kg and males from 0.5 kg to 1.0 kg. Females for experiment were selected according to following criteria: the belly of females had to be fully distended and bulging, soft and resilient to touch.

The experiment was carried out at the "Czarci Jar" (near Olsztynek, Northern-East Poland) hatchery and the laboratory of Department of Lake and River Fisheries, Warmia and Mazury University in Olsztyn. In the hatchery fish were kept without feeding in 1 m^3 tanks (KUJAWA et al. 1999a), with maximum load of fish up to 30 kg m^{-3}. Males and females were kept together. During all years of experiment fish were kept at the same conditions: tanks volume, fish density, water flow, photoperiod (natural), dissolved oxygen level (between 75 and 80%). The only variable was temperature. During the first three years the fish were kept in natural temperature (not modified; water was taken from Drwęca River), whereas in the last year of the study fish from one group were kept in thermostatically controlled temperature.

Water temperature was measured twice daily. Females were checked every three days before the first spawning, and twice daily after the first spawning. During the first three years of study, all females spontaneously matured without any hormonal stimulation. As a spawned females had been identified specimens without signs, mentioned above, and vest of eggs (which were not released in the tank) were certified after soft pressure of abdomen covers. For experimental observations 56, 49 and 52 females were selected in the first, second and third year of study respectively. In the last (fourth) year of study, females were randomly divided into three groups (20 specimens in each group), where:

– group 1 (control group) – fish were kept in natural conditions (average temperature about 1°C);

– group 2 (hormonally treated group) – fish were kept in natural water conditions but later were hormonally induced to spawn, using Ovopel (Unic--Trade, Hungary) at the dose of one pellet kg^{-1}. One Ovopel pellet containing 18–20 μg of highly active analogue of GnRH and 8–10 mg of metoclopramide – a dopamine antagonist (HORVATH et al. 1997);

– group 3 (temperature manipulated group) – fish were kept two weeks at 6°C and later water temperature was rapidly (during one day) lowered to 1°C.

Males were mature since they were brought to the hatchery and it was possible to squeeze semen from males during the entire period of captivity. During experiment some spawns characteristics, such as: number of ovulated females, ovulation time, survival of eyed-egg stage embryos, were noted. Because during the first three years of study the fish spawned spontaneously in tanks, it was impossible to recognize females fecundity. Similar situation was observed in the control group during the last year. In these groups spawned females were moved from the tanks. To determine embryos survival eggs were removed from tanks (water with eggs was siphoned through fine mesh) and incubated in Weiss jars. In the 4^{th} year, in groups 2 and 3 when the females were matured and ready to spawn (eggs were certified by gentle pressure of abdomen), the eggs were stripped manually into plastic containers, mixed with the semen from 3–5 males (randomly chosen) and fertilized by adding water according to method described by KUCHARCZYK et al. (1998b). Eggs collected each day were incubated separately in Weiss jars. In the first three years of study, eggs were incubated in open-water-system where natural water temperature was maintained. In the 4th year of investigation eggs were incubated in Weiss jars in recirculating system, equipped with cooling device, which allowed keeping the temperature of incubation below 4°C, till eyed-egg-stage. The eggs survival was examined after three days of incubation and at the eyed-egg stage. All these manipulations have been carried out after slight anaesthesia of fish (0.5-0.7 cm^3 dm^{-3}) with 2-phenoxyethanol (Sigma-Aldrich, Germany).

Statistical differences between groups (embryos survival to the eyed-egg-stage) in the fourth year of study were analyzed using one-way analysis of variance (ANOVA) and Tukey's *post-hoc* test at significance level below 5% ($P<0.05$).

Results

In the first year of the experiment the temperature of water was steady and on a quite high level till the middle of January. At night from the 9th to 10th of January water temperature dropped below 5°C (Figure 1). Sudden thermal break down stimulated spawners' rapid final gametes maturation. As a result all of the females matured properly and the gametes were intensively collected in short intervals. The quality of eggs was satisfactory and their survival remained on high level up to eyed-egg-stage (Figure 2 and Figure 3).

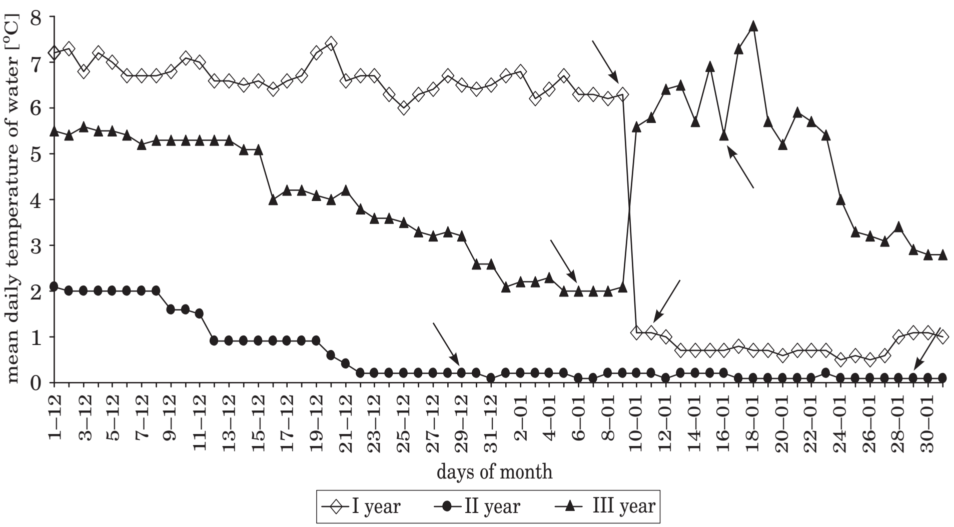

Fig 1. Fluctuations of water temperature during consecutive three years of study (arrows are showing time of the begin and the end of the burbot spawning)

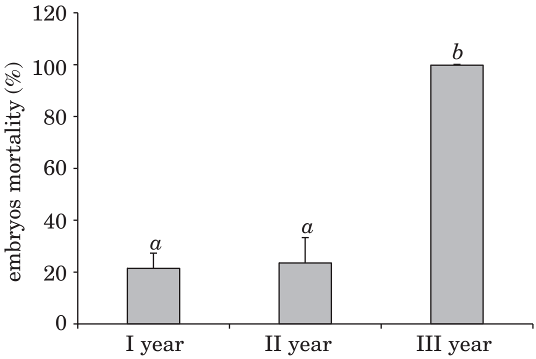

Fig. 2. Mortality of embryos in the 4th day of incubation (data marked with the same letter did not differ statistically)

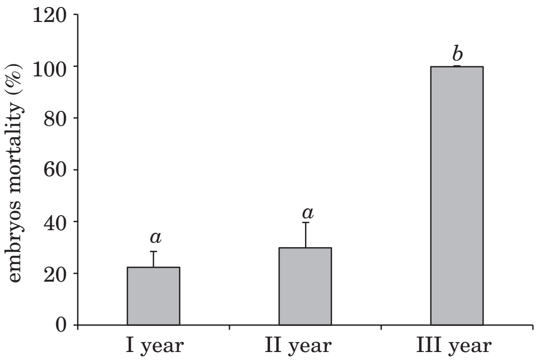

Fig. 3. Mortality of embryos in the eyed-egg-stage (data marked with the same letter did not differ statistically)

The temperatures in the 2nd year were completely different. The spawning season was cold which influenced negatively the synchronization of maturation of spawners (Figure 1). The temperature of water was near 0°C at the end of December. After more than a week of steady temperature conditions only some females matured. Gametes were collected during long period of time, when the temperature was steady and oscillated around 0°C. However, the quality of eggs (from all females) was, again, satisfactory. Survival on the 3rd day of incubation was high (Figure 2). Over 70% of embryos survived to the eyed-egg stage (Figure 3). Spawning in 2nd year of study started as the earliest and ended as the latest one.

At the beginning of December in the 3rd year of study, the temperature of water oscillated around 5°C. Then it decreased during 5 weeks to 2°C and after that, in the next few days, females matured. After 4 days from the 1st spawning, the temperature of water increased suddenly to the same level as for beginning of December (Figure 1). It caused a shorter period of spawning. Despite the good quality of gametes, survival of embryos was unexpectedly low. After three days of incubation mortality was about 99% (Figure 2) and all incubated eggs did not survived to the eyed-egg stage (Figure 3).

Natural temperature of water during the 4th year of study was similar to this of the 2nd year of experimentation (Figure 4). The data obtained in the last year of study are presented in Table 1. Fish stimulated hormonally or thermally, spawned successfully. It was in contrast to results obtained from the control group. There were no differences in embryos survival between all groups, but remarkable differences were noted in duration of spawning. Females from the control group spawned during 17 days, whereas spawning of treated groups (groups 2 and 3) lasted only few days (Figure 5).

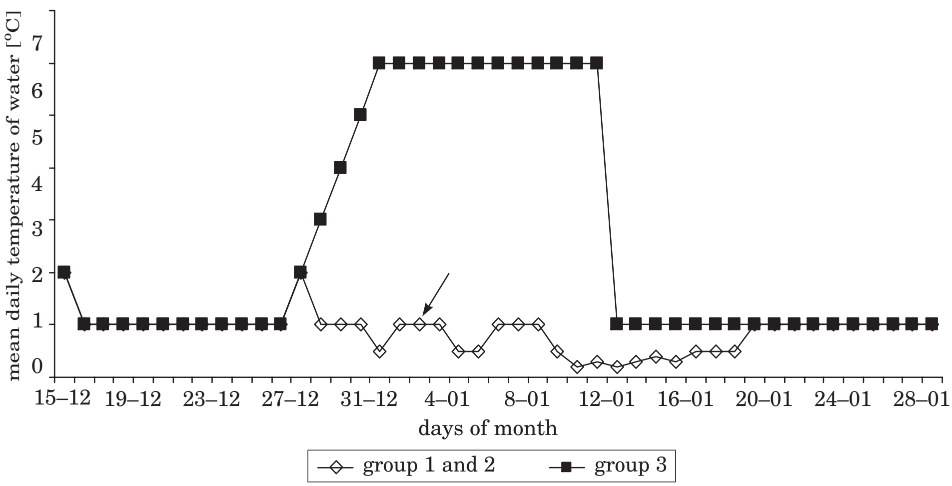

Fig. 4. Daily fluctuations of water temperature during the 4th year of study (arrow indicates day of hormonal stimulation of females from group 2)

Table 1

Results of reproduction of burbot in the 4th year of study

Specification	Natural conditions (group 1)	Hormonal stimulated (group 2)	"Warm" water/low temperature impact (group 3)
Number of females	20	20	20
Percentage of ovulated females	65%	95%	95%
Spawning time (days)	17	4	2
Survival of embryos at 3rd day of incubation	95.0 ± 2.2^{a}	94.0 ± 3.1^{a}	95.2 ± 2.1^{a}
Survival of embryos to the eyed-egg stage	86.1 ± 2.3^{a}	85.2 ± 3.5^{a}	85.6 ± 3.2^{a}

* Data in rows marked with the same letter did not differ statistically

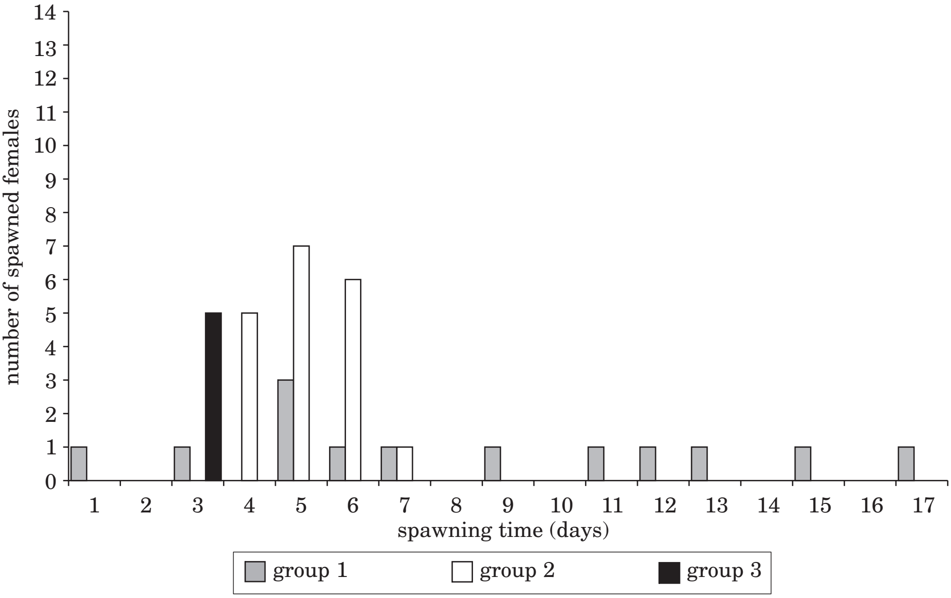

Fig. 5. Number of spawned females during 4th year of study

Discussion

In order to execute the artificial spawning of burbot the spawners need to be captured from their natural habitat. One of the major reasons for such operation is extreme mortality of brood-fish in ponds (KLESZCZ et al. 2001). Additionally data dealing with domestication of burbot is not available. KUCHARCZYK et al. (2004) reported that less than 50% of fish ate trout pellets under controlled conditions but fish survival in captivity was excellent. A change in burbot diet into living or frozen fish caused an increased percentage of fish which take food to about 70%. Nevertheless, there is an existing high risk of introducing of pathogens with "outside-fish".

The essential rule in keeping burbot spawners in captivity prior to breeding is to ensure an adequate low temperature regime, in which fish not only survive but also digest food. This corroborates with the quantity of gastric acids secreted by burbot organism. At temperature of 1°C the quantity of secreted gastric acids is much larger than at 10°C (GOMAZKOV 1961). However, at the same time, the temperature should be maintained on a quite high level, which prevents spontaneous breeding in basins. In the first year of this study the temperature of 6°C appeared to be adequate to keep the thermal regime as mentioned above. The initiation of spawning was protracted, in opposite to all years of study and the duration of spawning time was in most cases shortened. Females were ready just after the thermal breakdown, which affected artificial spawning very positively. This phenomenon creates perspectives for thermal control of ovulation time quite precisely. The synchronization of breeding obtained in that year was very similar to synchronization after hormonal stimulation under controlled conditions, as executed by KUCHARCZYK et al. (2004).

On the other hand, a slow downgrade of temperature in the second year of experimentation did not negatively influenced the reproduction of burbot. Despite the quite prolonged period of spawning, the final effect was pretty satisfactory – characterized with 70% survival of embryos to the eyed-egg stage A similar result of artificial spawning was reported by KUCHARCZYK et al. (1998b) and KLESZCZ et al. (2001). At such low temperatures fish behaved very calm, facilitating the process of reproduction. But a very long period of such process was very exhausting for fish. Each day small portions of eggs were collected and therefore it was necessary to use lots of incubation devices. With addition, during the spawning season the temperature of water below 5°C was needed for a long period of time, which may cause difficulties in many fish farms. It might also affect the time of larvae hatching. In present study, each portion of eggs was hatched at a different moment causing differentiation in growth (and finally in food competition and cannibalism) (KUJAWA et al. 2002). It requires also larger number of rearing tanks.

Analysis of the 3rd year of study led to the conclusion that the slow but quite large downgrade of temperature in consecutive five weeks, was the reason of females' maturation. Spawning began at 2°C temperature of water and its was very promising, henceforward good quality eggs were collected. The effect of positive and significant gradation of temperature during the process of final maturation confirmed that even at rise of temperature, to the level at which normal development of embryos is impossible, after the 4th day of spawning, the females were still ovulating. The extreme mortality (over 99%) of embryos was caused by the high temperature of incubation. Mass mortality of incubated embryos occurred after the sudden increase of temperature to above 5°C. Other authors (STEINER et al. 1996, KUJAWA et al. 1999b) reported that this level of temperature is lethal for burbot embryos. It should be quoted that any trial to incubate eggs in such thermal regimes resulted in almost immediate mortality.

In many freshwater fish, synchronization of ovulation under controlled conditions is possible, mainly with hormonal treatment (KUCHARCZYK et al. 1996, 1998a, 2005, 2008, ZAKĘŚ, SZKUDLAREK 1998, KOUŘIL et al. 2007, KREJSZEFF et al. 2008, 2009, SZCZERBOWSKI et al. 2009, ŻARSKI et al. 2009b). It is particularly essential in artificial reproduction of wild spawners (KUCHARCZYK et al. 1997a, KUCHARCZYK et al. 1998a, HONG, ZHANG 2003, HEYRATI et al.

2007). It improves the work during the spawning season and permits more effective utilization of hatchery facilities. Data from the last year of this study showed that it is possible to obtain much better synchronization of burbot spawning in captivity after application of hormonal stimulation (KUCHARCZYK et al. 1998b, KUCHARCZYK et al. 2004) as well as after thermal stimulation. Moreover, the influence of temperature on burbot females final maturation seems to be the major factor.

Probably, maintenance of breeders in water temperature of 6°C and thereafter sudden decrease to 1–2°C should be the reason of high synchronization of breeding and satisfactory effects on spawning. Unfortunately, such temperature manipulations are not always possible for application in commercial fish farms. The results obtained in the 3rd spawning season of burbot show that similar environmental and thermal conditions are the reason of failure in recruitment success of this species in particular year. Thus, the dramatic progress of environment pollution and climatic changes are very important factors, which require intensive researches in burbot aquaculture. Especially when endemic populations of this species and their habitats are vulnerable by human activities (PARAGAMIAN et al. 2008).

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PHYSICOCHEMICAL CHARACTERISTICS OF LINSEED OIL AND FLOUR

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K e y w o r d s: linseed oil, flour, chemical composition, fatty acids, dietary fiber composition, dietary fiber forms.

A b s t r a c t

The objective of the study was to determine the chemical composition of a new linseed cultivar Złocisty, characterized by a light seed coat. In this study, determinations were conducted for contents of: water and volatile substances, protein, fat, dietary fiber, acid detergent fiber (ADF) and neutral detergent fiber (NDF), pectins, starch, saccharides, methyl esters of fatty acids, peroxide number of fat, acidic and iodine values of fat, as well as for the percentage contribution of particular forms of lipids, sterols and tocopherols.

An analysis of the chemical composition of linseed oil and flour demonstrated that both of these products may be valuable components of dietary supplements. The chemical composition of linseed oil was determined with special attention paid to bioactive substances from tocopherols, sterols and phospholipids. Based on the assayed chemical composition of flour, it appears that it might constitute a rich source of dietary fiber and zinc. The management of both of these semi-products affords the possibility of waste-free seed processing.

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Abstrakt

Celem pracy jest ocena składu chemicznego nasion lnu nowej odmiany Złocisty o jasnej okrywie nasiennej. W trakcie badań oznaczono ilość: wody i substancji lotnych, białka, tłuszczu, błonnika pokarmowego, błonnika detergentowego kwaśnego (ADF) i obojętnego (PDF), pektyn, skrobi, cukrów, estrów metylowych kwasów tłuszczowych, liczbę nadtlenkową, kwasową i jodową tłuszczu, a ponadto oznaczono udział poszczególnych form lipidów, sterole i tokoferole.

Przedstawione w pracy wyniki składu chemicznego oleju i mąki lnianej wskazują, że oba te produkty mogą być wartościowym komponentem preparatów z grupy suplementów diety. Oznaczono skład chemiczny oleju, ze szczególnym zwróceniem uwagi na substancje biologicznie aktywne z grupy tokoferoli i steroli oraz fosfolipidów. Na podstawie składu chemicznego mąki ustalono, że może ona stanowić bogate źródło błonnika pokarmowego i cynku. Zagospodarowanie obu tych półproduktów stwarza możliwość bezodpadowego przerobu nasion.

Introduction

Vegetable and animal fats are one of the major constituents of food. In the past, attention was mainly paid to their energetic value, while their health--promoting and even therapeutic values remained underestimated. At that time, it was not known that fats were a valuable source of biologically-active substances. Owing to the various possibilities of man to access sources of edible fats in different climatic zones, the contribution of vegetable and animals fats in the everyday diet of particular societies was, and still is, diversified. The basic fat of the Arctic population is the fat of fish and marine animals, whereas in the case of the steppe population – animal fats (lard, suet), in the case of the population inhabiting the moderate climatic zone – plant and animal fats (with prevailing intake of vegetable fats), and in the case of the population of the equatorial zone – oils of tropical plants. In turn, the Southern-European, Mediterranean cuisine has been predominated by vegetable fats obtained, most of all, from olive trees. The cuisine of the Central Europe, including the Polish diet, was mainly based on animal fats (lard, butter) and occasionally – in the period of Lent – also on vegetable oils produced from seeds of hemp, flax, linseed, and sunflower. The oils were obtained as a result of pressing earlier heated seeds on various pressing devices (expellers, hydraulic presses). The current state of the art in this respect indicates that the process of heating up or roasting seeds destroys most of the biologically-active substances in oil seeds, with vitamins and sterol being particularly degraded. In the twentieth century, even though the role of vitamins in nutrition was explicitly identified, the oil industry did not introduce any new production technologies. Drastic conditions of roasting seeds before their pressing were still in use. It was not until the end of the last century that cold-pressed oils, including linseed oil, achieved widespread recognition. Cold-pressed oil constitutes a rich source of essential fatty acids (EFA). They serve a number of important nutritional functions in the human body although, paradoxically, they are not synthesized therein and thus must be delivered with food (PASIOWIEC-ŻUREK 2005). A number of authors claim that a deficiency of EFAs may be a causative agent of various diseases, because they participate in the synthesis of hormones regulating different vital and immune processes (KRYGIER 1997). Especially high quantities of unsaturated fatty acids are utilized by the brain and the nervous system. These acids are also a constituent of cellular membranes and determine the availability of fat-soluble vitamins (A, D, E, K). The first scientist to identify the beneficial properties of linseed oils was a doctor of biological and natural sciences – Joanna Budwig (1909–2003). She was the first to introduce linseed oil to a patient's diet.

Flour remaining after the process of seed pressing is also a valuable curative component. In Poland, it has been applied in the treatment of digestive tract diseases and as a wound-healing agent.

Over the years, flax – as an industrial plant providing a valuable oil and fibers for textiles – has undergone a number of breeding modifications involving its fatty acid composition, fiber content and seed coat color. To date, most studies have addressed the seeds of traditional cultivars, characterized by a dark seed coat, whereas few publications have been devoted to seeds of a new cultivar with a light, golden seed coat. For this reason, the objective of the present study was the chemical characteristics of linseeds of the Złocisty cultivar, characterized by a yellow seed coat.

Material and Methods

The object of the study was cold-press linseed oil and linseed flour remaining after the pressing process. These semi-products were obtained upon pressing linseeds of Złocisty cultivar with a light seed coat. The seeds were purchased in 2008 and were pressed on a Komet type expeller (Germany). The temperature of the pressing head did not exceed 40°C. The resultant oil was purified by centrifugation in an MPW340.ik type centrifuge, whereas the pomace was ground in a laboratory mill TECATOR and standardized by sieving through a screen with a 0.25 mm mesh diameter.

Analytical methods: The refraction index and density were determined with the method described by KREŁOWSKA-KUŁAS (1993). The content of water and volatile substances was assayed according to the Polish Standard (*Oleje i tłuszcze...* PN-EN ISO 662), whereas protein content was determined according to Kjeldahl's method (KLEPACKA 2000), fat content – acc. to the Polish Standard (*Oznaczanie zawartości tłuszczu...* PN-73/R-66164), dietary fiber content – acc. to the Polish Standard (*Oznaczanie zawartości błonnika pokar-*

mowego... PN-A-79011-15:1998), acidic dietary fiber (ADF) content – acc. to AOAC Standard (*Official methods...* 1990), content of pectins following the method of Morris (PIJANOWSKI 1973), content of starch in a solution of hydrochloric acid – with the polarimetric method (*Official methods...* 1975), content of saccharides – acc. to the Polish Standard (*Przetwory owocowe...* PN-90/A-75101/07) and content of methyl esters of fatty acids – with the method of gas chromatography acc. to the Polish Standard (*Analiza estrów...* PN-EN ISO 5508). The peroxide number was determined according to the Polish Standard (*Tłuszcze roślinne...* PN-ISO 3960), the acidic value – acc. to the Polish Standard (*Tłuszcze roślinne...* PN-74/R-66165), whereas the iodine value – following the method of Hanuš (KREŁOWSKA-KUŁAS 1993). The content of particular lipid fractions was assayed acc. to the Polish Standard (*Produkty przetwarzania...* PN-EN 14105:2004), content of sterols – acc. to the Polish Standard (*Oleje...* PN-EN ISO 12228), and content of tocopherols – acc. to the Polish Standard (*Artykuły żywnościowe...* PN-EN 12822). The concentrations of zinc and selenium were determined using the method of WHITESIDE and MINER (1984).

Results and Discussion

Natural fats extracted from different oil seeds, including linseeds, are a multi-component mixture of various lipids, with triacylglycerols being the major constituent. All other lipids contained in natural lipids are commonly referred to as concomitant substances (phospholipids, glycolipids, sterols, fat-soluble vitamins, carbohydrates). The percentage contribution of individual components is not a constant value and is determined by a variety of factors, including: seed maturity, fat extraction method, method and time of storage. The percentage composition of cold-pressed linseed oil is provided in Table 1. And so, in the cold-pressed linseed oil examined, the concentration of triacylglycerols accounted for 97±1.5%, that of partial acylglycerols (di- and monoglycerols) for 1.5±0.5% and that of polar phospholipids – for 0.5±0.1%. The contents of other components (tocopherols, free fatty acids, sterols and carbohydrates) did not exceed 1.0%. The refraction index is a typical trait of fats and oils. In linseed oil produced from seeds of traditional cultivars it accounts for 1.480 (AMOO et al. 2006), which is slightly higher than that determined in the linseed oil examined in the current study, *i.e.* 1.477 (Table 2). The value of the acidic level determines the quantity of free fatty acids. In the case of oils, this value is not constant either, as it results from the hydrolysis process. In the linseed oil examined, the value of the acidic level did not exceed values stipulated in the Polish Standard (*Tłuszcze roślinne...*

PN-A-869006/A1). Likewise, the peroxide level – which is a measure of fat rancidity – did not exceed values determined in the Polish Standard (Table 2). In turn, the iodine number, which is a measure of unsaturated fatty acid content of fat, was determined in the analyzed fat at a level of 139.53 g I_2/100 g. In linseed oils produced from seeds of traditional cultivars, the value of this parameter accounted for 178 g I_2/100 g.

Table 1
Composition (%) of linseed oil produced by cold-pressing of seeds

Specification	Content
Triacylglycerols	96.0±1.5
Partial acylglycerols + free fatty acids	1.5±0.5
Polar lipids	1.5±0.6
Other constituents	1.0±0.2
Sterols (mg/100 g)	250
Tocopherols (mg/100 g)	37.4

Table 2
Selected physicochemical parameters of linseed oil produced by cold-pressing of seeds

Parameters	Oil
Density (kg dm^{-3})	0.927
Refractive index (20°C)	1.477
Content of water and volatile substances (%)	0.084
Acidic value (mg KOH g^{-1})	0.88
Iodine value (g I_2/100g)	139.53
Peroxide number (meq O_2 kg^{-1})	0.34

The fatty acid composition of linseed oil and fat remaining in the flour is presented in Table 3. Linseed oil is a rich source of polyunsaturated fatty acids, including primarily: linolic acid and α-linolenic acid belonging to omega-3 fatty acids (Table 3). The percentage contribution of both these acids reached around 73%. A negligibly higher content of α-linolenic acid was determined in fat remaining in the flour, which may be due to the fact that during cold--pressing a higher quantity of polar fat (richer in polyunsaturated fatty acids) remains in the linseed flour. The third fatty acid, in terms of content, is oleic acid whose content in oil reached 17.3% and in flour fat – 14.3%. In comparing the results obtained with literature data, a conclusion may be drawn that the genetic modification that had led to a change in the color of seed coat, did not evoke any significant changes in fatty acids composition (BERGLUND 2002).

Table 3
Content of fatty acids (%) in linseed oil and flour fat

Fatty acid	Content of fatty acid in:	
	oil	fluor fat
Myristic ($C_{14:0}$)	0.10	0.05
Palmitic ($C_{16:0}$)	5.03	8.17
Palmitoleic ($C_{16:1}$)	0.10	0.06
Margaric ($C_{17:0}$)	0.10	0.10
Stearic ($C_{18:0}$)	4.01	2.02
Oleic ($C_{18:1}$)	17.33	14.31
Octadecanoic ($C_{18:1}$)	0.60	0.50
Linolic ($C_{18:2}$)	22.73	21.62
α-linolenic ($C_{18:3}$)	50.00	53.17

Table 4
Selected constituents of linseed flour

Constituents	Content (g/100 g f.w.)
Pectin	17.5
Fat	9.9
Saccharides	3.0
Protein	37.4
Starch	7.7
Total dietary fiber	63.3
Soluble dietary fiber	11.9
Insoluble dietary fiber	51.4
NDF*	38.1
ADF*	27.2
Cellulose	17.8
Hemicellulose	10.9
Lignins	9.4
Zinc (mg/100 g)	13.27
Selenium (μg/100 g)	0.6

*NDF – NEUTRAL DETERGENT FIBER
*ADF – ACIDIC DETERGENT FIBER

Linseed oil is a rich source of tocopherols and sterols. In the oil tested the content of tocopherols accounted for 37.4 mg/100 g and of sterols – for 250 mg/100 g. The results obtained in our study correspond with findings of BARTKOWIAK-FLUDRA et al. (2006) (tocopherols). In turn, linseed flour may be a valuable component of dietary supplements. It contains considerable quantities of dietary fiber, including pectins and protein. In addition, it is a rich source of zinc. Contents of starch and saccharides reached ca. 10%, whereas the content of fat remaining after the pressing process accounted for 9.9% (Table 4).

Dietary fiber occurs in all products of plant origin. The notion of dietary fibers describes organic compounds of cellular membranes and supportive tissues of plants that remained after the removal of proteins, fats and carbohydrates. They are resistant to hydrolysis with digestive enzymes in the gastrointestinal tract of man (DIOWKSZ 2006). In the reported study, the content of dietary fiber (crude fiber) in linseed flour was shown to reach 63.3%. Methods based on acidic and base-acidic hydrolysis make the determination of selected fractions of dietary fiber impossible, duet to losses resulting from the use of concentrated acids or lyes. For this reason, fractions of dietary fiber non--digestible in the gastrointestinal tract are often determined by means of detergent methods. In laboratory practice, use is made of various combinations of detergents and media, which enables obtaining two type of dietary fiber. The application of a detergent in a neutral medium enables determining the neutral detergent residue, i.e. the content of cellular membranes of plants in the material examined, whereas the use of a detergent in an acidic medium enables assaying the acidic detergent fiber (ADF), which corresponds to the contents of lignin and cellulose. In the material analyzed in our study, the content of neutral detergent fiber (NDF) accounted for 38.1% and was higher by ca. 10% than that of the acidic detergent fiber (Table 4). Apart from the total fiber content and detergent fiber content, we have also determined the so-called dietary fiber, which constitutes residues of cell walls resistant to enzymatic hydrolysis in the gastrointestinal tract of man. Dietary fiber is not a homogenous substance and thus it includes compounds that are soluble in water (pectins, gums, mucilages) and those that are insoluble in water (cellulose, hemicellulose, lignins, resistant starch). In the linseed flour examined, the insoluble dietary fiber was found to prevail and its content was ca. 5 times higher than that of the soluble dietary fiber. The content of pectins – that constitute the water-soluble dietary fiber – was determined at a level of 17.5 g/100 g flour. The contribution of the selected components of the insoluble dietary fiber fractions, including: cellulose, hemicellulose and lignins, accounted for 37.1 g/100 g flour.

Conclusions

The results presented in respect of the chemical composition of oil and flour obtained from linseed of Złocisty cultivar indicate that both these products may be a valuable component of preparations from a group of dietary supplements. The chemical composition of oil was confirmed with special emphasis put on its bioactive substances belonging to groups of tocopherols, sterols and phospholipids. In turn, linseed flour remaining after the pressing process may serve as a rich source of dietary fiber and zinc. The management of both these semi-products affords the possibility of waste-free processing of linseeds.

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