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Comparison of response of Scots pine seedlings to micro-irrigation and organic fertilization on a post-arable land at zoo-melioration treatment applied under rainfall-thermal conditions of Bydgoszcz and Stargard Szczeciński

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Abstract: *Comparison of response of Scots pine seedlings to micro-irrigation and organic fertilization on a post-arable land at zoo-melioration treatment applied under rainfall-thermal conditions of Bydgoszcz and Stargard Szczeciński*. The aim of the study was to determine the effect of microirrigation (microjet sprinkling and drip irrigation) and organic fertilization (compost prepared on the base of sewage sludge) on the growth of Scot pine seedlings (*Pinus sylvestris* L.), cultivated on a post-agricultural ground at zoo-melioration treatment applied, in two different regions. Field experiments were carried out in Kruszyn Krajeński (loose sandy soil of VI quality class) near Bydgoszcz and in Lipnik near Stargard Szczeciński (sandy soil of IVb quality class). Irrigation was used in three treatments: without irrigation (control), drip irrigation, microjet sprinkling. Fertilization was used in two variants: mineral fertilization (standard applied in forest nurseries), organic fertilization (compost). Weather conditions of vegetation periods were characterized using the following indices: air temperature (t), rainfall amount (P), Sielianinov's hydrothermic index (K), potential evapotranspiration according to Szarov's formula (Etp), rainfall deficiency ($N = Etp - E$), quotient Etp/P according to Drupka's proposal. Irrigation significantly increased the height and the diameter of Scot pine seedlings. There were no significant differences in the characters of the growth between the two irrigation systems. Fertilization of Scot pine seedlings with the compost increased significantly the height of seedlings. Interaction of irrigation with organic fertilization in shaping of Scot pine seedling height and diameter was noted. Pine seedlings grown on plots fertilized with compost under irrigation conditions were characterized by increased height and diameter. The better effects were obtained in Lipnik than in Kruszyn Krajeński. Joint effect of organic fertilization and microjet sprinkling positively influenced the density and the species number of Oribatida in Kruszyn Krajeński. Obtained results indicated that the amelioration measures used can positively influence on the growth of Scot pine seedlings on a post-agricultural ground.

Key words: weather conditions, irrigation requirements, micro-irrigation, post-arable land, sewage sludge, Scots pine seedlings, amelioration with soil animals, Acari, Oribatida.

INTRODUCTION

Water in forest-tree nurseries is best regulated through carefully designed irrigation systems and practices [McDonald 1984]. The use of irrigation enables systematic supply of water to young plants and securing adequate moisture for edaphon. Seedlings of trees should be grown on soils characterized by advantageous physical and biological properties and rich with nutrients. Introduction of edaphon to soils, especially those on post-arable land, being connected with organic fertilization and irrigation should considerably improve soil conditions which are decisive for quality of seedligs.

Soil processes and soil fertility is determined by edaphon [Górny 1975]. In contrast to soils of Scots pine forests, oribatid mites living in arable land create not numerous gatherings which are characterized by relatively low species differentiation. This disadvantageous situation can be improved by mulching which can be treated as zoomelioration (amelioration with soil animals). According to opinion of Mazur and Tracz [1996], zoomelioration can consist in the improvement of living conditions for native populations of soil animals or with the use a new species introduction.

The aim of the paper was to determine the effect of micro-irrigation and organic fertilization on the growth of Scots pine (*Pinus sylvestris* L.) seedlings as well as on the occurrence of soil mites in a post-arable land of two different sylvan-natural regions.

MATERIAL AND METHODS

Field experiments were carried out in 2003–2004 on post-arable grounds in Kruszyn Krajeński near Bydgoszcz on a loose sandy soil belonging to VI quality class (very weak rye complex) and Lipnik near Stargard Szczeciński – on a sandy soil belonging to IVb quality class (good rye complex) (Tab. 1).

The experiments were run in a *split-plot* system with four replications [Bruchwald 1997]. Two different factors were compared: irrigation (control – without irrigation, drip irrigation, microjet sprinkling) and fertilization (mineral fertilization, organic fertilization with compost). The single plot area was 4 m^2 and contained 4 rows (4 m length) of Scots pine seedlings. Total number of plots in each experiment was 24 (3 × 2 × × 4).

Drip irrigation was done with the usage of drip lines „T-tape" (in-line emitters spaced 20 cm apart). Microjet irrigation was done with the use of microjets "Hadar". Terms of irrigation and water rates were established according to "Directives for irrigation of forest nurseries on open areas" [Pierzgalski et al. 2002].

TABLE 1. Geographical location and soil conditions of the field experiments

Specification	Kruszyn Krajeński	Lipnik
Geographical location		
North latitude (N)	φ = 53° 04’ 00”	φ = 53° 20’ 37”
East longitude (E)	λ = 17° 51’ 33”	λ = 14° 58’ 14”
Altitude (m)	65	25
Soil conditions		
Quality class	VI	IVb
Soil suitability complex	(7) very weak rye complex	(5) good rye complex

Organic fertilizer was produced on the base of sewage sludge (80%) and highmoor peat (20%). This fertilizer was spread (dose: 100 $t \cdot ha^{-1}$) in spring and mixed with the topsoil (10 cm deep) before establishing of exact field experiments. Zoomelioration measures consisted in the mixing of topsoil (2 cm deep) with an organic matter obtained from the surface of partial cutting in habitat of fresh coniferous forest. This substrate contained the living soil mesofauna which was very abundant. This measure was conducted directly before seeding.

In late autumn the growth of plants was evaluated. The height of seedlings (cm) and shoot diameter (mm) were measured.

The soil samples for investigation on mites were taken twice a year (in May and October). The samples of 17 cm^2 and 3 cm deep were taken from all plots in 3 replications. Mites were extracted from the material in high gradient Tullgren funnels. Oribatid mites (including the juvenile stages) were determined to species. Other mites were determined to order. In general, 3194 mites (Acari) were examined, including 1116 Oribatida. The density of mites N was calculated for 1 m^2 of a soil. Species diversity of oribatid mites was determined with the use of general species number S, mean number of species in a sample s as well as using Shannon index of species diversity H [Magurran 1988].

The experimental data has been statistically processed by analysis of variance [Bruchwald 1997]. Fisher-Snedecor test was used to determine a significance of influence of experimental factors and Tukey test was used to define significant differences between the combinations.

Sielaninov's hydrothermic index (K) was calculated according to [14]:

$$K = \frac{P}{0.1\sum t}$$

where:
P – rainfall total in a particular month of the vegetation period (mm),
Σt – sum of mean daily air temperature in a particular month of the vegetation period (°C).

Potential evapotranspiration (Etp) was determined using Szarov's formula [Ostromęcki 1973]:

$$Etp = \alpha\, \Sigma t$$

where:
α – coefficient (mm/24 hours and 1°C) modified according to Grabarczyk's proposal for conditions of Poland (0.25 – April, 0.24 – May, 0.23 – June, 0.21 – July, 0.20 – August, 0.19 – September) [Grabarczyk 1989],
Σt – sum of mean daily air temperature in a particular month of the vegetation period (°C).
Additionally, the rainfall deficiency $N = Etp - P$ [Ostromęcki 1973] and the quotient $Etp\ P$ were given according to Drupka's proposal [Drupka 1986].

RESULTS AND DISCUSSION

Climatic conditions, irrigation requirements and course of irrigation

The mean air temperature during the vegetation period (April-September) in the years of the study was similar to the multi-annual average, both in Kruszyn

Krajeński as well as in Lipnik (Tab. 2). The experimental site in Kruszyn Krajeński was characterized by lower temperatures and rainfall amounts as compared to those in Lipnik (Tab. 3).

The values of the Sielianinov's hydrothermic index for the particular months of the vegetation period, were in most cases (months) in the range 0.5–1.0 (Tab. 4). This means that during these months irrigation was needed. According to opinion of Drupka [1986], irrigation requirements are justified when *Etp* calculated for the vegetation period (IV–IX) is higher than 515 mm. Evapotranspiration estimated for the all studied vegetation periods was higher than this value (Tab. 5). Irrigation requirements

TABLE 2. Air temperature (*t*) during the vegetation period (°C)

Year of the study	Months of the vegetation period						Mean for IV–IX
	IV	V	VI	VII	VIII	IX	
Kruszyn Krajeński							
1st	6.4	14.4	17.6	19.2	18.4	13.6	14.9
2nd	7.5	11.3	14.7	16.4	17.9	12.7	13.4
Lipnik							
1st	9.4	13.0	16.0	17.9	19.9	13.9	15.0
2nd	9.2	13.1	15.8	19.4	16.6	15.5	14.9

TABLE 3. Rainfall (*P*) conditions during the vegetation period (mm)

Year of the study	Months of the vegetation period						Total for IV–IX
	IV	V	VI	VII	VIII	IX	
Kruszyn Krajeński							
1st	13.3	12.1	34.3	88.8	17.8	11.2	177.5
2nd	12.1	44.4	35.8	41.8	85.6	24.8	244.5
Lipnik							
1st	20.7	39.5	61.0	69.8	47.2	33.5	271.7
2nd	13.7	67.5	25.7	76.2	53.2	25.8	262.1

TABLE 4. Sielianinov's hydrothermic index (*K*) during the vegetation period

Year of the study	Months of the vegetation period						IV–IX
	IV	V	VI	VII	VIII	IX	
Kruszyn Krajeński							
1st	0.69	0.27	0.65	1.49	0.31	0.27	0.65
2nd	0.54	1.27	0.81	0.82	1.54	0.65	0.99
Lipnik							
1st	0.73	0.98	1.27	1.26	0.76	0.80	0.99
2nd	0.50	1.66	0.54	1.27	1.03	0.55	0.96

TABLE 5. Evapotranspiration (*Etp*) according to Szarov during the vegetation period (mm)

Year of the study	Months of the vegetation period						Total for IV–IX
	IV	V	VI	VII	VIII	IX	
Kruszyn Krajeński							
1st	48	107	121	125	114	78	593
2nd	56	84	101	107	111	72	531
Lipnik							
1st	70	97	110	117	123	79	596
2nd	69	97	109	126	103	88	592

during the vegetation periods of the study were confirmed by the values of the rainfall deficiency (Tab. 6) and the quotient *Etp/P* (Tab. 7). According to opinion expressed by Drupka [1986], irrigation requirements are justified when the rainfall deficiency (*Etp* – *P*) during the vegetation period is higher than 150mm and the ratio *Etp/P* for the vegetation period is higher than 1.4.

The seasonal irrigation rates were dependent on rainfall. Total rates of water in drip irrigation and micro-jet sprinkling were higher in Kruszyn Krajeński than those in Lipnik (Tab. 8). The differences

TABLE 6. Difference (*Etp* – *P*) during the vegetation period (mm)

Year of the study	Months of the vegetation period						Total for IV–IX
	IV	V	VI	VII	VIII	IX	
Kruszyn Krajeński							
1st	34.7	94.9	86.7	36.2	96.2	66.8	415.5
2nd	43.9	39.6	65.2	65.2	25.4	47.2	286.5
Lipnik							
1st	49.3	57.5	49.0	47.2	75.8	45.5	324.3
2nd	55.3	29.5	83.3	49.8	49.8	62.2	329.9

TABLE 7. Relationship (*Etp/P*) during the vegetation period

Year of the study	Months of the vegetation period						Mean for IV–IX
	IV	V	VI	VII	VIII	IX	
Kruszyn Krajeński							
1st	3.6	8.8	3.5	1.4	6.4	7.0	3.3
2nd	4.6	1.9	2.8	2.6	1.3	2.9	2.2
Lipnik							
1st	3.4	2.4	1.8	1.7	2.6	2.3	2.2
2nd	5.0	1.4	4.2	1.6	1.9	3.4	2.3

TABLE 8. Seasonal irrigation water rates (mm)

Year of the study	Drip irrigation		Microjet sprinkling	
	Kruszyn Krajeński	Lipnik	Kruszyn Krajeński	Lipnik
First year	200	110	290	130
Second year	141	83	187	140
Mean	170	97	238	135

were connected with rainfall conditions of both of the experimental sites.

Growth of one-year old seedlings

Control plots (without irrigation) at Kruszyn Krajeński were characterized by the incomplete emergence of Scots pine seedlings. One-year old seedlings were very short and their height was, on average for period of the study, 2.1 cm only (Tab. 9). Organic fertilization was in such conditions completely ineffective.

The usage of micro-irrigation created possibilities for full emergence of seedlings. Irrigation caused a significant increase of their height and diameter which ranged from 10.8 to 12.5 cm and from 1.6 to 1.9 mm, respectively. Better results, both height and diameter, were obtained on drip-irrigated plots. The differences between the seedling height on the drip-irrigated plots and the height of those with microjet-sprinkling were not significant.

The height and diameter of seedlings grown on non-irrigated plots at Lipnik were higher than those at Kruszyn Krajeński, and amounted (mean for two variants of fertilization) 4.7 cm and 1.8

TABLE 9. Effect of irrigation and fertilization on the on the growth of one-year old Scots pine seedlings in experiments at Kruszyn Krajeński (K) and Lipnik (L), mean of 2 years

Specification	Fertilization	Growth of seedlings			
		Diameter [Ø] (mm)		Height [h] (cm)	
		K	L	K	L
Control (without irrigation)	N1	0.9	1.5	2.1	4.1
	N2	0.8	2.1	2.1	5.4
Drip irrigation	N1	1.7	3.0	11.6	7.6
	N2	1.9	2.7	12.5	8.6
Microjet sprinkling	N1	1.6	3.0	10.8	7.7
	N2	1.8	3.4	11.9	9.5
LSD0.05	(I)	0.237	0.122	0.596	0.522
	(II)	n.s.	0.136	0.428	0.439
	(I) x (II)	0.250	0.236	0.812	0.760
	(II) x (I)	0.137	0.231	0.741	0.758

N_1, N_2 – without organic fertilization and with organic fertilization (compost), respectively,
LSD – Lowest Significant Difference,
I and II – experimental factors.

mm, respectively. This was certainly caused by higher rainfall amount during the period of the study. Both the irrigation systems significantly increased the height and diameter of seedlings. But these results were lower than those at Kruszyn Krajeński. It can be explained by lower irrigation rates which were used at Lipnik as a result of higher rainfall amount and on the other hand by slightly differences in properties of the experimental soils, too.

Better results of the use of micro-irrigation were obtained in other experiments which were carried out simultaneously at Forest Nursery [15]. The one-year old seedlings grown on the forest soil were characterized by increased height and diameter as compared to adequate results of the experiments on post-arable soils.

Growth of two-year old seedlings

The results obtained from the experiments with two-year old seedlings were also better on the sandy soil at Lipnik than on the loose sandy soil at Kruszyn Krajeński (Tab. 10). These seedlings were characterized by the higher height and diameter both on control as well as on irrigated plots.

An interaction of irrigation system and organic fertilization in shaping of Scots pine seedling height and diameter was observed in the both experiments. Pine seedlings grown on the plots fertilized with compost under irrigation conditions were characterized by increased height and diameter.

Positive influence of micro-irrigation systems on the growth of Scots pine seedlings cultivated on the post-arable land is confirmed by the results of previous studies concerning the use of sprinkler irrigation under conditions of forest nurseries [Babiński and Białkiewicz 1992], [Hilszczańska 2002], [Pierzgalski et al. 2002].

The use of micro-irrigation in other simultaneous experiments on the forest soil was more effective [16]. Two-year old Scots pine seedlings were characterized by increased height and diameter in comparison to results of these experiments conducted on post-arable soils. Significant interaction of irrigation and organic fertilization was also observed. There were no significant differences in the seedling height between the two irrigation systems studied (drip irrigation and micro-jet sprinkling).

Occurrence of mites

The soil mites (Acari), especially Oribatida, are abundant in soil of Scots pine forests – from 100 to 200 thou. individuals · m^{-2} [Klimek 1999], but in forest nurseries the density of these mites is lower [Rolbiecki et al. 2005a], [Rolbiecki et al. 2005b]. Density of mites on the investigated plots on post-arable land at Kruszyn Krajeński ranged from 3.51 to 7.27 thou. individuals · m^{-2}, but at Lipnik was lower and more equalized (2.31–4.26 thou. individuals · m^{-2}) (Tab. 11). On the most of the plots at Kruszyn, Actinedida were most obundant, and plots at Lipnik were characterized by domination of saprophage Oribatida. The number of the mites was relatively balanced and there were no significant differences between particular treatments of the experiment. At Kruszyn, difference in the average number of oribatid mites between control plots (without irrigation and organic fertilization)

TABLE 10. Effect of irrigation and fertilization on the growth of two-year old Scots pine seedlings in experiments at Kruszyn Krajeński (K) and Lipnik (L), mean of 2 years

Specification	Fertilization	Growth of seedlings			
		Diameter [ø] (mm)		Height [h] (cm)	
		K	L	K	L
Control (without irrigation)	N_1	3.2	5.4	8.0	22.3
	N_2	3.0	8.1	7.2	24.3
Drip irrigation	N_1	4.3	7.3	13.9	30.6
	N_2	4.7	7.6	15.3	29.9
Microjet sprinkling	N_1	3.0	6.8	12.2	30.7
	N_2	4.8	7.1	16.2	31.6
$LSD_{0.05}$	(I)	0.387	1.000	2.113	2.136
	(II)	0.503	0.714	n.s.	1.937
	(I) x (II)	0.872	1.236	n.s.	1.128
	(II) x (I)	0.800	1.312	n.s.	1.098

Explanations – see Table 9.

TABLE 11. Abundance (N in 1000 individuals · m^{-2}) of mites, number of species (S), average number of species (s) and Shannon index (H) for gatherings of Oribatida under different irrigation and fertilization systems on objects at Kruszyn Krajeński (K) and Lipnik (L)

Index – group of mites	Object	Irrigation					
		Control		Drip		Microjet	
		N_1	N2	N_1	N2	N_1	N_2
N – Acari	K	4.14	9.38	4.52	5.84	3.51	7.27
	L	2.31	3.61	4.26	3.06	3.31	3.16
N – Acaridida	K	0.98	1.76	0.25	0.30	–	0.40
	L	0.08	0.48	0.20	0.25	0.18	0.38
N – Actinedida	K	1.83	2.53	1.40	1.43	1.71	2.43
	L	0.48	0.63	0.80	0.60	0.75	0.93
N – Gamasida	K	0.78	1.96	1.83	2.46	0.95	1.71
	L	0.48	0.98	0.93	0.58	0.53	0.25
N – Tarsonemida	K	0.03	1.03	0.03	0.15	0.08	0.10
	L	0.10	0.13	0.13	0.03	0.28	0.05
N – Oribatida	K	0.53	2.11*	1.00	1.51	0.78	2.63*
	L	1.18	1.40	2.21	1.61	1.58	1.56
S – Oribatida	K	6	10	10	11	9	13
	L	15	11	16	10	15	11
s – Oribatida	K	0.58	2.13*	1.00	1.13	0.92	1.58*
	L	1.33	1.71	1.92	1.54	1.67	1.54
H – Oribatida	K	1.29	2.15	2.05	1.54	1.89	1.58
	L	2.22	1.90	1.94	1.95	1.97	2.00

* Significant difference between control plot N_1 and a certain plot.

and plots irrigated with microjets and fertilized with compost were statistically significant. It shows a distinct positive influence of organic fertilization and microjet sprinkling (interaction) on these mites. Similar results were obtained at forest nursery [Rolbiecki et al. 2005a, Rolbiecki et al. 2005b].

In the investigated area at Lipnik 24 species of oribatid mites were found, and this number ranged from 11 to 16 as dependent on the experimental treatment. At Kruszyn – 20 species of oribatid mites were found and they ranged from 6 to 13 on particular treatments. *Oribatula tibialis* (Nicolet) predominated in the gatherings of oribatid mites on the control plots (without irrigation) at Kruszyn, but on irrigated plots *Tectocepheus velatus* (Michael) was the most abundant. This species – *Tectocepheus velatus* (Michael) was the most abundant on all the plots at Lipnik. Both the species are eurytopic but they prefer also forest soils, especially soils of Scots pine forests [Klimek 1999, 2000]. Among Oribatida such the species like *Chamobates cuspidatiformis* (TrägÍrdh), *Scutovertex sculptus* Michael, *Oppiella minus* (Paoli), *Oppiella nova* (Oudemans) were also relatively abundant. Species composition of Oribatida on the investigated area indicated that the amelioration measures caused positive results, and some of species – representatives of forest soil fauna – are able to adapt under proper conditions (soil moisture and additional organic matter) to difficult for them conditions of post-arable soils.

CONCLUSIONS

1. Micro-irrigation systems significantly increased the height and diameter of Scots pine seedlings in both the experiments. Better results were obtained at Lipnik than at Kruszyn Krajeński. There were no significant differences in the investigated parameters of seedling growth between the drip irrigation and micro-jet sprinkling.
2. Fertilization of seedlings with the compost from sewage sludge with peat admixture significantly increased the height under irrigation conditions only. An interaction of irrigation system and organic fertilization in shaping of Scots pine seedling height and diameter was observed.
3. It was found – on the base of acarologic study – that in the case of plots with microjet sprinkling and organic fertilization joint effect, the species number and the density of Oribatida increased at Kruszyn Krajeński, but at Lipnik the factors did not influence significantly these indices.
4. Obtained results indicated that amelioration measures which were used in the experiments, can advantageously influence on the Scots pine seedling growth on post-arable grounds.

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Streszczenie: *Porównanie reakcji siewek sosny zwyczajnej na mikronawodnienia i nawożenie organiczne na gruncie porolnym z udziałem zabiegu zoomelioracji w warunkach opadowo-termicznych Bydgoszczy i Stargardu Szczecińskiego*. Celem badań było określenie wpływu mikronawodnień i nawożenia organicznego na wzrost jednorocznych i dwuletnich siewek sosny zwyczajnej, uprawianych na gruncie porolnym z udziałem zabiegu zoomelioracji, w dwóch różnych regionach. Równoległe doświadczenia polowe przeprowadzono w Kruszynie Krajeńskim pod Bydgoszczą (luźna gleba piaszczysta klasy VI) oraz w Lipniku pod Stargardem Szczecińskim (gleba piaszczysta klasy IVb). Czynnikiem pierwszego rzędu było nawadnianie w trzech wariantach: bez nawadniania (kontrola), nawadnianie kroplowe, mikrozraszanie. Czynnik drugiego rzędu stanowiło nawożenie w dwóch wariantach: nawożenie mineralne (standard stosowany w szkółkach leśnych), nawożenie organiczne (kompost). Pojedyncze poletko o powierzchni 4 m^2 obejmowało 4 rzędy roślin o długości 4 m. Łączna liczba poletek w doświadczeniu wynosiła 24 (3×2×4).

Nawóz organiczny wyprodukowany na bazie osadów ściekowych (80%) i torfu wysokiego (20%), rozrzucono wczesną wiosną i przemieszano z wierzchnią warstwą gleby do głębokości 10 cm, przed założeniem ścisłych eksperymentów polowych w ilości 100 t ha^{-1}. Zabieg zoomelioracji (przeprowadzony bezpośrednio przed wysiewem nasion) polegał na zmieszaniu wierzchniej warstwy gleby (2 cm) z materią organiczną pozyskaną z siedliska boru świeżego.

Scharakteryzowano warunki pogodowe okresów wegetacji wykorzystując: wartości temperatury powietrza (*t*), ilości opadów (*P*), współczynnik hydrotermiczny Sielianinova (*K*), ewapotranspirację potencjalną według Szarowa (*Etp*), deficyt opadów (*N* = *Etp* – *P*), iloraz *Etp*/*P* według propozycji Drupki.

Nawadnianie istotnie zwiększyło wzrost oraz średnicę siewek sosny. Nie stwierdzono istotnych różnic w analizowanych parametrach wzrostu pomiędzy dwoma systemami nawodnieniowymi. Nawożenie siewek sosny nawozem organicznym istotnie zwiększyło wysokość sosny. Współdziałanie nawadniania i nawożenia organicznego kształtowało wysokość i średnicę siewek sosny. Siewki rosnące na poletkach nawadnianych oraz nawożonych organicznie charakteryzowały się większą wysokością i średnicą. Lepsze efekty zastosowanych czynników stwierdzono w doświadczeniu przeprowadzonym w Lipniku niż w Kruszynie Krajeńskim. Stwierdzono pozytywny efekt współdziałania nawożenia organicznego i mikrozraszania na zagęszczenie osobników oraz liczbę gatunków Oribatida w Kruszynie Krajeńskim. Uzyskane wyniki wskazują, że zastosowane zabiegi melioracyjne mogą pozytywnie wpływać na wzrost siewek sosny na gruncie porolnym.

Słowa kluczowe: warunki pogodowe, potrzeby nawadniania, mikronawadnianie, grunt porolny, osad ściekowy, siewki sosny zwyczajnej, zoomelioracje, Acari, Oribatida

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